Government of Nepal

Ministry of Energy

Department of Electricity Development

Anamnagar, Kathmandu

Guidelines for Power System Optimization of Hydropower Projects

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Foreword

Nepal is blessed with precious water resources that accounts for enormous hydroelectric potential. The perennial nature of rivers and steep gradients of country's topography provide an ideal condition for the development of hydroelectric projects. Despite serious efforts by concerned agencies, development of hydroelectric projects has not gained sufficient speed, principally due to insufficient funds and basic infrastructure facilities. As a result, Nepal is suffering from acute shortage of electric energy which is badly affecting people's daily life in general, and country's development activities in particular. Hence, the development of hydropower projects at the earliest possible time has become an urgent task to be undertaken by the Government.

In this connection, to harness the hydropower potential of the country and to satisfy the increasing domestic power demand, the Department of Electricity Development (DoED) has made serious efforts to identify potential hydropower projects throughout the country.Promulgation of liberal hydropower development policy has profoundly encouraged the national and international entrepreneurs to be engaged in the development of hydropower projects of different capacities. Development process of hydropower projects covers system planning, design and layout phases.

The system planning and design including optimization of different hydropower projects under similar categories differed in depth and extension of studies carried out. Hence, it is being realized that power system optimization guidelines are needed to assist the planers/promoters of hydropower projects. The guidelines will help various public/independent power producers to follow a uniform, consistent and converging approach for optimization study during planning, design and analysis of hydropower projects at the feasibility level of studies in the Nepalese context. The guidelines will provide information about all types of analytical procedures and relevant values that are needed for power system optimization of hydropower projects in the Nepalese context. The intended users of the guidelines will be hydropower developers or agencies including public/private sectors and professional personnel of relevant agencies working in the power sector.

The Department sincerely acknowledgeswith hearty gratitude the invaluable suggestions, comments and the endeavor of Technical Advisory Group (TAG) members, stakeholders from governmental and non-governmental institutions and other participants of the Consultative Workshop organized for finalizing of the guidelines. We arealso very much thankful to the Joint Venture of SILT Consultants (P.) Ltd. and Environment & Resource Management Consultant (P.) Ltd. for undertaking the assignment of preparing the Guidelines.

Dinesh Kumar Ghimire
Director General
Department of Electricity Development
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TECHNICAL TERMS

Average Energetic Coefficient:	Ratio of energy generated to water flow
Average Load:	Hypothetical constant load over a specified time period
Base Load:	Minimum load over a given period of time
Base Load Plants:	Plants supplying load for the lower region of the load curve, which run throughout the year at constant load, e.g. hydropower plants with large storage, thermal plants
Basin:	Area of land draining into a stream at a given location
Capital cost:	Costs associated with construction
Constraints:	Conditions which are to be satisfied
Dam:	Structure built across the river to store and/or raise the level of water
Depreciation:	Decrease in worth over time as they wear out physically or are replaced by newer or more economic facilities
Demand:	Rate at which energy is required by a customer or by a system
Discount rate:	Rate of interest reflecting the time value of money that is used to convert benefits and costs occurring at different times to equivalent values at a common time
Energy:	Capacity to do work
Escalation:	Rise in prices
Flow (Discharge):	Quantity of water per unit time
Forebay:	Enlarged body of water just in front of penstock
Grid:	Transmission network interconnecting electric power systems
Gross head:	Difference between water level at the point of diversion of water and at the point where the water is returned back to the river
Head loss:	Loss of energy due to friction and other factors
Head:	The vertical length of a column of water
Heat rate:	Amount of energy expressed in joules or kilo calories required to produce 1 KWh of electric energy
Hydrocascade:	A group of plants in which the inflow from upstream plant has impact on downstream plant
Hydronetwork:	A network of reservoirs, turbines and spillway
Hydropower:	Electrical power generated with water
Installed capacity:	Maximum power which can be developed by all generators of the plant at the normal head and with full flow
Intake:	A structure constructed for entry of water to conduit system
Interest during construction:	Accumulated money disbursed by a utility to pay off interest on the capital invested in the plant during construction.
Interest rate:	Ratio between interest chargeable at the end of a period of time to the money invested at the beginning of the period
Load duration curve:	Curve showing the relationship between load and probability of exceedence
Load factor:	Ratio of average load to peak load
Load:	Amount of power needed to be delivered at a given point on an electric system
Loading order:	The relative rankings assigned to units and blocks of units to be dispatched
Long Run Marginal cost:	Increase in total cost for producing one additional unit of product
Loss of load probability:	Proportion of time when the available generation is expected to be unable to meet the system load

Model:	Simplified representation of reality
Net head:	Difference between gross head and loss, available for generating power
Nominal discharge:	Maximum discharge at which the plant is designed
Objective function:	Mathematical function to be optimized
Optimization:	Selecting the best or optimum solution from a set of alternative solution
Outage:	Out of service
Peak load:	Maximum load in a stated period of time
Peak load plants:	Plants supplying load at the top portion of the load curve (peak load), which run for a few hours in the year, e.g. run-of-river plants with pondage, diesel station
Penstock:	Conduit for conveying water from reservoir to turbine
Plant factor (Capacity factor):	Ratio of actual energy produced to maximum possible energy that could have been produced
Plant life:	Useful life of plant
Power balance equation:	Equation which shows the balance between demand and power generation from different sources
Power house:	Structure in which the generators and other electro-mechanical equipment are housed
Power:	Rate of generation of energy
Present worth:	Mathematical process by which different monetary amounts are moved either forward or backward in time to a common point in time
Primary (firm) power:	Power available at all times of year
Pumped storage plants:	Operation whereby water is raised during off-peak periods by means of pumps and stored for later use in the production of electricity during peak load periods
Reserve margin:	Measure of the generating capacity that is available over and above the amount required to meet the system load requirements.
Run of river plants:	Hydroelectric power plant using the flow of a stream as it occurs and having little or no reservoir capacity for storage
Salvage value:	An estimate of an asset's net market value at the end of its estimated life
Scenario:	Possible outcomes by considering different alternatives
Secondary power:	Power in excess of primary demand
Sensitivity:	Change in output due to change in input/parameters
Sinking fund:	Fund established to accumulate a desired future amount of money at the end of a given length of time through the collection of a uniform series of payments
Spillways:	Structure through which excess water flows
Spinning reserve:	The generating capacity that can be called on in a few seconds to supply power in the event of sudden load increases or unit failures
Storage plants:	A hydroelectric power plant water utilizes water stored in reservoir
Surge tank:	A storage reservoir for releasing the water hammer pressure
Tunnel width:	Addition of plants to minimum number, the total representing maximum number (in configuration generation)
Thermal power:	Electric power generated by heat
Turbine:	A hydraulic motor that converts the energy of the water into mechanical energy
Unserved energy:	Expected amount of energy not supplied per year owing to generating capacity deficiencies and/or shortages in basic energy supplies
Utilization factor:	Ratio of peak load developed during certain period of time to the installed capacity of the plant

Variable costs:	Raw materials costs, by-product credits, and those processing costs which vary with plant output
Water balance equation:	Balance of inflow and outflow taking into account the net change in storage

ABBREVIATION AND ACRONYMS

ACV	Total accumulated value of the reservoir energy contents
ASCII	American Standard Code for Information Interchange
B.S.	BikramSambat
B/C	Benefit Cost Ratio
CCD	Common Case Data
CD	Compact Disc
CEA	Central Electricity Authority
COD	Commercial Operation Date
CONCST	Construction Cost
CONGEN	Configuration Generator
DHM	Department of Hydrology and Meteorology
DPR	Detailed project report
DR	Incremental Energy Contents
DYNPRO	Dynamic programming Optimization
DoED	Department of Electricity Development
EA	Inflow Energy
ECLA	Economic Commission for Latin America
EDP	Electricidade de Portugal
EIA	Environmental Impact Assessment
EMIN	Minimum requirements for base load generation
ENS	Energy not served
ENSCST	Energy not served cost
EMP	Environment Managemant Plan
FDC	Flow Duration Curve
FIXSYS	Fixed System
FVW	Marginal Value Of Water
GDP	Gross Domestic Product
GIS	Geographic Information System
GoN	Government of Nepal
GWh	Gigawatt Hour
HPP	Hydropower Project
IAEA	International Atomic Energy Agency
ID	Identification
INPS	Integrated National Power System
IPPAN	Independent Power Producers' Association, Nepal
JV	Joint Venture
KV	KiloVolt
KW	Kilowatt
KWh	Kilowatt hour
LDC	Load Duration Curve

LOADSY	Load System
LOLP	Loss-of-Load Probability index
LRMC	Long Run Marginal Cost
m	Meter
m^3/s or cumec	Meter Cube Per Second
MERSIM	Merge and Simulate
mm	Milimeter
MoSTE	Ministry of Science, Technology and Environment
MoEn	Ministry of Energy
MoWR	Ministry of Water Resource
MS	Microsoft
MW	Mega Watt
MWh	Mega Watt hour
MWB	Base capacity in MW
MWC	Available capacity in MW
NHA	National Hydropower Association
NEA	Nepal Electricity Authority
NPV	Net Present Value
NRs	Nepali Rupees
NWP	National Water Plan
O & M	Operation and Maintenance Cost
OPCOST	Operation Cost
ORNL	Oak Ridge National Laboratory
PKMW	Period Peak Load
%	Percentage
PSO	Power system optimization
P-S	Pumped Storage
RMA	Maximum Equivalent Reservoir Contents
RMI	Minimum Equivalent Reservoir Contents
ROR	Run-Of-River
(P.) Ltd.	Private Limited
Q_{20},Q_{40},…Q_{90}	Discharge of 20%, 40%, ….. 90% exceedence (subscript denotes probability in percent)
Ref.	Reference
SALVAL	Salvage Value
SD	Standard Deviation
SHP	Small Hydropower Project
SHPAN	Small Hydropower Project Association Nepal
TAG	Technical Advisory Group
ToR/TOR	Terms of Reference
TVA	Tennessee Valley Authority
VARSYS	Variable System
WASP	Wien Automatic System Planning
WECS	Water and Energy Commission Secretariat

EXECUTIVE SUMMARY

Introduction

Nepal is endowed with precious water resources that accounts for an economical potential of 43000 MW (National Water Plan 2005), of which only less than 1.5% has been harnessed so far. The perennial nature of rivers and steep gradients of country's topography provide an ideal condition for the development of hydroelectric projects. National Water Plan (2005), has recognized that water is one of the principal physical resources that can play a major role in enhancing the pace of overall development of Nepal. Nevertheless, despite serious efforts by concerned agencies, development of such hydroelectric projects has not gained sufficient speed, principally due to insufficient funds and basic infrastructure facilities. As a result, Nepal is suffering from heavy load shedding and acute shortage of electricity which is badly affecting people's daily life in general, and country's development activities in particular. NEA's latest peak load forecast for integrated national power system (INPS) for the period 2004-2020 shows that peak load demand in the system could grow by 8% every year based on current GDP growth of 4%.

Promulgation of liberal hydropower development policy has profoundly encouraged the national and international entrepreneurs to be engaged in the development of hydropower projects of different capacities. To supplement to the Headworks and Water Conveyance System Design Guidelines that was prepared for public/independent power producers, DoED has employed SILT and ERMC -JV hereafter referred as the Consultant for the **Preparation of the Guidelines for Power System Optimization of Hydropower Projects.**

Objective

The main objective of this project is to develop **Guidelines for Power SystemOptimization of Hydropower Projects.** These guidelines will help various public/independent power producers follow a uniform, consistent and converging approach for optimization study during planning, design and analysis of hydropower projects at the feasibility level of studies in the Nepalese context. These guidelines will provide common platform and form a basis to compare the projects on equal footing.

Scope of work

The DoED has outlined the broad scope of works for this project and has employed the Consultant to carry out the works envisioned in the terms of references (TOR). Scope of works demands to collect and review numerous government documents, hydrological data, regulations, acts, feasibility studies, best-practices, optimization models, and guidelines. As outlined in the TOR the consultant requires to construct an optimization model by using VALORAGUA and WASP and develop guidelines for Power System Optimization (PSO) of hydropower projects.

The understanding of TOR by the Consultant was iterated in the bid as well as in the contract agreement. In this report it has been reiterated further.

Desk Study

After signing the contract the Consultant set up the office and initiated the desk study. The objective of the desk study was to study the scope of works and carryout activities that were required by the TOR at the initial stage of the project.

Understandings,Reviews and Outline of the Guidelines

Consultant has elaborated further the understanding of the job, reviewed various documents and developed an outline of the Guidelines for Power System Optimization of Hydropower Projects. Consultant has followed an industrial standard approach for preparation of Guidelines for Power System Optimization of Hydropower Projects. The structure of the Guidelines is developed by incorporating the spirit of Cleint's TOR. In addition, cautions are made to make it not conflicting with the earlier government documents and guidelines. However, the efforts to make the Guidelines simple, comprehensive, complete and practical has been continued through the study period and the improvements has been reported to the Client.

Field Visit

The consultant hasbeen organized site visits to different generation, transmission and distribution sites to familiarize with the Nepalese Power System. The field visit took place from May 31 to June 3, 2013. The field visit covered various types of generation stations, switchyards, substations, and control stations. Generation stations covered reservoir hydropower plants such as Kulekhani cascade, Hetauda Diesel Plant, run-of-river type station with pondage such as Kaligandaki A, Middle Marsyangdi and Marsyangdi, and run-of-river type without pondage such as recently completed Bijaypur hydropower plant. Switchyards of most of generation plants were visited. Regional substations such as those at Bharatpur and at Lekhnath were visited.

Data Collection for Modeling

All hydro-meteorological data were collected from Department of Hydrology and Meteorology (DHM) and checked for consistency using double mass curve technique. Data were compiled as per available historical hydrological data of al hydrometric stations published by DHM for checking consistency of collected data. The monthly discharge data from 1963 up to 2010 were available as per recorded by DHM.

The information of all hydropower plants and thermal plats required for setting models were collected from available reports and publications of NEA, DoED, IPP and websites.

Methodology

A package for power system optimization of hydropower projects has been developed by using the two f available models: **VALORAGUA** and **WASP**.

VALORAGUA

The VALORAGUA Model is a software package for Decision Support in Electric System Planning. This tool has special emphasis on optimal use of a mixed-system, integrated in load/generation areas linked by a transmission network. A marginal approach leading to the computation of nodal prices is considered reflecting the variation of the cost function if the load in the node increases one unit. The whole horizon is one year, the time interval, a month or a week, generally called period, each period with five sub periods called load-steps defined to represent the peak (first load step), the intermediate (second, third and fourth load steps) and the base hours (fifth load step). This computer tool essentially provides the information needed to support and to assist the decision maker process in electric sector. This tool, like what happens with many optimization models, is being a result of a set of updates, due to the natural evolution of mathematical techniques, to better cover the new constraints and conditions in the operation of the Electric Power System and also to be adapted to an open electricity market. The model enables a detailed management of the electric power system, represented as an interconnected collection of main subsystems: production subsystem, transmission subsystem and consumption subsystem. Each component of every subsystem is completely individualized, with its identification and topological connection to the electric and/or the hydraulic network, and performs an economic or physical activity. River network will be taken in consideration designing the hydraulic network with hydropower plants. Likewise the model takes into account whether the plants are in cascades or independent. If a new plant is added in the cascade, the hydraulic network should be revised accordingly.

WASP

The Wien Automatic System Planning Package (WASP) was originally developed by the Tennessee Valley Authority (TVA) and Oak Ridge National Laboratory (ORNL) of the United States of America. WASP-IV is designed to find the economically optimal generation expansion policy for an electric utility system within user-specified constraints. It utilizes probabilistic estimation of system-production costs, unserved energy cost, and -reliability, linear programming technique for determining optimal dispatch policy satisfying exogenous constraints on environmental emissions, fuel availability and electricity generation by some plants, and the dynamic method of optimization for comparing the costs of alternative system expansion policies. The WASP model is aimed at finding an optimal expansion plan for a power generating system over a period of up to 30 years against the constraints imposed by the planners. The optimum option is evaluated in terms of minimum discounted total costs.

Modeling using VALORAGUA and WASP

All data files of VALORAGUA are in ASCII format. Except CADIR.DAT and INFLOW.DAT which contain large amount of data, all other files are prepared using text editor. However, these data files can also be prepared directly in text editor. Main input files CADIR.DAT and INFLOW.DAT have been prepared in this study by using EXCEL and MATLAB. Collected data for these two files are assembled in EXCEL spreadsheets, and a code in MATLAB is written to read EXCEL data files and generate output in required ASCII format.

Like VALORAGUA, all input files of WASP are in ASCII format. The input files LOADSYS.DAT, FIXSYS.DAT and VARSYS.DAT have been prepared in by using EXCEL and MATLAB. Except these three files, other remaining files are of small size, which are directly prepared using text editor.

First, module CLEARD must be run in order to initialize the direct access file G14 for the particular VALORAGUA study. This is followed by a run of CADIR in order to prepare all the basic characteristics of the power system configuration(s), including the necessary hydro data. For the first run, VALAGP is run with a year of good quality data to check if there are any errors. Finally, a run of VALAGP for all the years of study will provide the required optimization of the operation of the system in the selected years. After VALAGP has been run, RESEX is executed to get overall results of simulation and

RESIM is executed to obtain more details for a particular hydroplant. Next, MAINT module is run in order to optimize the maintenance schedule of the thermal power plants for each given configuration and probably a new sequence of runs of CADIR and VALAGP could be undertaken in order to try to improve the results of the previous simulation in terms of operating costs. It should be noted, however, that the CLEARD program is only run at the beginning of the process since any subsequent run of this program will erase any previous information contained in the direct access file G14.

If the purpose of the VALORAGUA study is to iterate with optimization runs of the WASP program, the VWASP module can be run to produce the hydro data for FIXSYS.DAT and VARSYS.DAT. If optimization of expansion is not the goal, the user may take the VALORAGUA end-results and do the analysis of results.WASP running sequence:

LOADSY, FIXSYS and VARSYS are data pre-processing modules, which can be run independent of each other. The data obtained from these modules are used for optimization. For optimization of expansion plan, CONGEN, MERSIM and DYNPRO are run in sequence. The DYNPRO module gives the final optimum solution.

Analysis of output data

Analysis of the output of VALORAGUA model is carried out from the output data saved in VALAGP.prn and RESEX.prn. VALAGP.prn displays the information on optimization.

Long Run Marginal Cost (LRMC) is computed for different scenarios by perturbation approach. After determining the reference optimized expansion plan and reference LRMC, monetary value of different sets of candidate hydropower plants has been determined. The outputs from VALORAGUA-WASP give the monetary value of candidate sets of hydropower plants.

From initial runs of these models, it was found that VALORAGUA/WASP run in 32-bit MS Windows® environment. Simultaneously, guidelines for users will be developed which will cover optimization of hydropower projects as well as hydropower plants.

Application of Model

Different scenarios are performed in this study:

1. Basic model: Hydroplants with Thermal and without export, design flow of hydroplants

2. Export option: Export (700MW) added in Basic model

3. Seasonal model: Hydroplants with Thermal and without export, design flow, seasonal consideration

    - Dry season: Jan-Apr
    - Wet season: May-Dec

4. GDP change: Hydroplants with Thermal and without export for adopted design flow, considering 5%, 7.5% and 10% GDP growth

5. Storage projects: Hydroplants with Thermal and without export for adopted design flow considering more storage projects

6. Consideration of major existing, under-construction and planned projects

In the recent version of VALORAGUA, maximum allowable number of hydroplants is 50, and maximum allowable number of hydrocascades is 18. Considering these limitations, maximum number of hydrocascades in all model application of the study is set to 18. Hydronetwork is designed in such a way that major existing hydroplants and major planned hydroplants from all over Nepal are included in the power optimization. Based on the availability of data, 46 hydroplants are included within 18 hydrocascades. Among them, 23 are existing plants and remaining are expansion candidates.

Table 1: Detail of hydro-cascades

Cascade No.	Code Name of plants	No. of plants	Name of plants
1	PUWA, MAI	2	PUWA, MAI
2	IKHUWA, PILUWA	2	IKHUWA, PILUWA
3	UTAMOR, MAIWA, MTAMOR, PHAWA, KABE-A, HEWA	6	UPPER TAMOR, MAIWA, MIDDELE TAMOR, PHAWA, KABELI-A, HEWA
4	UTAMAK, SIPRIN	2	UPPER TAMAKOSHI, SIPRIN
5	KHANI	1	KHANI
6	KHIM-1	1	KHIMTI-1
7	U-BHOT, CHAKU, BARAMC,SUNKOS, SUNKON	5	UPPER BHOTEKOSHI, CHAKU, BARAMCHI,SUNKOSHI (SMALL), SUNKOSHI (NEA)
8	BALE-A, BALE-B	2	BALEPHI-A, BALEPHI-B
9	INDRAW	1	INDRAWATI
10	U-SANJ, L-SANJ, CHILIM, RASGAD, TRIS3A, TRIS2B, TRIS, DEVIGH	8	UPPER SANJEN, LOWER SANJEN, CHILIME, RASUWAGADHI, TRISHULI3A, TRISHULI2B, TRISHULI, DEVIGHAT
11	KULEK1, KULEK2, KULEK3	3	KULEKHANI1, KULEKKHANI2, KULEKKHANI3
12	BUDHIG	1	BUDHI GANDAKI
13	UMARSY, MMARSY, KHUDI, LCHEPE, MARSYG	5	UPPER MARSYANGDI, MIDDLE MARSYANGDI, KHUDI, LOWER CHEPE, MARSYANGDI
14	BIJAYP	1	BIJAYPUR
15	MODI, LMODI, KGANDA	3	MODI, LOWER MODI, KALI GANDAKI
16	ANDHI	1	ANDHI
17	JHIMRK	1	JHIMRK
18	CHAMEL	1	CHAMELIYA

Diesel Plants

Hetauda: 10 MW
Duhabi: 39.5
Total installed capacity of existing hydro plants, expansion candidate plants and thermal existing = 2775 MW
Consumption (load) subsystem

- Electric code: Nepal as single node
- Fixed Power Demand (primary demand) for simulation year 2030
- Secondary Power Demand

Inflow data: Data of 30 years from 1980 to 2009 for 46 points.

Input data for both VALORAGUA and WASP have been prepared for all considered scenarios. The results of model simulation as the LRMC and LOLP have been compared in the following tables:

Table 2: LRMC comparison for different scenarios

Scenario	Case	LRMC (Cts/Kwh)
1	Basic	3.9
2	Export	3.8
3	Dry	11.7
	Wet	5.0
4	5.5%GDP	4.2
	7.5%GDP	6.6
	10%GDP	12.7
5	Additional Storage projects to scenario1	3.6
6	Major projects	3.5

Table 3: Average LOLP comparison

Scenario	Case	LOLP (%)
1	Basic	4.28
2	Export	4.20
3	Dry	33.53
	Wet	5.63
4	5.5%GDP	9.00
	7.5%GDP	20.0
	10%GDP	60.1
5	Additional Storage projects to scenario1	2.91
6	Major projects	3.49

VALORAGUA-WASP models simulate combined hydro-thermal system. Therefore, the model cannot be executed without thermal component. In hydro system, ROR, PROR and storage plants are considered. All scenarios except scenario 5 and 6 include 2 storage plants. Scenario-5 includes 5 storage plants and scenario-6 includes 6 storage plants.

The following is the result of comparative analysis of various scenarios.

LRMC for export option is slightly less than basic case. In this case, there should be excess energy for export. LRMC for dry season is higher than wet season due to the low generation of power. LRMC increases with the increase of GDP due to increment of load. LRMC with more storage projects is less. The result of LOLP is also in agreement with the result of LRMC. The result shows that hydro system with the combination of simple run off river, peaking run off river, and storage hydropower plants will be the best option for Nepalese context.

Sensitivity Analysis

Sensitivity analysis refers to the change in the output of model due to change in parameter. In power optimization study using VALORAGUA-WASP, some parameters are estimated using available data whereas some parameters are assigned from the prevailing conditions. In this study, following case studies are performed as a part of sensitivity analysis:

1. Reference case (scenario 1 described above as a Base case , having 46 plants: 23 existing + 23 expansion)
2. Design flow for existing plant and Q25 for expansion candidates
3. Design flow for existing plant and Q30 for expansion candidates
4. Design flow for existing plant and Q40 for expansion candidates
5. Design flow for existing plant and Q50 for expansion candidates
6. Design flow for existing plant and Q60 for expansion candidates
7. Unserved energy cost: 30 cents/kwh, 55 cents/kwh, 80 cents/kwh and 1 USD

Table 4: LRMC comparison

Case	Description	LRMC (Cts/Kwh)
1	Reference case	3.9
2	Q25, Qdesign	3.9
3	Q30, Qdesign	3.7
4	Q40, Qdesign	3.7
5	Q50, Qdesign	3.8
6	Q60, Qdesign	3.5
7	ENS 30 Cent	3.1
	ENS 55 Cent	3.9
	ENS 80 Cent	4.5
	ENS 1USD	5.0

Table 5: Average LOLP comparison

Scenario	Case	LOLP (%)
1	Basic	4.28
2	Export	4.20
3	Dry	33.53
	Wet	5.63
4	5.5%GDP	9.00
	7.5%GDP	20.0
	10%GDP	60.1
5	Additional Storage projects to scenario1	2.91
6	Major projects (no thermal addition)	4.65
7	**Time horizon**	
	Long	3.5
	Medium	4.3
	Short	4.4

Comparing cases 1-4, LRMC for case 3 is the highest and case 1; case 2 is in the same range; and it is minimum for case4. Average LOLP for case 3 is minimum among cases 1-4. Although there is no fixed trend of LRMC from case 1 to 4, the average LOLP for cases 2-4 is in the same range. This shows that adopting the design flow in the range of Q40-Q60 for the expansion plants is satisfactory. In case 5, LRMC increases with the increase in cost of unserved energy. If the cost is higher, LRMC will also become higher. The average LOLP shows the reverse trend of LRMC. If the cost is higher, the loss of load will be lower.

Technical Advisory Group (TAG)

DoED has formed an expert panel consisting of initially seven experts and experienced personnel involved in power system planning, analysis and hydropower system optimization activities from different but related Government and non-Governmental agencies like IOE, BPC, NEA and private sector experts. The expert panel has continuously advised and suggested the consultant on the study activities at different phases of this project. The selection of the expert panel was carried out by DoED from the list of recommended experts by the consultant.

Residential Workshops

The main objective of the workshop was to collect input, suggestions and experience of experts working in hydropower and relevant field of study. These inputs from the workshop have beenincorporated in the Draft Final Report to prepare qualitative and practical guidelines in Nepalese context. The workshop has been held on June 26 and 27, 2015 at Park Village Hotel, Kathmandu with TAG members, Senior Authoritiesof DoED, MoEnand different experts working in hydropower.

Conduction of Training

The Training Programme has been organized and conducted for the use of VALORAGUA and WASP to DoED, MoEn, NEAand independent private developers' professionals for two weeks from September 17, 2015 at DoED Meeting Hall. The total number of participants has beenfourteen and selection of participants for training has been carried out by the DoED.

The major outline and content of the trainings hasbeen limited to the following:

- VALORAGUA model and its working, usage and applications
- WASP model and its working, usage and applications
- Data input and database preparation for model
- Model running and simulation practices
- Analysis and interpretation of Outputs of model etc.

Guidelines for Power System Optimization of Hydropower Projects

After completion of customization of the model, the consultant has developed Guidelines for Power System Optimization of Hydropower Projects. The Guideline has been divided into two sections i.e. A and B section. The Section A of Guidelinealong with the software package will help to the government agencies, planning commissions, public power producers and NEA with the uniform and consistent/converging approach for power system optimization study during long term planning, licensing stage, design and analysis of hydropower projects. And, Section B will help to the Independent power producers, NEA and Government agencies and professionals who are engaged in hydropower development for optimization of the individual projects at Feasibility level study.Hence, the outline of the guidelines has been presented below:

SECTION A

1. INTRODUCTION

1.1 Background

Nepal is blessed with precious water resources that accounts for an economical potential of 43000 MW, of which only less than 1.5% has been harnessed so far. The perennial nature of rivers and steep gradients of country's topography provide an ideal condition for the development of hydroelectric projects. Hence, to harness the hydropower potential of the country and to satisfy the increasing domestic power demand, the Department of Electricity Development (DoED) has made serious efforts to identify potential hydropower projects throughout the country. Promulgation of liberal hydropower development policy prepared by DoED has profoundly encouraged the national and international entrepreneurs to be engaged in the development of hydropower projects of different capacities. Development process of hydropower projects covers system planning, design and layout phases. The system planning and design including optimization of different hydropower projects under similar categories differed in depth and extension of studies carried out. Hence, for consistent approach of system planning, design and analysis at the feasibility level, a Guideline for Power System Optimization of Hydropower Projects is necessary.

1.2 Objective of Guidelines

The main objective of the Guideline is to provide guidance while adhering to uniform, consistent and converging approach, for the optimization study during planning, design and analysis of hydropower projects at the feasibility level of studies in the Nepalese context. These guidelines will provide common platform and form a basis to compare the projects on equal footing.

1.3 Scope of Guidelines

The Guidelines has been based on two widely used optimization models: VALORAGUA and WASP. The VALORAGUA-WASP model is used for the power system optimization of a mixed hydro-thermal system for a whole area such as country, state or region. Therefore, the guidelines hasnot focused on optimization of individual systems of generation, transmission, distribution, import or export and assume that these individual sub-systems are optimized a priori. Standalone projects are assumed to be optimized a priori before including them in the system for system optimization.

1.4 Concept of Optimization

Optimization should maximize the benefits from the power system while doing expansion planning or developing best operating policies. This is valid for the power system as well the power plants in the power system. Optimization philosophy has been discussed for various for the system as well for the plant. This section has described in detail the concept of optimization in hydro-thermal system.

1.5Philosophy of Power System Optimization

Power optimization of hydropower projects is aimed at maximizing the benefits of hydropower considering power demand, production, transmission, and distribution systems with the highest possible rate of efficiency assuring reliable, safe and economic operational conditions of the desired system of production.

2. LITERATURE REVIEW ON POWER SYSTEM

This section has described the detail information on involved energy institutions in Nepal, status of electric power development, review on electricity market (Import and Export of electricity), review on acts, plan, policy and guidelines on hydropower developments and review on different available power system optimization models.

3.VALORAGUA AND WASP MODELS

3.1 VALORAGUA model

3.2 WASP model

This section has focused on two models: VALORAGUA and WASP which have been the optimization models that have gonethrough the Guidelines. Working principles, input and output modules of both models have been described in this chapter.

4. DATABASE AND FILES

Different types of data needed in optimization work are presented in this section. These data include: hydrological data, power data, loadings, generation, costs/tariffs, plant characteristics and reservoir/pond characteristics.

4.1 Hydrological Data Preprocessing

- To prepare data in prescribed format, processing of data is done in the before model set up. The processing includes
- Delineation of basin and computation of basin area
- Computation of mean monthly data
- Checking consistency of hydrological data using double mass curve technique
- Computation of discharge at ungauged intake location from known discharge at upstream/downstream location or transfer from neighbouring basin
- Preparation of flow and power duration curve

4.2 Preprocessing of Load data

In this section, the collection of load data, forcasting of load demad and plotting of Load Duration Curve (LDC) has been described in detail.

4.3 Estimating Cost of Unserved Energy (CUE)

Different methods to estimate the Cost of Unserved Energy (CUE) have been described in this section.

4.4 Description of VALORAGUA files

In this section, the input data preparation methods for different modules of VALORAGUA are described:

- CADIR
- VALAGP
- MAINT
- RESEX
- RESIM
- VWASP

5. OptimizationFramework

This section presents the flow chart of optimization procedure using two models.

6. Optimization of Power System

With the input data of sample scenario, the output of power optimization using both models hasexplained in this section.

This section has been written considering the system characterization by VALORAGUA and WASP. The components include:

- Electric nodes
- Fixed power Demand
- Secondary power demand
- Maintenance Crew
- Thermal power plants and Imports
- Hydraulic nodes
  - Reservoirs
  - Spillways
  - Hydro turbine plant
  - Pumping plant
- Transmission lines

Design of hydraulic network

This section describes the procedure for preparing hydraulic network with an example considered as a basic scenario.

Power optimization

With the input data of sample scenario, the output of power optimization using both models is explained in this section.

LRMC computation

The procedure for LRMC computation is explained in this section giving example of basic scenario.

7. Scenario Analysis

In this section, the different scenarios have been setup and their LRMC have been computed.

8. Sensitivity Analysis

The sensitivity analysis can be carried out by varying different parameters in the reference case and compare their LRMCs to decide the best option. Hence, this section presents some examples of the sensitivity analyses of varying with some parameters.

9. Recommendations

This section gives a summary of recommendations that can be made from the outcomes of optimization.

SECTION B

1. COMPONENT OPTIMIZATION

1.1 INTRODUCTION

The objective of component optimization of hydropower projects is to adopt the best combination of different components e.g. weir/dam height, settling basin, headrace system, penstock pipe and number of units.

For Run-of-river (RoR) scheme, the component optimization is done for waterways (canal, tunnel, penstock and tailrace), and the number of units. For the storage type hydropower scheme, in addition to above, the dam height including pondage area should be optimized.

In RoR scheme, sizing of components like weir, intake, settling basin, forebay, surge tank, powerhouse are normally governed by hydraulic requirement and hence generally not optimized individually. Cost for access road, land acquisition, and transmission line are independent upon installed capacity and are considered constant for all alternatives. However, structures like canal, tunnel, penstock and tailrace shall be optimized based on the revenue lost due to head loss and cost of construction. The scheme with maximum net present value (NPV) shall be adopted as the optimum installed capacity.

For storage schemes, the dam height should be optimized based on the storage volume and energy generated with different installed capacity. For each height and installed capacity of the dam, the components like tunnel, penstock should be optimized separately. The installed capacity for which the NPV is the maximum shall be selected as the optimum.

1.2 INSTALLED CAPACITY OPTIMIZATION

The power can be calculated for different percentile of available flow. Increasing the percentile of available flow, the design discharge reduces. Decreasing the design discharge, the size of hydropower components such as intake, settling basin, conveyance system, penstock etc. decreases. Hence, the project cost reduces. But, the project capacity as well as energy also reduces due to the decrease in design discharge, thereby decreasing annual revenue. Hence the revenue and cost is traded to get optimum benefit. For this generally, the flow with 25% available to 70% available with certain interval is calculated from the flow duration curve, and power and revenue is calculated. The cost for each option is also calculated and then optimization study is done. The optimum capacity is taken as installed capacity.

1.3 DAM

Dams and weirs are primarily intended to divert the river flow into the water conveyance system leading to the powerhouse. Dams also produce additional head and provide storage capacity.

The choice of dam type depends largely on local topographical and geotechnical conditions. For instance if sound rock is not available within reasonable excavation depth, rigid structures such, as concrete dams are difficult. Conversely, for narrow valleys, it can be difficult to find space for separate spillways, and concrete dams can be the natural choice with their inherent possibilities to integrate spillways etc. in the dam body.

1.4 SPILLWAY

Spillway is a structure constructed at a dam site for effective disposing of surplus water from upstream to downstream. It is a safety valve for a dam. There is clear difference between dry and wet season flows, flood flows can have catastrophic effects on whatever structure is built in the stream. To avoid damage the excess water must be safely discharged over the dam or weir. For this reason carefully designed overflow passages are incorporated in dams as part of the structure. These passages are known as spillways. Due to the high velocities of the spilling water, some form of energy dissipation is usually provided at the base of the spillway.

1.5 CANAL

The objective of the design of canal is to determine the size and configuration that meets the criteria for the least cost. The cost determination usually is not limited to construction cost alone but often includes an economic analysis of costs and benefits. The best form of cross-section of a canal is a section which gives maximum discharge for a minimum cross-section i.e. the wetted perimeter should be minimum for economical channel section.

1.6 TUNNEL

For the optimization of diameter of the tunnel, the factors to be considered are: velocity requirement, head loss in tunnel, interest of capital cost of tunnel, annual operation and maintenance charge. The optimization is based on the increment of tunnel cost with respect to the tunnel diameter (sectional area) and the value of energy lost which is a function of the tunnel sectional area. A larger diameter for a given discharge leads to smaller head losses and hence greater will be the net head available to the turbine. Thus the power and energy production will be increased. On the other hand a greater size tunnel means less velocity and greater capital investment. Therefore, a size that will give the least capital cost over the lifetime of the plant is considered to be the optimum diameter / sectional area.

1.7 PENSTOCK

The inside diameter of penstock should be determined to be economical diameter. The economical diameter is a diameter which minimizes the sum of annual cost of penstock pipe and annual value of power loss due to loss of head.

1.8 SELECTION OF TYPES OF TURBINES AND NUMBER OF UNITS

Turbine selection and plant capacity determination requires the detailed information on head and possible plant discharge. The usual practice is to base selection of the annual energy output of the plant and least cost of the energy of the particular scale of the hydropower installation.

Conclusion and Recommendation

Nepal is suffering from heavy load shedding and acute shortage of electric energy which is badly affecting people's daily life in general, and country's development activities in particular. NEA's latest peak load forecast for integrated national power system (INPS) for the period 2004-2020 shows that peak load demand in the system could grow by 8% every year based on current GDP growth of 4%. Hence, the development of hydropower projects at the earliest possible time has become an urgent task to be undertaken by the Government. Further, the power export potential and power market opportunity for Nepal also exists in India. National Water Plan (2005) predicts a power export potential of 683.6 MW by 2027.

For expansion optimization of hydropower network the Client has committed to develop guidelines for Power System Optimization of Hydropower Projects as well as optimization of individual power plants at the feasibility stage of planning, design and analysis of hydropower projects.

Reference and study materials, guidelines, standards, codes, articles, law, acts, regulations, practices and hydro-development plans have been collected and reviewed. The collection of relevant materials has been continued throughout the study.

Many of the data which were needed for Power System Optimization of Hydropower Projects were not publicly available or published. So, the Client has cooperated in obtaining the required documents from government agencies or independent power producers and some data were reasonably assumed which were not available in Nepalese context.

The power system optimization has been done with VALORAGUA and WASP models, in which the results from VALORAGUA were fed as input to WASP. The results from the model simulation have been referred to prepare the Guideline for Power System Optimization of Hydropower Projects in Nepal.

This kind of study has been done very first time in case of Nepal. Hence, this study can be improved by using more sophisticated tools and more reliable data in the future.

Section A

Chapter 1

Introduction

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1. INTRODUCTION

1.1 BACKGROUND

Electrical energy is produced by two types of plants: thermal plant and hydropower plant. Most thermal plants use steam turbines and coal, natural gas, or nuclear fuel. Hydroelectric generators are driven by water turbines. Many large electric power production systems include interconnected thermal and hydroelectric plants. Hydropower generation is limited by the availability of water. Thermal plants are often used to meet base-load requirements supplemented by hydropower during times of peak energy demands.

Each hydropower plant is unique with its own design. The hydropower system includes dam, intake, conduit (penstock), turbine, generators, control mechanism, housing for equipment, transformers and transmission lines. Trash racks, gates, surge tank, forebay and other appurtenant hydraulic structures may also be required. Hydropower plants may be classified as run-of-river, storage, or pumped storage. Run-of-river (ROR) plants have little storage and use stream flow as it occurs. Storage type plants have sufficient storage capacity to carry over water from wet season to dry season or from year to year. In a pumped storage plant, water from tailwater pool is pumped back to headwater pool.

Nepal is blessed with precious water resources that accounts for an economical potential of 43000 MW, of which only less than 1.5% has been harnessed so far. The perennial nature of rivers and steep gradients of country's topography provide an ideal condition for the development of hydroelectric projects. The latest statistics shows that more than 90% of the total available electric power developed in Nepal is the hydropower. National Water Plan (NWP, 2005) has recognized that water is one of the principal physical resources that can play a major role in enhancing the pace of overall development of Nepal. Nevertheless, despite serious efforts by concerned agencies, development of such hydroelectric projects has not gained sufficient speed, principally due to insufficient funds and basic infrastructure facilities. As a result, Nepal is suffering from heavy load shedding and acute shortage of electric energy which is badly affecting people's daily life in general, and country's development activities in particular. The latest peak load forecast made by Nepal Electricity Authority (NEA) for integrated national power system (INPS) for the period 2004-2020 shows that peak load demand in the system could grow by 8% every year based on current gross domestic product (GDP) growth of 4%. Hence, the development of hydropower projects at the earliest possible time has become an urgent task to be undertaken by the Government.

In this connection, to harness the hydropower potential of the country and to satisfy the increasing domestic power demand, the Department of Electricity Development (DoED) has made serious efforts to identify potential hydropower projects throughout the country. Promulgation of liberal hydropower development policy prepared by DoED has profoundly encouraged the national and international entrepreneurs to be engaged in the development of hydropower projects of different capacities. Development process of hydropower projects covers system planning, design and layout phases. The system planning and design including optimization of different hydropower projects under similar categories differed in depth and extension of studies carried out. Hence, for consistent approach of system planning, design and analysis at the feasibility level, a Guideline for Power System Optimization of Hydropower Projects is necessary.

1.2 OBJECTIVE OF GUIDELINES

The main objective of the Guideline is to provide guidance while adhering to uniform, consistent and converging approach, for the optimization study during planning, design and analysis of hydropower projects at the feasibility level of studies in the Nepalese context. These guidelines will provide common platform and form a basis to compare the projects on equal footing. The guidelines will provide information about all types of analytical procedures and relevant values that are needed for power system optimization of hydropower projects in the Nepalese context. Preparation of guidelines for power system optimization will essentially be guided by two principles:

a. Demand for electricity is not unlimited.
b. Availability of funds to finance the construction of hydropower projects is also not unlimited.

1.3 SCOPE OF GUIDELINES

Different models are available for power system optimization. The Guidelines will be based on two widely used optimization models: VALORAGUA and WASP. International Atomic Energy Agency (IAEA) has developed the computer model called WASP (Wien Automatic System Planning Package), which has been made available to interested Member States for use in long term expansion planning of their power system. In order to overcome the limitations of WASP, the IAEA decided to acquire the computer model called VALORAGUA, developed by the Electricidade de Portugal (EDP). The VALORAGUA-WASP model is used for the power system optimization of a mixed hydro-thermal system for a whole area such as country, state or region. Therefore, the guidelines will not focus on optimization of individual systems of generation, transmission, distribution, import or export and assumes that these individual sub-systems are optimized a priori. Standalone projects are assumed to be optimized a priori before including them in the system for system optimization.

In the context of VALORAGUA-WASP model, the Guidelines cover the following:

- Hydrosystem and thermal system
- Focus on power generation and possible import/export of electric energy in the system
- Existing and planned/underconstruction projects
- Run-of-river and storage type of hydro plants
- Compilation and processing of data
- Formats of data files
- Format of output files
- Design of hydronetwork for optimization
- Setting parameters of model
- Running sequence of model
- Determination of the monetary value of different sets of hydropower plants
- Generation of scenarios and computation of Long Run Marginal cost (LRMC)
  - Base case scenario
  - Inclusion of export
  - Optimization covering the impact of gross domestic product (GDP) growth
  - Optimization covering different combinations of hydropower plants
  - Optimization covering short term (at least 5 years), medium term (at least 15 years) and long term (at least 25 years) planning
- Sensitivity analysis

It should be noted that major existing power plants connected to the national grid (INPS) will be included for calculating current operation policy and LRMC. The user will be able to consider each plant in the system individually. Then future projects can be added to the system for long term expansion power planning, and provision for optimizing each plant will be made available to the user. It should also be noted that the distribution system has been envisioned as a demand node for this study.

The proposed guidelines are supposed to help the users to identify the best generation expansion plan based on existing infrastructure. At the feasibility study level of generation expansion, transmission and distribution (demand) become the constraints or the boundary conditions. Although the voltage levels affect the system performance, this study does not consider voltage variation as it is an issue for transmission line modeling rather than system optimization.

1.4 CONCEPT OF OPTIMIZATION

Selecting the best or optimum solution from a set of alternative solution is referred to as optimization. In other words, optimization is finding the least or the most value such as cost. An optimization problem includes the following:

- Objective: value (e.g. cost) to maximize or minimize
- Objective function (cost function): mathematical function to be optimized (maximized or minimized)
- A set of variable controlling objective function (dependent and independent or decision variable)
- Constraints: imposed conditions
- Parameters: constant chosen during optimization set up

Mathematically, optimization problem can be set as follows:

Find the values of x1, x2,…..,xn which minimize f(x)

Subject to

Bi(x) <=0, I = 1, 2, …, m

Sj(x) = 0, j= 1,2,……., m

Where X is n-dimensional vector (design vector, decision variable), f(x) is objective function, Bi(x) and Sj(x) are constraints.

A feasible solution is that minimizes or maximizes the objective function the optimal solution. Many problems are formulated as single objective optimization. Sometimes multiple objectives are also assigned for specific problems. The objective functions maybe constrained or unconstrained. However, in most of the cases constrains are imposed.

The constraints of an optimization model contain decision-variables that are unknown and parameters whose values are assumed known. Constraints are expressed as equations and inequalities. The solution of an optimization model, if one exists, contains the values of all of the unknown decision-variables. It is mathematically optimal in that the values of the decision-variables satisfy all the constraints and maximize or minimize an objective function. This ‘optimal’ solution is of course based on the assumed values of the model parameters, the chosen objective function and the structure of the model itself.

The following are the major steps in constrained optimization:

- Prepare list of all variables for a particular problem.
- Assess the criterion for optimization and formulate the objective function with variables and parameters.

- Formulate constrains (equality/inequality): formulation of equations satisfying governing processes, use well known physical principles such as mass balances, energy balance, empirical relations, implicit concepts and external restrictions, identify the independent and dependent variables
- Simplify the objective function and model for complex problems
- Solve the optimization problem (algorithm for solution)

For continuous and differentiable functions, the method used in differential calculus is the classical method for optimization. Besides classical method, the other methods of optimization include linear programming (linear objective function and constraints), quadratic programming (quadratic objective function and linear constraints), non-linear programming (non-linear objective function and constraints), dynamic programming (splitting problems into smaller sub-problems), stochastic programming (some of the constraints depending on random variables) etc.

1.5 PHILOSOPHY OF POWER SYSTEM OPTIMIZATION

Power system is the surrogate of generation, transmission, and consumption networks of electric energy. Power optimization of hydropower projects is aimed at maximizing the benefits of hydropower considering power demand, production, transmission, and distribution systems with the highest possible rate of efficiency assuring reliable, safe and economic operational conditions of the desired system of production. The optimization should maximize the benefits from the power system while doing expansion planning or developing best operating policies. In power optimization study, the objective function relates various costs, constraints are imposed, and the optimization algorithm minimizes costs. The constraints are formulated by considering water balance, power balance, upper and lower bounds etc.

Chapter 2

Literature Review on Power System

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2. LITERATURE REVIEW ON POWER SYSTEM

2.1 INVOLVED INSTITUTIONS IN NEPAL

2.1.1 Nepal Electricity Authority (NEA)

Nepal Electricity Authority (NEA) was established on August 16, 1985 (Bhadra 1, 2042) under the Nepal Electricity Authority Act in 1984, through the merger of the Department of Electricity of Ministry of Water Resources, Nepal Electricity Corporation and related Development Boards. The primary objective of NEA is to generate, transmit and distribute adequate, reliable and affordable power by planning, constructing, operating and maintaining all generation, transmission and distribution facilities in Nepal's power system both interconnected and isolated.

Responsibilities:

In addition to achieving above primary objective, NEA's major responsibilities are:

a. to recommend to Government of Nepal, long and short- term plans and policies in the power sector.

b. to recommend, determine and realize tariff structure for electricity consumption with prior approval of Government of Nepal.

c. to arrange for training and study so as to produce skilled manpower in generation, transmission, distribution and other sectors.

2.1.2 Department of Electricity Development (DoED)

Electricity Development Center (EDC) was established on July 16, 1993 (2050,Shrawan 1) under the then Ministry of Water Resources (MOWR) to develop and promote electricity sector and to improve financial effectiveness of this sector at the national level by attracting private sector investment. It was later renamed as Department of Electricity Development (DoED) on February 7, 2000 (2056 Magh 24). The Department of Electricity Development (DoED) is responsible for assisting the Ministry in implementation of overall government policies related to power/electricity sector. The major functions of the Department are to ensure transparency of regulatory framework, accommodate, promote and facilitate private sector's participation in power sector by providing "One Window" service. Under the prevailing law and regulations, DOED receives license applications and other pertinent documents from independent power developing entrepreneurs and carries out due diligence. Based on the findings, it recommends to the MoEn for the licenses to power projects. DoED equally emphasizes new projects from government as well as private sectors.

2.1.3 Department of Hydrology and Meteorology (DHM)

Government of Nepal started hydrological and meteorological activities in an organized way in 1962. The activities were initiated as a section under the Department of Electricity. The section was subsequently transferred to the Department of Irrigation and was ultimately upgraded to Department status in 1988 as the Department of Hydrology and Meteorology (DHM). DHM has a mandate from Government of Nepal to monitor all the hydrological and meteorological activities in Nepal. The scope of work includes the monitoring of river hydrology, climate, agrometeorology, sediment, air quality, water quality, limnology, snow hydrology, glaciology, and wind and solar energy. General and aviation weather forecasts are the regular services provided by DHM.

The Principal Activities of DHM:

- Collect and disseminate hydrological and meteorological information for water resources, agriculture, energy, and other development activities.
- Issue hydrological and meteorological forecasts for public, mountaineering expedition, civil aviation, and for the mitigation of natural disasters.
- Conduct special studies required for the policy makers and for the development of hydrological and meteorological sciences in the region.
- Promote relationship with national and international organizations in the field of hydrology and meteorology.

2.1.4 Water and Energy Commission Secretariat (WECS)

The Water and Energy Commission (WEC) was established by GoN in 1975 with the objective of developing the water and energy resources in an integrated and accelerated manner. Consequently, a permanent secretariat of WEC was established in 1981 and was given the name, Water and Energy Commission Secretariat (WECS). The primary responsibility of WECS is to assist GoN, different ministries relating to Water Resources and other related agencies in the formulation of policies and planning of projects in the water and energy resources sector.

2.1.5 Department of Irrigation (DOI)

Department of Canal was formally established in 1952 under the ministry of Construction and Communication. The department then passed different stages working under different ministries and finally ended up as Department of Irrigation in 1987.

Department of Irrigation (DoI) has a mandate to plan, develop, maintain, operate, manage and monitor different modes of environmentally sustainable and socially acceptable irrigation and drainage systems - from small to larger scale surface systems and from individual to community groundwater schemes. Its ultimate aim is to provide year round irrigation facilities and increase the irrigable area of the country to higher limits.

2.1.6 Department of Water Induced Disaster Prevention (DWIDP)

In order to mitigate water induced disasters in Nepal, the then Water Induced Disaster Prevention Technical Centre (DPTC) was established under the Ministry of Water Resources under an agreement between the Government of Nepal and the Government of Japan on 7 October 1991. To institutionalize the objectives and achievements of the DPTC, the Department of Water Induced Disaster Prevention (DWIDP) was established on 7 February 2000 under the Ministry of Water Resources. The objective of establishing the department is to implement the programs of river and river basins conservation and to develop related appropriate technology, research, information systems, human resource and institutional development activities and to raise awareness of communities so as to mitigate water-induced disasters.

2.2 STATUS OF ELECTRIC POWER DEVELOPMENT IN NEPAL

The basin-wise hydropower potential of Nepal is shown in Table 2.1

Table 2-1: Basinwise hydropower potential capacity of Nepal

River Basin	**Major rivers (>1000km^2)**	**Small rivers (300-1000 km^2)**	**Total (MW)**
SaptaKoshi	18750	3600	22350
SaptaGandaki	17950	2700	20650
Karnali&Mahakali	32680	3500	36180
Southern River	3070	1040	4110
Country Total	72450	10840	83290

According to NEA report, the total installed electric power capacity of Nepal as of year 2013 is 762 MW (Table 2-2). The total installed hydropower capacity as of year 2013 is only 708 MW.

Table 2-2: Installed capacity (NEA, 2013)

Hydropower (NEA)	477930 KW
Hydropower (IPP)	230589 KW
Thermal (NEA)	53410 KW
Solar (NEA)	100 KW
Total	**762029 KW (762MW)**

2.1.7 Major hydropower plants in operation

Major hydropower projects operating in Nepal were reviewed are shown in Table 2.3 along their installed capacity and commercial operation date (COD). The total installed capacity of major hydropower plants as shown in Table 2-3 is 459.15 MW. The NEA is the owner of these projects.

Table 2-3: Major Hydropower Plants in Nepal (NEA, 2011)

S.N.	**Name**	**Power (kW)**	**COD**
1	Kali Gandaki "A"	144,000	Aug 16, 2002
2	Middle Marsyangdi	70,000	Dec 14, 2008
3	Marsyangdi	69,000	Nov 5, 1989
4	Kulekhani No. 1	60,000	May 14, 1982
5	Kulekhani No. 2	32,000	Nov, 1986
6	Trisuli	24,000	1967[a]
7	Gandak	15,000	Apr, 1979
8	ModiKhola	14,800	Dec 9, 2000
9	Devighat	15,000	Dec, 1984[b]
10	Sunkosi	10,050	Jan, 1972
11	Puwakhola	6,200	Dec, 1999
12	Chatara	3,100	Jul, 1996
13	Panauti	2,400	1965
14	Seti	1,500	1985
15	Fewa	1,000	1969

Notes: a- originally 21.0 MW – upgraded to 24 MW in 1995; b - originally 14.1 MW capacity upgraded to 15.0 MW in 2011.

2.1.8 Hydropower plants developed by IPPs

The total installed capacity as shown in Table 2-4 of hydropower plants developed by independent producers is 174.526 MW. The power is purchased by NEA.

Table 2-4: IPP Plants in Nepal (NEA, 2011)

S.N.	Plant Name	Power (kW)	COD
1	KhimtiKhola	60,000	Jul 11, 2000
2	BhotekoshiKhola	45,000[a]	Jan 24, 2001
3	Chilime	22,000	Aug 25, 2003
4	Indrawati - III	7,500	Oct 7, 2002
5	JhimrukKhola	12,000	Aug 1, 1994
6	AndhiKhola	9,400[b]	July 1, 1991
7	SyangeKhola	183	Jan 23, 2002
8	PiluwaKhola	3,000	Sep 18, 2003
9	RairangKhola	500	Dec 16, 2004
10	SunkoshiKhola	2,500	Mar 24, 2005
11	ChakuKhola	3,000[c]	Jun 15, 2005
12	KhudiKhola	3,450	Dec 30, 2006
13	BaramchiKhola	4,200	Jan 11, 2007
14	ThoppalKhola	1,650	Oct 30, 2007
15	SisneKhola	750	Sep 18, 2007
16	SaliNadi	232	Nov 17, 2007
17	PhemeKhola	995	Nov 21, 2007
18	PatiKhola	996	Feb 9, 2009
19	Seti-II	979	Feb 25, 2009
20	RidiKhola	2,400	Oct 27, 2009
21	Upper HadiKhola	991	Nov 8, 2009
22	Mardi Khola	3,100	Jan 22, 2010
23	Mai Khola	4,500	Jan 28, 2011
24	Lower Piluwa	990	Jul 17, 2011
25	HewaKhola	4,455	Aug 2, 2011

Notes: a-originally licensed for 36MW, b – 5.1 MW operating and being upgraded to 9.4MW; c – 1.5 MW operating

2.1.9 Small Hydropower Plants

The small hydropower plants shown in Table 2-5, which are not connected to INPS, supply a total of 4.536 MW power to isolated communities.

Table 2-5: Small Hydropower Plants in Nepal (NEA, 2011)

S.N.	Plant name	Power (kW)
1	Dhankuta	240
2	Jhupra	345
3	Gorkhe (Illam)	64
4	Jumla	200
5	Dhading	32
6	Syangia	80
7	Helambu	50
8	Darchula (I) & (II)	300
9	Chame	45
10	Teplejung	125
11	Manang	80
12	Chaurjhari (Rulum)	150
13	Syarpudaha (Rukum)	200
14	Bhojpur	250
15	Barjura	200
16	Bajhang	200
17	ArughatGorkha	150
18	Okhaldhunga	125
19	Pupalgad (Dadeldhura)	100
20	Achham	400
21	Dolpa	200
22	Kalikot	500
23	Heldung (Humla)	500

2.1.10 Thermal Power Plants Developed by NEA

Shown in Table 2.6 are only two active diesel plants in Nepal which produce electric power of 53.410 MW. These plants were developed to meet the peak loads.

Table 2-6: Thermal Plants in Nepal (NEA,2011)

S.N.	Plant Name	Power (kW)
1	DuhabiMultifuel (6 units)	39,000
2	Hetauda (7 units)	14,410

From the above tables it is clear that the system is hydro dominated. The share of thermal capacity is just 8.2% of the total installed capacities and 11.3% of the total installed capacities connected to INPS.

2.1.11 Power Plants under Construction

Shown in Table 2-7 are the major hydropower plants under construction which after completion will deliver a total of 592W to the INPS.

Table 2-7: Major Power Plants under Construction (NEA, 2011)

S.N.	Plant Name	Power (kW)	Expected COD
1	Upper Tamakoshi	456,000	Dec 25, 2015*
2	Chameliya	30,000	2013
3	Kulekhani III	14,000	2014
4	Upper Trishuli -3 'A'	60,000	2014
5	Rahughat	32,000	2017
6	Gamgad	400	2012

Note: *First 2 units will be commissioned, on July 14, 2016 other two will be completed

Shown in Table 2-8 are other IPP plants under construction which after completion will deliver a total of 79.696 the INPS. From the table, it is evident that many projects have been delayed.

Table 2-8: IPP Power Plants under Construction (NEA, 2011)

S.No.	Name of Project	Location(District)	Capacity(kW)	Expected COD
1	L IndrawatiKhola	Sindhupalchowk	4,500	Jun 29, 2006*
2	Lower Modi I	Parbat	9,900	Aug 18, 2011*
3	SipringKhola	Dolkha	9,658	Dec 16, 2011*
4	SiuriKhola	Lamjung	4,950	Feb 12, 2011*
5	AnkhuKhola – 1	Dhading	8,400	Feb 13, 2012*
6	Bijayapur-1	Kaski	4,410	Apr 13, 2011*
7	Middle Chaku	Sindhupalchowk	1,800	Dec 31,2010*
8	BhairabKunda	Sindhupalchowk	3,000	May 15, 2011*
9	CharanawatiKhola	Dolakha	3,520	Apr 13,2012*
10	Lower ChakuKhola	Sindhupalchowk	1,765	Jul 16,2008*
11	Jiri Khola	Dolkha	2,200	Jul 15,2012*
12	PikhuwaKhola	Bhojpur	2,475	Mar 13,2013
13	Mai Khola	Ilam	15,600	Jul 14, 2013
14	Belkhu	Dhading	518	Apr 13, 2011*
15	MailungKhola	Rasuwa	5,000	Mar 31, 2004*
16	JhyadiKhola	Sindhupalchowk	2,000	May 30, 2012*

Notes: * delayed

2.1.12 Classification of hydropower plants

Based on the regulation of flow, the hydropower plants can be classified as follows:

1. Run-of-river plant
    i. with simple run-off
    ii. with daily pondage
2. Storage plant

In view of this classification, among plants in operation, only KuleKhani I & II have storage of flow, whereas all other hydropower plants are Run-Of-River type. Some of the hydropower plants such as Marsyandi, Middle Marsyandi, Kaligandaki A and PhewaKhola include some daily pondage. All other plants have no pondage or no significant pondage. In the optimization guidelines, this classification will be adhered to and all INPS plants will be included in the database of the software.

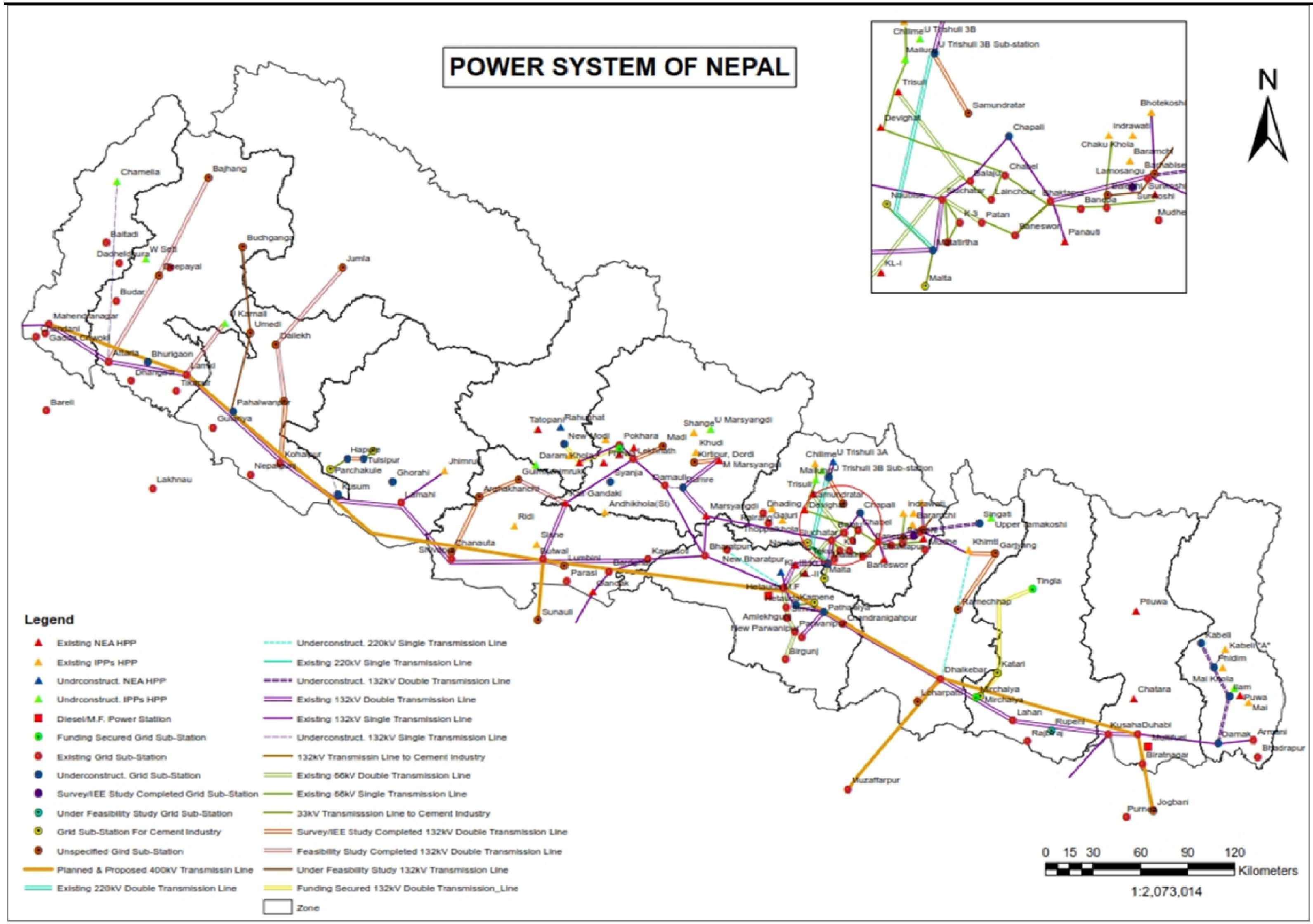

Figure 2-1: Power Development map of Nepal

2.1.13 Long Term Electricity Demands and Economic Scenarios

Several documents regarding policy directives, annual reports, regulations, acts, and other materials were collected. These documents shed some insight into the long term electricity (power and energy) demand in Nepal. The Twenty Year Hydropower Development Plan (2010) projects a demand of 4,607 MW in 2030 under the assumption that the GDP growth will be at 5.6%. It also projects that electricity will replace other fuels for domestic use, as a result of which the total demand could be estimated at 11,480 MW. In Table 2-9, it is shown how demand for energy will evolve in time. The Twenty Year Hydropower Development Plan (2010) estimated an energy use of 0.50 million Terra Joules by 2015 and 0.92 million Terra Joules by 2030.

Table 2-9: Projected energy use for a GDP growth of 5.6%

S.N.	Forms of Energy	2015		2030	
		Mill Terra Joules	%	Mill Terra Joules	%
1	Fuel wood	0.350	70	0.3956	43
2	Electricity	0.015	3	0.1564	17
3	Kerosene	0.025	5	0.092	10
4	LP G	0.015	3	0.092	10
5	Petrol	0.005	1	0.0092	1
6	Biogas	0.005	1	0.0184	2
7	Agri residues	0.015	3	0.0092	1
8	Dung	0.020	4	0.0184	2
9	Air-fuel	0.005	1	0.0092	1
10	Coal	0.015	3	0.0368	4
11	Diesel	0.03	6	0.0828	9
12	Total	0.50	100	0.92	100

In Figures 2-2 and 2-3 the fractional shares of various types of energy resources in 2015 and 2030 are shown. From the charts it can be seen that use of electricity grows from 3% (2015) to 17% (2030). Likewise a vast reduction can be observed in the projected values of fuel wood use, the 70% share (2015) will be reduced to 43% by 2030. It was estimated that fuel wood be replaced by electricity, kerosene, LPG and biogas.

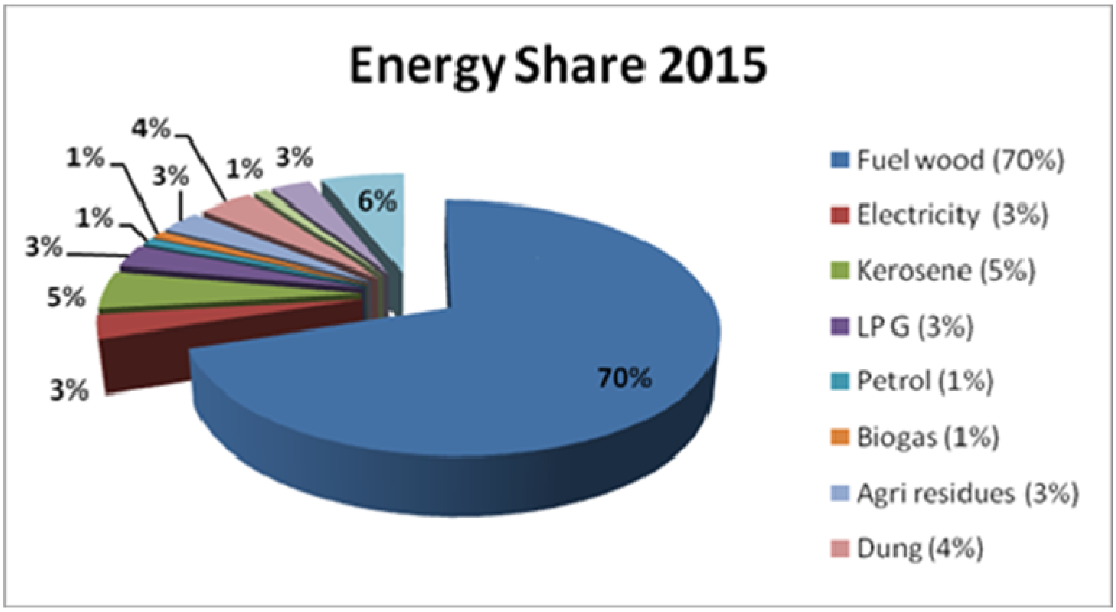

Figure 2-2: Projected energy use and energy resource distribution in 2030 for a GDP growth of 5.6%

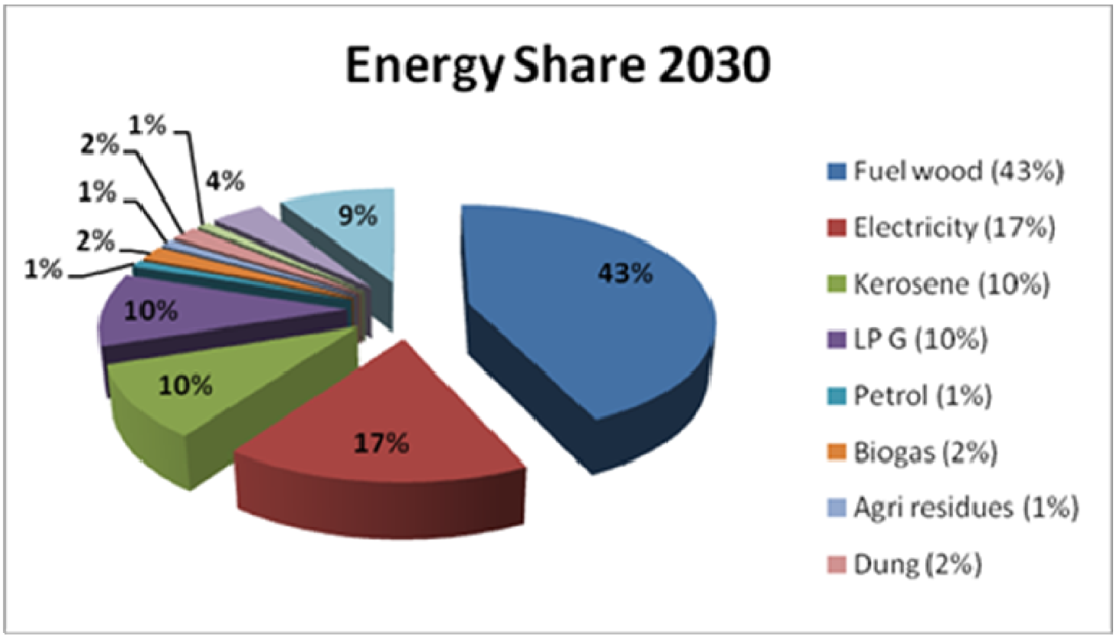

Figure 2-3: Projected energy use and energy resource distribution in 2030 for a GDP growth of 5.6%

On the other hand, at GDP growth of 4%, the historical energy use in 2005 was found as shown in Figure 2.4. It was dominated by the traditional type of energy sources such as fuel wood, agricultural residues, animal dung etc. Based on the projected energy listed in Table 2-9. The Twenty Year Hydropower Development Plan, has estimated future energy use as shown in Table 2-10.

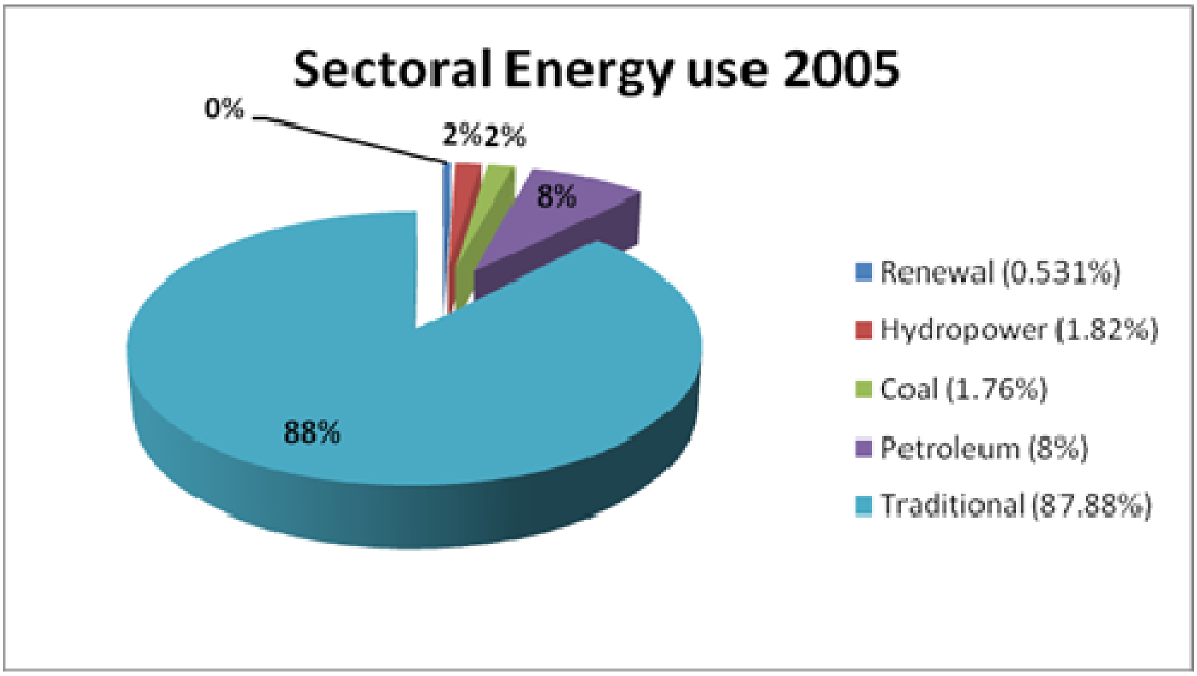

Figure 2-4: Sector-wide Energy use distribution in 2005

Table 2-10: Overview of future energy use in Nepal

S.N.	**Energy Index**	**Unit**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
1	Per Capita Energy	Giga Joules	15.0	16.0	16.0	17.0	19.0	23.0
2	Per Capita Electricity	kWh	67.0	80.0	124.0	231.0	496.0	1070.0
3	Household Electricity Use	Percent	1.0	2.0	4.0	7.0	13.0	17.0
4	Energy Per Household	Giga Joules	76.0	79.0	78.0	78.0	76.0	77.0
5	Non-Carbon Electricity Share	Percent	1.7	1.9	2.8	4.8	9.3	16.5
6	Share Of Renewable Energy In Total Energy Use	Percent	11.7	11.9	11.2	12.3	15.4	22.1
7	Imported Electric Energy As Fraction of Total Energy	Percent	10.6	13.4	18.0	23.4	29.9	34.8
8	Per Capita Greenhouse Gas Production	kg	474.0	459.0	420.0	392.0	508.0	672.0

From the Table 2-10 and the pie chart shown in Figure 2-5, it can be seen that the projected electric use and its growth is significant. According to Electricity Authority Annual reports, the current use of total electric energy is 2601.53 GWh for 2010, which calculates 102.8 kWh per capita (total population was estimated at 26,620,809 according to Central Bureau Statistics on September 27, 2011, RSS news).

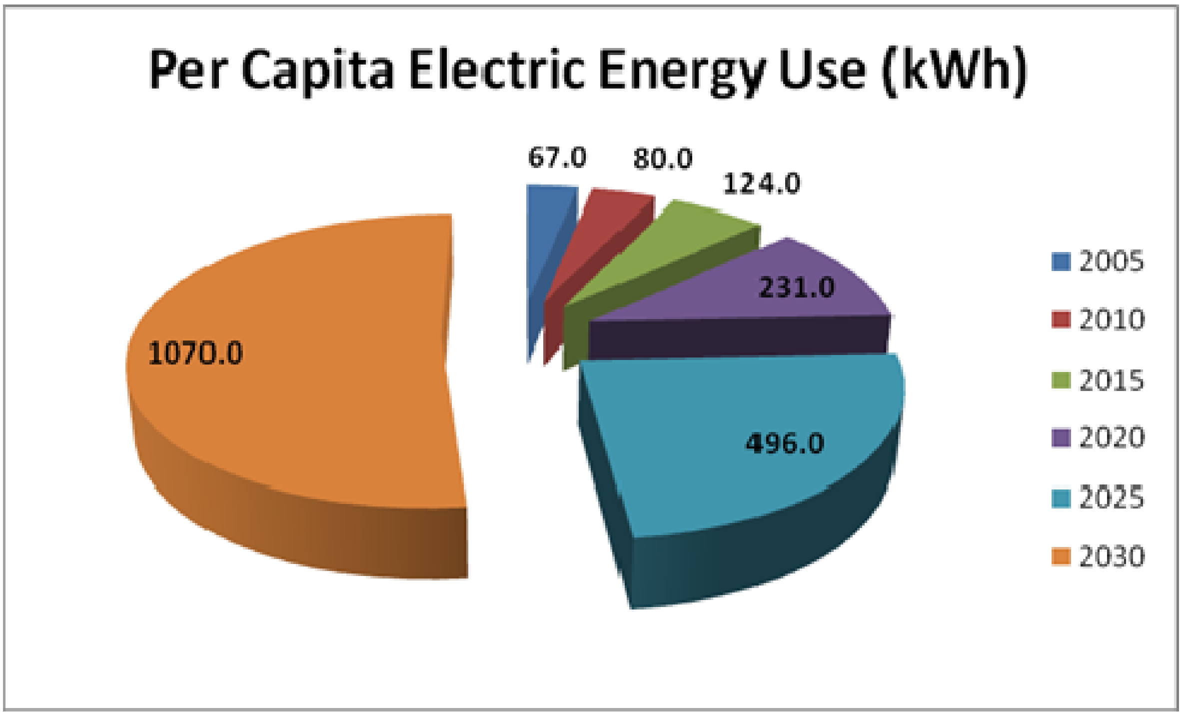

Figure 2-5: Projected Per Capita Electric Energy Use for Years 2005 – 2030

National Water Plan (2005) recognized that water is one of the principal physical resources that can play a major role in enhancing the pace of overall development of a country. It envisions that water resources development can significantly contribute to poverty alleviation and economic growth.

In the same line, the Twenty Year Hydropower Development Plan estimates show a tremendous paradigm shift of future energy use in Nepal. As shown in Table 2-11, the Twenty Year Plan envisions a regular addition of electric energy into the system. In 2025-2029 alone it is anticipated that 18,034 MW of hydropower energy be added into the system.

Table 2-11: Additional installed capacities for years 2010 to 2029

S. N.	**Period**	**Installed Power MW**
1	2010 – 2014	2057.0
2	2015–2019	2423.0
3	2020 – 2024	5114.0
4	2025 – 2029	18034.0

The Nepal Electricity Authority has also projected the electric energy demand and system peak load demands as shown in Table 2-12. Long term load forecasts are based on their in-house methods.

Table 2-12: Electric Energy and Power Forecast

S.N.	Fiscal year	Energy (GWh)	System Peak Load (MW)
1	2010-11	4,430.70	967.1
2	2011-12	4,851.30	1,056.90
3	2012-13	5,349.60	1,163.20
4	2013-14	5,859.90	1,271.70
5	2014-15	6,403.80	1,387.20
6	2015-16	6,984.10	1,510.00
7	2016-17	7,603.70	1,640.80
8	2017-18	8,218.80	1,770.20
9	2018-19	8,870.20	1,906.90
10	2019-20	9,562.90	2,052.00
11	2020-21	10,300.10	2,206.00
12	2021-22	11,053.60	2,363.00
13	2022-23	11,929.10	2,545.40
14	2023-24	12,870.20	2,741.10
15	2024-25	13,882.40	2,951.10
16	2025-26	14,971.20	3,176.70
17	2026-27	16,142.70	3,418.90
18	2027-28	17403.60	3679.10

As shown in Table 2-13, Ten Year Hydropower Development Plan (2009) estimated the loads and planned incremental installations of additional hydropower capacities for years 2011 – 2020.

Table 2-13: Ten Year Projection of Annual Electricity Demand, Production, Deficit and Surplus

S.N.	Year	Incremental (MW)	Total Installed (MW)	Load projection			Deficit/Surplus (MW)		
				at GDP growth rates			at GDP growth rates		
				5.50%	7.50%	10.00%	5.50%	7.50%	10.00%
1	2011	88	972	949	958	978	23	14	-6
2	2012	209	1181	1036	1059	1109	-64	-87	-137
3	2013	969	2151	1140	1185	1278	-168	-213	-306
4	2014	871	3021	1249	1531	1685	-277	-559	-713
5	2015	1117	4139	1368	1703	2033	-396	-731	-1061
6	2016	1721	5860	1498	1895	2430	-526	-923	-1458
7	2017	2227	8087	1640	2110	2997	-668	-1138	-2025
8	2018	2113	10200	1784	2336	3595	-812	-1364	-2623
9	2019	2007	12207	1942	2589	4254	-970	-1617	-3282
10	2020	3387	15593	2112	2882	4990	-1140	-1910	-4018

2.3 REVIEW OF EXPORT MARKET POTENTIAL

This study aims to assess short term, medium term and long term export market potential as Nepal can hold strong economic status by selling power. Power development of Nepal shall not be limited to use in boundary but international market shall be opened. Nepalese hydropower development should give program that promotes energy security in South Asia. It is anticipated that the planning of export potential shall focus on following three areas:

- Cross border energy trade
- Energy market formation
- Regional clean energy development.

The export market contains countries also including Afghanistan, Bangladesh, Bhutan, India etc. The future expansion of export market begins with neighboring power market. As National Water Plan also envisions that the prosperity of Nepal is dependent on how Nepal develops its water resources, one of the major sources of income for Nepal would be development of hydroelectric energy and sell it particularly to India. Hence, the Consultant clearly recognizes the rationale of export market potential of electric energy, particularly to India and it has started to collect up-to-date official data on Indian market through electronic media and search engines.

One of the determining factors for future hydropower development in Nepal is Indian electricity market dynamics. For example, According to Central Electricity Authority of India (CEA), the present shortage (2012-2013) of electric power in India is 12,159 MW and a shortage of 87 Billion KWh of energy was recorded (see Table 2-14).

Table 2-14: All-India Actual Power Supply Position (April, 2010- March, 2011)

S.N.	**Market**	**Peak Load (MW)**	**Energy Billion kWh**
1	Requirement	135453	998
2	Availability	123294	911
3	Shortage	12159	87
4	Shortage by system weight	9.0%	8.7%

National electricity plan, Central electricity Authority India has made studies on various demand scenarios based on different Gross Domestic Product (GDP) Growth Rate of India. The future demand scenario of Indian energy requirement also serves the export market potential for Nepali generations. In Table 2-15 shown are the energy requirement projections for Indian planning for years from 2012-2022.

Table 2-15: Demand of Energy in India

S. N.	**Year**	**GDP Growth Rate**	**Energy Requirement**
		(%)	**(GWh)**
1	2012-13	9	1001922
2	2013-14	9	1080438
3	2014-15	9	1165108
4	2015-16	9	1256413
5	2016-17	9	1354874
6	2017-18	8.1	1450982

7	2018-19	8.1	1552008
8	2019-20	8.1	1660783
9	2020-21	8.1	1778109
10	2021-22	8.1	1904861

The power and energy demands in India for 12th and 13th plans are projected as in Table 2-16.

Table 2-16: Demand Adopted for Generation Planning Studies

S.N.		Energy Requirement (GWh)	Peak Load (MW)
1	2016-17 (12th Plan end)	1,354,874	199,540
2	2021-22 (13th Plan end)	1,904,861	283,470

Ironically, the shortage of energy in India is a market potential and business opportunity for Nepal. Hence, a rigorous assessment of Indian electricity market needs to be incorporated in the proposed optimization software such that the planner can scrutinize scenarios with or without export potential. In addition, guidelines will be provided to update this assessment dynamically.

National Water Plan envisions the export market as shown in Table 2-17.

Table 2-17: Projected demand, production & export potential for years 2002 - 2027

S.N.	Years	Demand (MW)	Electricity Production (MW)	Export (MW)
1	2002	449	527.5	78.5
2	2007	667.1	641.5	-25.6
3	2012	960.1	1076.6	116.5
4	2017	1355.4	1794.6	439.2
5	2022	1894.6	2480	585.4
6	2027	2661.4	3345	683.6

National Water Plan states that large exports are not planned as it would depend on market. India has projected large deficit of hydro-electricity in India, one third of which is attributed to Bihar and Utter Pradesh. These states are much closer to Nepal rather than India's under-developed potential of Brahmaputra. Bangladesh also projects a power deficit of 5,000 MW by 2020. National Water Plan stresses that regional power grid concept should be promoted by Nepal to take additional benefits from power export. It should also be noted that the cost to extract electricity from coal-fired plants is estimated at USD 1,200 – 1,400 /kW.

The Twenty Year Hydropower Development Plan (2010) has identified that the following 400 KV transmission line made of Double Circuit Moose Conductor be constructed in mutual agreement with India.

- Dhalkebar – Mujjaffarpur 140 km long, of which 40 km will be through Nepal. It will be able to evacuate up to 1500 MW to/from India.
- Hetauda-Dhalkebar 140 km long.

- Dhalkebar- Duhabi 160 km long.

It is anticipated that these transmission lines will open up doors for massive electricity export to India. It should be noted that options will be made in the optimization model as well as in the guidelines to incorporate export market potentials and export nodes.

2.1.14 Seasonal Variation Demand in Nepal and India

Consultant understands the essence of seasonal variation of energy and capacity demand, and hence, it has initiated to review seasonal variations of energy and capacity demand in Nepal and India as envisioned by the scope works listed in the TOR. Efforts are made to collect official documents and data pertinent to seasonal variation of energy and capacity demand in Nepal and India. Annual reports by Nepal Electricity Authority for years 2009, 2010, 2011 (e-copies) were downloaded from the NEA website. For other data pertaining to seasonal variation, a request letter from the Client is sent to the NEA and the Consultant has been following up for the data. Unlike other demand data, historical seasonal variation is poorly studied and data on seasonal variation is scars.

The Ten Year Hydro-electricity Development Plan (TYHEDP), prepared by the Ministry of Water Resources (2009) has projected seasonal variations of power for years 2011 – 2020 in view of Government's commitment to deliver electricity to each home and intensify industrial development. Two seasons (Wet and Dry) are considered. Wet season covers months from April 16 to December 14, whereas Dry season covers months from December 15 to April 15. TYHEDP has envisioned three GDP growth rates (Low equal to 5.5%, Medium equal to 7.5% and High equal to 10.0%) for which load projections were calculated and deficit and/or surpluses of firm power was calculated as shown in Table 2.18. The energy system of Nepal is managed through load-shedding and therefore, a real picture of seasonal variation of actual demand is still to make. However, in couple of past years immediately after completion of Kali Gandaki A, a trend of seasonal variation was observed. The Consultant is striving to obtain this data from NEA.

In India, earlier studies were conducted only to estimate the capacity addition required to meet the annual demand projections. Central Electricity Authority India recognizes that five seasonal blocks of months: April-June, July-September, Oct- November, December-January and February-March are essential to ensure that the seasonal demand of the system in order to assess the capacity addition requirement.

Table 2-18: Seasonal Variation of Electricity Production, Demand, Deficit and Surplus

S.N.	Year	To be added (MW)		Total Installed (MW)		Load projection (MW)			Deficit / Surplus (MW) at GDP growth rates					
						at GDP growth rates			5.5%		7.5%		7.5%	
		Wet	Dry	Wet	Dry	5.5%	7.5%	10.0%	Wet	Dry	Wet	Dry	Wet	Dry
1	2011	59	29	651	321	949	958	978	-298	-628	-307	-637	-327	-657
2	2012	157	52	808	373	1036	1059	1109	-228	-662	-251	-686	-301	-735
3	2013	727	242	1535	616	1140	1185	1278	395	-525	350	-569	257	-662
4	2014	528	343	2063	958	1249	1531	1685	814	-291	532	-573	378	-726
6	2015	688	429	2751	1388	1368	1703	2033	1384	20	1048	-315	718	-645
7	2016	1091	630	3842	2018	1498	1895	2430	2345	521	1947	123	1412	-412
8	2017	1500	727	5342	2745	1640	2110	2997	3702	1105	3233	635	2345	-252
9	2018	1240	873	6582	3618	1784	2336	3595	4798	1834	4246	1282	2987	23

10	2019	1315	692	7897	4310	1942	2589	4254	5955	2368	5308	1721	3644	56
11	2020	2210	1177	10107	5486	2112	2882	4990	7995	3374	7225	2604	5117	496

In addition, it should be noted that the diurnal variation of peak loads are also important to assess the required addition of hydropower capacities. Efforts are being made to collect historical data of diurnal variation of loads and the source of such data is NEA. For example, data on diurnal variation of power such as shown in Figure 2-6 are available from NEA (NEA, 2013).

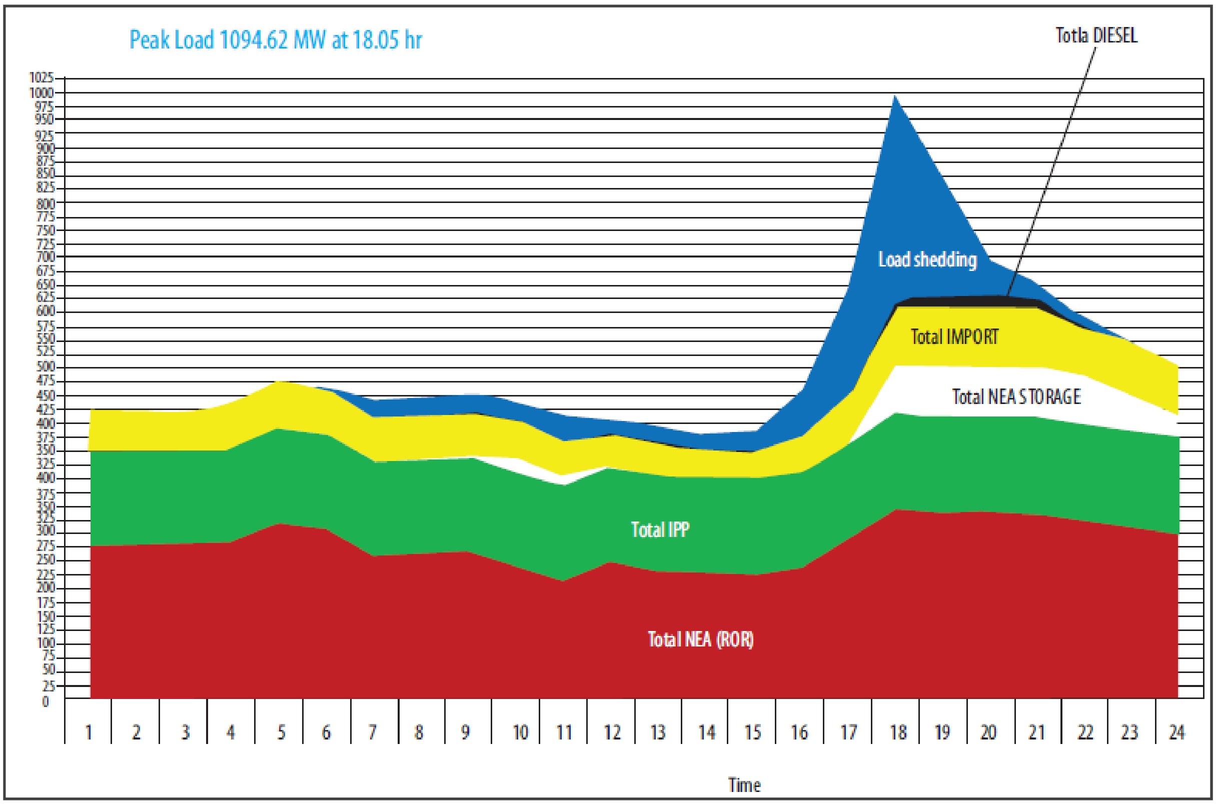

Figure 2-6: System Load Curve of the Peak Day of 2012 (NEA November 13, 2012)

2.4 ACTS, PLAN, POLICY AND GUIDELINES ON HYDROPOWER

Water Resource Act was enacted in 1992 for the rational utilization, conservation, management and development of the water resources of Nepal which is available in the different forms. The act includes the following aspects:

- Aspects on utilization of water resources
- Water Users Association
- Provisions of license
- Environmental aspects

Electricity act was enacted in 1992 for developing electricity by regulating survey, generation, transmission and distribution of electricity and to standardize and safeguard the electricity services.

Water Resources Strategy (WRS) of Nepal was approved in 2001 with a goal to improve the living standard of Nepalese people in a sustainable manner. The Water Resources Strategy outputs will contribute to this goal through the achievement of short-, medium- and long-term purposes, defined as follows:

- Short-term (5-year) Purpose: Implementation of the comprehensive Water Resources Strategy provides tangible benefits to people in line with basic needs fulfillment, supported and managed by capable institutions involving all stakeholders.
- Medium-term (15-year) Purpose: The Water Resources Strategy is operationalized to provide substantial benefits to people for basic needs fulfillment as well as other increased benefits related to sustainable water use.
- Long-term (25-year) Purpose: Benefits from water resources are maximized in Nepal in a sustainable manner.

The ten strategic outputs required to achieve these purposes are:

Output 1: Effective Measures to Manage and Mitigate Water -Induced Disasters are functional.

Output 2: Sustainable Management of Watersheds and Aquatic Ecosystems Achieved.

Output 3: Adequate Supply of and Access to Potable Water, Sanitation and HygieneAwareness provided.

Output 4: Appropriate and Efficient Irrigation available to Support Optimal,

Sustainable Use of Irrigable Land

Output 5: Cost-Effective Hydropower Developed in a Sustainable Manner.

Output 6: Economic Uses of Water by Industries and Water Bodies by Tourism,

Fisheries and Navigation optimized.

Output 7: Regional Cooperation for Substantial Mutual Benefits achieved.

Output 8: Enhanced Water -Related Information Systems are functional.

Output 9: Appropriate Legal Frameworks are functional.

Output 10: Appropriate Institutional Mechanisms for Water Sector Management are functional.

Following indicators were laid down for hydropower subsector in WRS:

- by 2007, 820 MW hydropower capacity developed to meet projected demand, including 70 MW for export;
- by 2007, laws making national contractors/consultants participation mandatory in all types of projects promulgated;
- by 2007, 25% of households supplied with electricity;
- by 2017, 2230 MW hydropower developed to meet projected demand of 2230 MW, including 400 MW for export;
- by 2017, 38% of household supplied with electricity;
- by 2027, 60% of households have access to electricity; and
- by 2027, Nepal is exporting substantial amounts of electricity to earn national revenue.

In order to implement the activities identified by the WRS, the Water and Energy Commission Secretariat (WECS) started formulating National Water Plan (NWP) in 2002, which was approved in 2005. The NWP includes programs in all strategically identified output activities so that all these programs, in consonance with each other, will contribute to maximizing the sustainable benefits of water use. The broad objective of the NWP is to contribute in a balanced manner to the overall national goals of economic development, poverty alleviation, food security, public health and safety, decent standards of living for the people and protection of the natural environment.

The NWP is a framework to guide, in an integrated and comprehensive manner, all stakeholders for developing and managing water resources and water services. The NWP has developed a set of specific short-, medium- and long-term action plans for the water sector, including program and project activities, investments and institutional aspects. The NWP also attempts to address environmental concerns.

The major doctrines of the NWP are integration, coordination, decentralization, popular participation and implementation of water-related programs within the framework of good governance, equitable distribution and sustainable development.

Following targets were set for hydropower subsector in NWP:

By 2007

- Hydropower generating capacity is developed up to 700 MW to meet the projected domestic demand at base case scenario without export;
- Legislation making participation of national contractors/consultants mandatory in all types of projects is enacted;
- Thirty-five per cent of the households are supplied with INPS electricity, 8% with isolated (micro and small) hydro systems and 2% with alternative energy sources;
- Per capita electricity consumption of 100 KWh is achieved.

By 2017

- 2,100 MW hydropower electricity is developed to meet the projected domestic demand at base case scenario, excluding export;
- Fifty per cent of the households are supplied with INPS electricity, 12% with isolated (micro and small) hydro system and 3% with alternative energy;
- Per capita electricity consumption of 160 KWh is achieved; and
- NEA is corporatized.

By 2027

- Up to 4,000 MW hydropower is developed to meet the projected domestic demand at base case scenario, excluding export;
- Seventy-five per cent of the households are supplied with INPS electricity, 20% with isolated (micro and small) hydro system and 5% with alternative energy sources;
- Per capita electricity consumption of over 400 KWh is achieved;
- Nepal exports substantial amounts of electricity to earn national revenue; and

- NEA is unbundled and privatized.

Hydropower development policy was approved in 2001 for harnessing hydropower potential of Nepal. Policies were formulated for the implementation of strategies for hydropower development. Working policy on following accepts were developed:

- Environment
- Water right
- Generation, transmission and distribution
- Special investment for infrastructure development of rural electrification
- Transfer of project
- Power purchase
- Visa for foreign investor
- Maximum utilization of local resources and means
- Management of investment risks
- Internal electricity market
- Export of electricity
- License
- Fess
- Tax and customs
- Institutional provision

Following guidelines were prepared by DoED, which are useful for the development of hydropower of Nepal.

- Guidelines for study of hydropower projects: The guidelines cover the following phases of study for the development of hydropower projects: Reconnaissance or preliminary study, Pre-feasibility study, Feasibility study.
- Guidelines for the Feasibility Study of PROR and ROR Hydropower Projects: The guidelines cover the PROR and ROR projects.
- Guidelines for Headworks Design: The guidelines cover headworks of run-of-river hydropower projects only. They encompass the common types of structures deemed suitable for headworks of both simple and pondage run-of-river schemes in Nepal. The guidelines deal with all four phases of the headworks development cycle, viz. survey and investigations, planning and design, construction and operation and maintenance. For each phase, the guidelines cover technical, economic and environmental considerations for headworks development.
- Guidelines for Water Conveyance Design: The guidelines cover the following aspects for the design of water conveyance system of hydropower projects: investigation and hydraulic models, design guidelines, guidelines for constructions, guide for operation and maintenance. The conveyance system include the following structures: settling basin, canal, pipe, tunnel, cross

drainage (aqueduct, siphon and super-passage), forebay / surge tank / surge shaft, penstock; and tailrace.

2.5 REVIEW ON ELECTRICAL SYSTEM PLANNING AND OPTIMIZATION MODELS

2.1.15 VALORAGUA

VALORAGUA was developed by Electricidade de Portugal (EDP). VALORAGUA means 'value of water' in Portuguese. The model is aimed at finding the most economical operational policy for a given configuration of hydro-electric power system, taking into account physical and operational constraints and random conditions that affect the system operation. A power system is schematically assumed to be composed of three parts: Generation (supply), Consumption (Demand) and Transmission (delivery/transport).

2.1.16 WASP

The WASP (Wien Automatic System Planning Package) tool permits the user to find an optimal expansion plan for a power generating system over a long period, within the constraints defined by the planner. It is maintained by the IAEA (International Atomic Energy Agency).

In WASP the optimum expansion plan is defined in terms of minimum discounted total costs. The entire simulation is carried out using 12 load duration curves to represent each year, for up to a maximum duration of 30 years. Conventional fossil-fuel, nuclear, and biomass power-plants can be simulated along with wind, wave, tidal, hydro power, and pumped-hydroelectric energy storage. Using the electricity demand for the future year, WASP explores all possible sequences of capacity additions that could be added to the system within the required constraints. These constraints can be based on achieving a certain level of system reliability, availability of certain fuels, build-up of various technologies, or environmental emissions. The different alternatives are then compared with one another using a cost function which is composed of capital investment costs, fuel costs, operation and maintenance costs, fuel inventory costs, salvage value of investments, and cost of energy demand not served.

2.1.17 MESSAGE

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) has been developed by the International Institute for Applied Systems Analysis (IIASA) in Austria since the 1980s. MESSAGE is a systems engineering optimization tool used for the planning of medium to long-term energy-systems, analyzing climate change policies, and developing scenarios for national or global regions. The tool uses a 5 or 10 year time-step to simulate a maximum of 120 years. All thermal generation, renewable, storage/ conversion, transport technologies, and costs (including SO2 and NOX costs) can be simulated by MESSAGE as well as carbon sequestration.

2.1.18 ProdRISK

ProdRisk is used for the optimization and simulation of hydrothermal systems, which has been developed by SINTEF (StiftelsenforIndustriellogTekniskForskning, Trondheim, Norway) since 1994. ProdRisk uses stochastic dual dynamic programming to solve the optimization problem. It is mainly used for medium and long-term hydro scheduling on local or regional energy-systems over a 2–5 year time horizon: the time-step used for the analysis is user-defined as hourly, daily or weekly. Only the electricity sector is modeled by ProdRisk and it simulates four technologies: thermal power-plants, wind power, hydro power, and pumped hydroelectric energy storage.

2.1.19 EMPS

EMPS has been developed and continually refined since 1975 by SINTEF (Stiftelsen for industriellogtekniskforskning) Energy Research (previously EFI) in Norway. EMPS is a computer tool for the simulation and optimization of the operation of power systems with a certain share of hydro power. EMPS aims at optimal use of hydro resources and thermal generation in relation to uncertain inflows, power demand, thermal generation availability, and spot type transactions between areas.

2.1.20 EnergyPLAN

EnergyPLAN has been developed and expanded on a continuous basis since 1999 at Aalborg University, Denmark. The main purpose of the tool is to assist the design of national or regional energy planning strategies by simulating the entire energy-system: this includes heat and electricity supplies as well as the transport and industrial sectors.

Chapter 3

VALORAGUA and WASP MODELS

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3. VALORAGUA AND WASP MODELS

3.1 VALORAGUA MODEL

3.1.1 Introduction to VALORAGUA

An electric power system is usually characterized as being a high dimension system with a wide technical and management complexity. The supply subsystem is composed by thermal power plants, biomass and cogeneration power plants, wind power plants and hydroelectric power plants being these last ones associated to reservoirs interconnected through rivers. In the purpose of supply security is important the management of electric power system. However this is a hard objective due in part to the uncertainty of future inflows to reservoir as well to the equipment availability or wind existence. In this type of hydro-thermal models the major problem is due to the storage capacity of reservoirs that is a limited resource and so is necessary do the balance between the present or future water utilization for power generation. The VALORAGUA model was designed to treat the great complexities of an electric power system with special emphasis on the detailed description of the hydro system and its management. The model was developed by Electricidade de Portugal (EDP). VALORAGUA means 'value of water' in Portuguese. The model is applicable to determine the optimal operational strategy for a fixed power system configuration, taking into account the most important constraints and uncertainties that characterize the operation of hydro-thermal power systems.

From a mathematical standpoint, the determination of the optimal expansion strategy of an electric power system, at the supply side, is a multidimensional sequential decision problem of high complexity, whose objective is to minimize the discounted sum of investment plus generation costs over a prescribed time horizon. Once the optimal composition of the generating system for an expected demand level is established, it is necessary to define the operational decision rules in order to operate the power system in the most economic manner under given reliability constraints, and taking into consideration the stochastic nature of the environment (e.g. water availability for power generation) and of the system itself.

The model enables a detailed management of the electric power system, represented as an interconnected collection of main subsystems: production subsystem, transmission subsystem and consumption subsystem. Each component of every subsystem is completely individualized, with its identification and topological connection to the electric and/or the hydraulic network, and performs an economic or physical activity. River network will be taken in consideration designing the hydraulic network with hydropower plants. Likewise the model takes into account whether the plants are in cascades or independent. If a new plant is added in the cascade, the hydraulic network should be revised accordingly.

3.1.1.1 Components of VALORAGUA

a) Consumption (load) subsystem

Electric code

Electric node represents geographical areas of generation/consumption.

Fixed Power Demand

The fixed power demand at an electric node at a given time period corresponds to the known demand to be met at that node, and is sometimes called primary demand to differentiate it from the secondary power demand (special consumers).

Secondary Power Demand and Exports

The secondary demand serves to model the power supply to special consumers, whereas the export subsystem consists of contracts for power exports, through the interconnection lines.

b) Generation subsystem

Thermal Power Plants and Imports

A thermal power plant is connected to the electric network and consumes fuel in order to generate electric power, whereas the import subsystem consists of a set of contracts for power imports.

Reservoirs

Reservoir represents hydraulic node, which is characterized by physical and operational variables. For each time interval of the simulation period, it is necessary for the model to know the water inflow (historical or generated) to each of the hydroelectric reservoirs.

Spillways

Spillway, used for disposing water from reservoir, is a part of hydraulic network.

Hydro Turbine Plants

A hydroelectric turbine plant is a power plant connected to the electric network for the gravitational energy of water converting into electric energy.

Pumped storage plant

A hydroelectric pumped storage plant is a power plant connected to the electric network which when working in pumping mode, consumes electric energy to transfer water from a reservoir located downstream of it to an upstream reservoir.

c) Transmission subsystem

The transmission/interconnection subsystem is modeled as an oriented network where the nodes represent geographical areas of generation/consumption and the links represent transmission or interconnection lines.

3.1.2 Optimization Concept in VALORAGUA

In electric power systems with significant hydroelectric regulating capabilities, this optimal operation policy will be highly dependent on the way reservoirs are operated throughout the year. This involves the solution of a sequential decision problem under a stochastic environment, whereby in each period (month), a decision must be made whether water should be used for generation in hydro plants in the current period or stored for later use in successive periods. In other words, the problem is to choose between the value of immediate use of water (associated to a storage variation) measured by the corresponding economy on "fuel", and the expected value of future benefits (associated to a non-immediate use of that water).

At time interval t, given S(t): the storage of the hydroelectric reservoirs at the beginning of the interval, W(t): the state of the hydrological system, $A_i(t)$: the availability of all components of the power system and $\bar{\phi}(S(t+1), t+1)$: a measure of the expected value of future operation costs, if S(t+ 1) is the storage of the reservoirs at the end of t, then the problem is: to choose among all feasible control actions (power output on thermal plants, discharged water flow through hydro turbine plants, pumped water flow through pumping units, power supplied to special consumers, power imports, power exports, power flows on the transmission lines), the control action that minimizes the expected value of all generation costs (current and expected future generation costs).

The problem is then:

Equation 3-1

$$min\left[\bar{\phi}(S(t+1),t+1)+\sum_{n=1}^{N}\left(\sum_{k\epsilon f_n}\sum_{j=1}^{J}C_{kj}\left(P_{kj}\right)\Delta_j-\sum_{k\epsilon \xi_n}\sum_{j=1}^{J}V_{kj}\left(P_{kj}\right)\Delta_j\right)\right]$$

where

f_n = subset of thermal plants and imports connected to electric node n

ξ_n= subset of special consumers and exports connected to electric node n

N = total number of electric nodes

J = total number of load steps

Δ_j = time duration of load step j

C_{kj} ,V_{kj} = costs and revenues functions

Constraints

a) Power balance equation in each electric node:

Equation 3-2

$\sum_{k\epsilon f_n}P_{kj}+\sum_{k\epsilon L_n}P_{kj}-\sum_{k\epsilon \xi_n}P_{kj}=D_{nj}-H_{nj}$for n = 1,……..,N and J = 1,………,J

where:

L_n = subset of transmission lines having electric node n as one terminal node

D_{nj}= fixed power demand in load step j at electric node n

H_{nj}= net hydroelectric generation in load step j at electric node n

$$H_{nj}=\sum_{k\epsilon h_n}P_{kj}-\sum_{k\epsilon p_n}P_{kj}$$

h_n = subset of hydro turbine plants connected to electric node n (including pumped storage plants in generating mode)

p_n= subset of pumping plants connected to electric node n (pumped storage plants in reverse or pumping mode)

b) Water balance equation in each hydraulic node

Equation 3-3

$$S_m(t+1)=S_m(t)+W-e-i+\sum_{k\epsilon e_m^{+}}d_k+\sum_{k\epsilon h_m^{+}\cup p_m^{-}}\left(\sum_{j}q_{kj}\,\Delta_j\right)-\sum_{k\epsilon e_m^{-}}d_k-\sum_{k\epsilon h_m^{-}\cup p_m^{+}}\left(\sum_{j}q_{kj}\,\Delta_j\right)$$

M = total number of reservoirs in the system

S(t) = initial storage at time interval t

S(t+ 1) = final storage in interval t

$h_{m,}^{+} p_{m,}^{+} e_{m}^{+}$ = the sets of the hydro turbine plants, pumping plants and spillways, respectively, located immediately upstream of the reservoir m

$h_{m,}^{-} p_{m,}^{-} e_{m}^{-}$ = the sets of the hydro turbine plants, pumping plants and spillways, respectively, located immediately downstream of the reservoir m

W=tributary inflow

i = mandatory release

e = evaporated volume

d_k = spilled volume

q_{kj} = discharged volume through turbine

c) lower and upper bounds on the discharged or pumped water flows

Equation 3-4:

$q_{kj}^{-} \leq q_{kj} \leq q_{kj}^{+}$for $\in h \cup P$, j=1……….J

d) lower and upper bounds on the storage of the reservoirs

Equation 3-5:

$S_{m}^{-}(t+1) \leq S_{m}(t+1) \leq S_{m}^{+}(t+1)$for m=1……….M

e) lower and upper bounds on the thermal power output and power imports

Equation 3-6:

$p_{kj}^{-} \leq p_{kj} \leq p_{kj}^{+}$ for $\in f$, j=1……….J

f) lower and upper bounds on the power supplied to special consumers and power exports

Equation 3-7:

$p_{kj}^{-} \leq p_{kj} \leq p_{kj}^{+}fork \in \xi$, j=1……….J

g) lower and upper bounds on the power flow on transmission lines

Equation 3-8:

$p_{kj}^{-} \leq p_{kj} \leq p_{kj}^{+}fork \in L$, j=1……….J

h) lower and upper bounds on the non-negativity of the spills

Equation 3-9:

$d_k \geq 0$

Primal and Dual Variables: economic Interpretation

For each time interval and for each hydrological condition the system management's problem is a particular case of the following more general optimization problem in the n variables $x_1, \ldots\ldots x_n$

min $f(x_1, \ldots\ldots x_n)$ [P]

subject to $gl(x_1, \ldots\ldots x_n) \geq b_l$

…………………………………………..

………………………………………..

$g_m(x_1, \ldots\ldots x_n) \geq b_m$

n the above expressions, f is a real value convex function of the n variables $x_1, \ldots\ldots x_n$ and each g_i is a real value concave function of the n variables $x_1, \ldots\ldots x_n$. The function f is known as the objective function of the problem and bi is the right hand side of the i-th constraint.

The variables $x_1, \ldots\ldots x_n$ are called the primal variables of the problem [P], and the set of points $x = (x_1, \ldots\ldots x_n)$ that satisfy all the constrains $g_i(x) \geq b_i$ is known as the set of feasible solution to problem [P].

In relation to the system management's problem, the primal variables at time interval t are the following:

Independent of load step:

S_m-final storage in reservoir m

d -volume of water spilled by each reservoir

Depending on the load step j

q_k -water flow discharged through hydro turbine plant k

q_k -water flow pumped by pumped storage plant k

P_k-power generated by thermal plant k or power imports under contract k

P_k -power supplied to special consumers under contract k or power export under export contract k

P_k -power flow on each transmission line k

To each constraint $g_i(x_1, \ldots\ldots x_n) \geq b_i$ of the optimization problem [P] there is a corresponding new non-negative variable, say μ_i, called the dual variable associated to the i-th constraint of the problem, which, at the optimum, has the following meaning:

if $f^*(b_l, \ldots, b_m)$ represents the optimum value of problem [P] when the right hand sides of the m constraints $g_l(x_1, \ldots, x), \ldots, g_m(x_1, \ldots, x_n)$ are respectively $b_l, \ldots, b_m$ then, under some regularity conditions on the functions f and $g_1, \ldots\ldots\ldots, g_m$ the dual variable μ_i associated to the i-th constraint $g_i(x_1, \ldots\ldots x_n) \geq b_i$ is given by:

$$\mu_i = \frac{\partial f^*(b_1 \ldots \ldots b_m)}{\partial b_i}$$

Hence, at the optimum, an economic interpretation of the dual variable μ_i is the following:

it represents the increase in the optimal value of the objective function if, other things being equal, the right hand side b_j is increased by one unit.

The most important dual variables of the system management's problem at time t are associated to each water balance equation and each power balance equation.

The dual variable associated to the water balance equation in reservoir m is named $\psi_m$and has the following economic interpretation: at the optimum, $\psi_m$is the marginal value of water in the reservoir m and represents the decrease in the objective function value if the initial storage $S_m(t)$ is increased by one unit of water.

The dual variable associated to the power balance equation in electric node n and load step j is named $\lambda_{n,j}$and has the following economic interpretation: at the optimum, $\lambda_{n,j}$is the marginal production cost in electric node n and load step j and represents the increase in the objective function if the hydroelectric generation is decreased by one unit, or, which is equivalent, if the fixed power demand, is increased by one unit.

Components of hydroelectric node

- thermal plants generation and imports (input)
- hydro turbine generation (input)
- fixed power demand (output)
- losses
- special consumers and exports (output)
- pumping (output)
- transmission power flows (input or output)

$C=C(F)-V(E)$

$B = (F + Q- P- E)\lambda$

B = Benefit, C=Cost

F= thermal power generation and imports

Q = hydro generation

P= pumping consumption

E= special consumers and exports

λ = marginal generation cost

3.1.3 Modules of VALORAGUA

The VALORAGUA model is composed of several modules or programs, each one with a specific function. The data input module is CADIR, the optimization module is VALAGP and others are data output modules. The following is the description of all modules of VALORAGUA.

CLEARD: The purpose of this module is to initialize (format) the direct access file G14 and reserve space for all variables needed to run the other modules.

CADIR: This module processes all information related to the selected power system configuration over the simulation period, as well as general data on time period, load step, and specific hydrological information. INFLOW.dat files contain monthly historical water inflows (which are called hydrological conditions), whereas CADIR.dat contains all other data pertaining to power system.

VALAGP: This module is the core of the model and it is used to determine the economically optimal operation policy of the electric power system.

MAINT: This module is used to determine an optimal maintenance schedule for the thermal power units for specified values of generation by the hydro power plants.

RESEX: This module can be used to print standard tables summarizing the global results of the optimal operation of all power plants.

RESIM : This module is used to print all values determined by VALAGP for a specified set of variables associated to a particular plant.

VWASP: This module is used to prepare the necessary data on the hydro subsystem to be used by the WASP Model.

3.1.4 Limitations of VALORAGUA

The optimization model set up will be based on following limitations of VALORAGUA.

- Maximum number of load steps: 5
- Maximum number of electric nodes: 6
- Maximum number of fixed and secondary demand nodes: 6
- Maximum number of different maintenance teams: 35
- Maximum number of thermal plants and imports: 35
- Maximum number of hydropower plants and reservoirs: 50
- Maximum number of pumped storage plants: 15
- Maximum number of hydrocascades: 18
- Maximum number of transmission lines: 25
- Maximum years for monthly inflow: 30
- Maximum number of reservoirs: 11

3.2 WASP MODEL

3.2.1 Introduction to WASP

The Wien Automatic System Planning Package (WASP) was originally developed by the Tennessee Valley Authority (TVA) and Oak Ridge National Laboratory (ORNL) of the United States of America. The preliminary version is used to analyze the economic competitiveness of nuclear power in comparison to other generation expansion alternatives for supplying the future electricity requirements of a country or region. The focus of the previous versions of the model was on the role of nuclear energy. Based on the experience gained in using the program, many improvements were made to the computer code by IAEA (International Atomic Energy Agency) Staff, which led in 1976 to the WASP-II version. Later, the needs of the United Nations Economic Commission for Latin America (ECLA) to study the interconnection of the electrical grids of the six Central American countries, where a large potential of hydroelectric resources is available, led to a joint ECLA/IAEA effort from 1978 to 1980 to develop the WASP-III version.

The inter-agency international symposium on Electricity and the Environment, Helsinki, 1991 also recommended incorporation of environmental and health impacts of electricity sector into comparative assessment of various electricity generation options for making realistic evaluation of different strategies for future development of the sector. The new version of the model with a number of new features has been completed in 1992 and named as WASP-IV.

WASP-IV is designed to find the economically optimal generation expansion policy for an electric utility system within user-specified constraints. It utilizes probabilistic estimation of system-production costs, unserved energy cost, and -reliability, linear programming technique for determining optimal dispatch policy satisfying exogenous constraints on environmental emissions, fuel availability and electricity generation by some plants, and the dynamic method of optimization for comparing the costs of alternative system expansion policies. The modular structure of WASP-IV permits the user to monitor intermediate results, avoiding waste of large amounts of computer time due to input data errors. It operates under DOS environment and uses magnetic disc files to save information from iteration to iteration, thus avoiding repetition of calculations that have been previously done.

The new features and enhancements incorporated in WASP-IV are:

- Option for introducing constraints on environmental emissions, fuel usage and energy generation
- Representation of pumped storage plants
- Fixed maintenance schedule
- Environmental emission calculations
- Expanded dimensions for handling up to 90 types of plants and larger number of configurations (up to 500 per year and up to 5000 for the study period).

3.2.2 Optimization Concept in WASP

The WASP model is aimed at finding an optimal expansion plan for a power generating system over a period of up to 30 years against the constraints imposed by the planners. The optimum option is evaluated in terms of minimum discounted total costs.

For each possible sequence of power units added to the system (expansion plan or expansion policy) against imposed constraints, the objective cost function is written as:

Equation 3-10:

$$B_j = \sum_{t=1}^{T} \left[\overline{I_{J,t}} - \overline{S_{J,t}} + \overline{F_{J,t}} + \overline{L_{J,t}} + \overline{M_{J,t}} + \overline{O_{J,t}} \right]$$

whereB_j is objective function of the expansion plan j, t is time in years, and the bar over the symbols has the meaning of discounted values to a reference date at a given discount rate i. The values will be summed for the study period (T years).

The rest members of the equations are the discounted values to a reference date.

$\overline{I_{J,t}}$ =Capital investment costs
$\overline{S_{j,t}}$ = Salvage value of investment costs
$\overline{F_{j,t}}$ = Fuel costs
$\overline{L_{j,t}}$= Fuel inventory costs
$M_{j,t}$= Non-fuel operation and maintenance costs and
$\overline{O_{j,t}}$= Cost of the energy not served

The optimal expansion plan is defined by:

Minimum B_j among all j

The WASP analysis requires as a starting point the determination of alternative expansion policies for the power system. If $[K_t]$ is a vector containing the number of all generating units which are in operation in year t for a given expansion plan, then $[K_t]$ must satisfy the following:

Equation 3-11:

$$[K_t] = [K_{t-1}] + [A_t] - [R_t] + [U_t]$$

where:

$[A_t]$ = vector of committed additions of units in year t,

$[R_t]$ = vector of committed retirements of units in year t,

$[U_t]$ = vector of candidate generating units added to the system in year t,

$[A_t]$ and $[R_t]$ are given data, and $[U_t]$ is the unknown variable to be determined; the latter is called the system configuration vector or, simply, the system configuration.

Defining the critical period (p) as the period of the year for which the difference between the corresponding available generating capacity and the peak demand has the smallest value, and if $P(K_{t,p})$ is the installed capacity of the system in the critical period of year t, the following constraints should be met by every acceptable configuration:

Equation 3-12:

$$(1 + a_t)D_{tp} \geq P(K_{tp}) \geq (1 + b_t)D_{tp}$$

which simply states that the installed capacity in the critical period must lie between the given maximum and minimum reserve margins, a_t and b_t respectively, above the peak demand $D_{t,p}$ in the critical period of the year.

The reliability of the system configuration is evaluated by WASP in terms of the Loss-of-Load Probability index (LOLP). This index is calculated in WASP for each period of the year and each hydro-condition defined. The LOLP of each period is determined as the sum of LOLP's for each hydro-condition (in the same period) weighted by the hydro-condition probabilities, and the average annual LOLP as the sum of the period LOLPs divided by the number of periods.

If $LOLP(K_{t,a})$ and $LOLP(K_{t,i})$ are the annual and the period's LOLP's, respectively, every acceptable configuration must respect the following constraints:

$$LOLP(K_{t,a}) \leq C_{t,a}$$

$$LOLP(K_{t,i}) \leq C_{t,p}$$

(for all periods) where $C_{t,a}$and $C_{t,p}$ are limiting values given as input data by the user.

If an expansion plan contains system configurations for which the annual energy demand Et is greater than the expected annual generation G_t of all units existing in the configuration for the corresponding year t, the total costs of the plan should be penalized by the resulting cost of the energy not served. Obviously, this cost is a function of the amount of energy not served N_t, which can be calculated as:

$N_t = E_t - G_t$

The user may also impose tunnel constraints on the configuration vector $[U_t]$ so that every acceptable configuration must respect:

$$[U_t^0] \leq [U_t] \leq [U_t^0] + [\Delta U_t]$$

where$[U_t^0]$is the smallest value permitted to the configuration vector $[U_t]$and$[\Delta U_t]$is the tunnelconstraint or tunnel width.

The generation by each plant for each period of the year is estimated based on an optimal dispatch policy which, in turn, is dependent on availability of the plants/units, maintenance requirements, spinning reserves requirements and any exogenous constraints imposed by the user on environmental emissions, fuel availability and/or generation by some plants. The user may impose constraints on environmental emissions, fuel usage and energy generation for a set of power plants through the new feature introduced in this version, i.e. through multiple group limitations. Such constraints take the form:

$\sum_{i \in I_j} COEF_{ij}\, G_i \leq LIMIT_j$, for J= 1,…………,M

where G_i is generation by plant i, $COEF_{ij}$ is per unit emission (for emission constraints) or per unit fuel usage (for fuel availability constraint), etc by plant i in group limitation j, $LIMIT_j$ is the user specified value for the limit and I_j is the set of plants taking role in group limitation j. These special constraints are handled by a new algorithm incorporated in WASP-IV, which determines dispatch of plants in such a way that these constraints are respected with minimum production cost.

The problem as stated here corresponds to finding the values of the vector $[U_t]$ over the period of study which satisfy expressions (2-1) to (2-9). This will be the "best" system expansion plan within the constraints given by the user. The WASP code finds this best expansion plan using the dynamic programming technique. In doing so, the program also detects if the solution has hit the tunnel boundaries of expression (2-8) and gives a message in its output. Consequently, the user should proceed to new iterations, relaxing the --constraints as indicated in the WASP output, until a solution free of messages is found. This will be the "optimum expansion plan" for the system.

3.2.2.1 Calculation of costs

The calculation of the various cost components is done in WASP with certain models in order to account for:

(a) Characteristics of the load forecast;

(b) Characteristics of thermal and nuclear plants;

(c) Characteristics of hydroelectric plants;

(d) Stochastic nature of hydrology (hydrological conditions); and

(e) Cost of the energy not served.

The load is modelled by the peak load and the energy demand for each period (up to 12) for all years (up to 30), and their corresponding inverted load duration curves. The latter represents the probability that the load will equal or exceed a value taken at random in the period (for computational convenience, the inverted load duration curves are expanded in Fourier Series by the computer program).

The models for thermal and nuclear plants are described, each of them, by:

- Maximum and minimum capacities;
- Heat rate at minimum capacity and incremental heat rate between minimum and maximum capacity;
- Maintenance requirements (scheduled outages);
- Failure probability (forced outage rate);

- Emission rates and specific energy use;
- Capital investment cost (for expansion candidates);
- Variable fuel cost;
- Fuel inventory cost (for expansion candidates);
- Fixed component and variable component of (non-fuel) operating and maintenance costs;
- Plant life (for expansion candidates).

The models for hydroelectric projects are for run-of-river, daily peaking, weekly peaking and seasonal storage regulating cycle. They are defined by identifying for each project:

- Minimum and maximum capacities;
- Energy storage capacity of the reservoirs;
- Energy available per period;
- Capital investment cost (for projects considered as expansion candidates);
- Fixed operating and maintenance (O & M) costs;
- Plant life (for projects considered as expansion candidates).

The hydroelectric plants are assumed to be 100% reliable and have no associated cost for the water. The stochastic nature of the hydrology is treated by means of hydrological conditions (up to 5), each one defined by its probability of occurrence and the corresponding available capacity and energy of each hydro project in the given hydro-condition.

The pumped storage plants are modelled by specifying:

- Installed capacity;
- Cycle efficiency;
- Pumping capacity (for each period);
- Generation capacity (for each period);
- Maximum feasible energy generation (for each period).

The cost of energy not served reflects the expected damages to the economy of the country or region under study when a certain amount of electric energy is not supplied. This cost is modelled in WASP through a quadratic function relating the incremental cost of the energy not served to the amount of energy not served. In theory at least, the cost of the energy not served would permit automatic definition of the adequate amount of reserve capacity in the power system.

In order to calculate the present-worth values of the cost components of Eq. (2-1), the present-worth factors used are evaluated assuming that the full capital investment for a plant added by the expansion plan are made at the beginning of the year in which it goes into service and that its salvage value is the credit at the horizon for the remaining economic life of the plant. Fuel inventory costs are treated as investment costs, but full credit is taken at the horizon (i.e. these costs are not depreciated). All the other costs (fuel, O&M, and energy not served) are assumed to occur in the middle of the corresponding year.

a) Capital investment cost and salvage values

$$\overline{I_{j,t}} = (1+i)^{-t'} \sum [UI_k MW_k]$$

$$\overline{S_{j,t}} = (1+i)^{-T'} \sum [\delta_{k,t} UI_k MW_k]$$

Where sum is calculated considering all (thermal, hydro or pumped storage) units k added in year t by expansion plan j,

UI_k= capital investment cost of unit k, expressed in monetary units per MW,

MW_k= capacity of unit k in MW,

$\delta_{k,t}$ = salvage value factor at the horizon for unit k,

i = discount rate,

t_0 = number of years between the reference date for discounting and the first year of the study

T = length (in number of years) of the study period

t =year of study

t' = t + t0 - 1

T' = T + t_0

b) Fuel costs

$$\overline{F_{J,t}} = (1+i)^{-t'-0.5} \sum_{h=1}^{NHYD} \left[\alpha_h \psi_{j,t,h}\right]$$

where α_h is the probability of hydro-condition h, $\psi_{j,t,h}$is the total fuel costs (sum of fuel costs for thermal and nuclear units) for each hydro-condition, and NHYD represents the total number of hydro-conditions defined.

c) Fuel inventory cost

$$\overline{L_{J,t}} = [(1+i)^{-t\prime} - (1+i)^{-T\prime}] \sum [UFIC_{kt} MW_{kt}]$$

where the indicated sum is calculated over all thermal units kt added to the system in year t, and $UFIC_{kt}$ is the unitary full inventory cost of unit kt (in monetary units per MW).

d) Operation and maintenance costs

$$\overline{M_{J,t}} = (1+i)^{-t'-0.5} \sum \left[UFO\ \&M_l.MW + UVO\ \&M_l.G_{l,t}\right]$$

where:

sum = sum over all units (l) existing in the system in year t,

$UFO\&M_l$ = unitary fixed O&M cost of unit l, expressed in monetary units per MW-year,

$UVO\&M_l$ = unitary variable O&M cost of unit l, expressed in monetary units per kWh,

G_l, t = expected generation of unit l in year t, in kWh, which is calculated as the sum of the energy generated by the unit in each hydro-condition weighted by the probabilities of the hydro-conditions.

e) Energy not served costs

$$\overline{O_{J,t}} = (1+i)^{-t'-0.5} \sum_{h=1}^{NHYD} \left[a + \frac{b}{2}\left(\frac{N_{t,h}}{EA_t}\right) + \frac{c}{3}\left(\frac{N_{t,h}}{EA_t}\right)^2\right] N_{t,h}\, \alpha_h$$

where:

a, b, and c are constants ($/kWh) given as input data, and:

$N_{t,h}$= amount of energy not served (kWh) for the hydro-condition h in year t,

EA_t = energy demand (kWh) of the system in year t.

In fact, the above expressions have been derived considering each expansion candidate as one single unit (Pumped storage, hydro, thermal or nuclear) whereas in WASP-IV the expansion candidates are defined as plants and the number of units (or projects) from each plant to be added in each year is to be determined by the WASP study. Besides, WASP-IV also

- combines capital investment cost and associated salvage value with the fuel inventory
- cost and its salvage value;
- aggregates operating costs by types of (fuel) plant;
- separates all expenditures (capital or operating) into local and foreign components;
- permits escalating all costs over the study period;
- has provisions to apply different discount rates and escalation ratios for each year, for the local and foreign cost components, and to change the constants (a, b, and c) for evaluating the energy not served cost from year to year.

3.2.3 Modules of WASP

The data input modules are CCD, LOADSY, FIXSYS and VARSYS. Three modules CONGEN, MERSIM and DYNPRO running in sequence produce the optimal solutions. The output of DYNPRO displays optimal solution. The input/output in the form of report is generated by REPROBAT.

CCD (Common case data): By running this module global parameters are initialized.

LOADSY (Load system description): This module processes period peak loads and load duration curves for the power system over the study period.

FIXSYS (Fixed system description): This module processes data pertaining to existing generation system, any pre-determined or committed additions or retirements of plants, and imposed constraints

VARSYS (Variable system description): This module processes data pertaining to various candidate power plants that are considered for expansion plan.

CONGEN (Configuration Generator): Based on the existing and candidate power plants as processed by FIXSYS and VARSYS, all possible year-to-year combinations are simulated that satisfy the specified inputs and constraints.

MERSIM (Merge and simulate): This module considers all combinations simulated by CONGEN and uses probabilistic simulation of system operation to calculate various outputs.

DYNPRO (Dynamic programming Optimization): This module determines the optimum expansion plan based on the operating costs derived from above modules, capital costs, energy not served costs and economic parameters and reliability criteria.

REMERSIM: This module is used to reproduce this information for the optimum schedule of additional outputs of MERSIM in the report.

REPROBAT: This module is used to write the report that summarizes the full or partial results for the optimum or near optimum power system expansion plan and for fixed expansion schedules.

3.2.4 Limitations of WASP

The output from VALORAGUA becomes input for WASP. Hence, the WASP model set up will also be based on limitations of VALORAGUA. WASP model running as standalone model has slightly lesser limitations than VALORAGUA. Following limitations are specific to WASP.

- Maximum years of study period: 30
- Maximum period per year: 12
- Maximum number of Load duration curves (one for each period and for each year): 360
- Types of plants grouped by "fuel" types: 10 types of thermal plants; and 2 composite hydroelectric plants and one pumped storage plants
- Thermal plants of multiple units: 88
- Types of plants candidates for system expansion: 12 types of thermal plants; 2 hydroelectric plant types, each one composed of up to 30 projects; and 1 pumped storage plant type with up to 30 composed projects
- Environmental pollutants (materials): 2
- Group limitations: 5
- Type of hydrological conditions: 5

Chapter 4

Databaseand Files

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4. DATABASE AND FILES

The first step and most important step in any optimization study is the collection of data from different sources, and preparing data in the format required for the models.

4.1 DATA COLLECTION

Data type, variables in that category and source of data are presented below.

Table 4-1: Data collection for VALORAGUA

S.N.	Data type	Variables	Source
1	Hydrological data	Monthly inflow hydrograph	Department of Hydrology & Meteorology (DHM), Estimation for ungauged location
2	Data for Hydro Turbine Plants, Pumped Storage Plants	Nominal flow (Design flow), Nominal head, Head loss at nominal flow, Internal consumption fraction, Average global efficiency, Forced outage rate, Technical minimum flow, Minimum tailwater level, Maximum flow capacity of plant (monthly), plant maintenance outage rate (monthly)	NEA, DoED, Independent power producers (IPP), website, reports, publications, site visits
3	Data for reservoir	Storage capacity, Fraction of the storage capacity defining the maximum operational storage, Fraction of the storage capacity defining the minimum operational storage, storage-elevation data Minimum operational final storage (monthly) Maximum operational final storage (Monthly) Evaporation data (monthly) Mandatory water releases (monthly)	NEA, DoED, IPP, website, reports, publications, site visits
4	Thermal power plants and import data	Nominal unit capacity, Average operation cost, Variation of operation costs, Unit technical minimum, Forced outage rate, Internal consumption fraction Number of units in service in each month Plant maintenance outage rate (monthly)	NEA, website, reports, publications, site visits
5	Electric Node data	Load Duration curve Number of load steps, duration of load steps Monthly fraction of the mean power demand corresponding to the each load step	NEA To be decided by user while modeling NEA
6	Fixed Demand data	Number of fixed demand, Annual energy demand, energy demand in each month	NEA
7	Secondary Demand and export data	Number of secondary demand, Average selling price, Maximum power supply in each month, Minimum power supply in each month	NEA

8	Transmission line data	Transmission capacity, Line Reactance , Line Resistance, Line operating voltage, Forced outage rate, Maintenance outage rate	NEA

Table 4-2: Data collection for WASP

S.N.	Data type	Variables	Source
1	Load data	Annual peak load, monthly peak load Load forecast LDC (monthly)	NEA NEA forecast or other forecasts NEA
2	Fixed system (Existing plants) data	Fixed operating and maintenance costs of hydroelectric plant Hydropower data Installed capacity, energy storage capacity Period inflow energy of the hydro project, Minimum generation in base in the period, Available capacity in period of the project Pumped storage project data Installed capacity, Cycle efficiency, Fixed operating and maintenance cost Pumping capacity, Generating capacity, Maximum feasible energy generation Thermal data Number of units, Minimum operating level of each unit, Maximum unit generating capacity, Heat rate at minimum operating level, Average incremental heat rate between minimum and maximum operating levels, Domestic fuel costs, Foreign fuel costs, Unit spinning reserve, Unit forced outage rate, Number of days per year required for scheduled maintenance of each unit, Maintenance class size, Fixed component of non-fuel operation and maintenance cost of each unit, Variable component of non-fuel operation and maintenance cost of each unit heat value of the fuel used by plant, percentage of polluting emission mainly SO_2 and NO_x	NEA, IPP, reports, websites, site visit to plants NEA, IPP, reports, websites, site visit to plants Obtained from VWASP of VALORAGUA or from NEA, IPP, reports, websites, site visit to plants NEA, IPP, reports, websites, site visit to plants NEA, reports, websites, publication of the thermal plants, site visit to thermal plants

3	Variable system (Planned plants) data	Hydropower, thermal and pumped storage Similar types of data as mentioned in the fixed system	Same source as Fixed system
4	Optimization data	Domestic discount rate, foreign discount rate Depreciable domestic and foreign capital cost of expansion candidate plant, Plant life (in years), Non-depreciable domestic and foreign capital cost of expansion candidate plant, Interest during construction, Construction time (in years)	NEA, website, feasibility/ Detailed project report (DPR), publications, websites

4.2 HYDROLOGICAL DATA PROCESSING

All hydro-meteorological data were collected from Department of Hydrology and Meteorology (DHM) and checked for consistency. Data were compiled as per available historical hydrological data of al hydrometric stations published by DHM (hard copy and soft copy) for checking consistency of collected data.

The monthly discharge data from 1963 up to 2010 were available as per recorded by DHM. However, there were discontinuous in data and the details of availability of these data are tabulated as shown inTable 4-3. In the table, availability of data is shown for the complete year otherwise indications of data-gaps are shown. By using the simplest technique these gaps are filled based on the longest data in the basin. Note that the hydrological data are grouped by river basins.

Table 4-3: Availability of Hydrological Data

S.N.	Basin	Station No.	Year																																														Total Years	Catchment Area (Km2)
			1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010		
1	Karnali	115																																								■	■	■	■	■	■	■					7	203
2	Karnali	120			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					42	1175
3	Karnali	125																																									■	■	■	■	■	■					6	228
4	Karnali	170				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																									22	190
5	Karnali	220											■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					34	1870
6	Karnali	225					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					40	824
7	Karnali	250	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					44	23229
8	Karnali	251.6																																									■	■	■	■	■	■					6	159
9	Karnali	253.9																																									■	■	■	■	■	■					6	196
10	Karnali	256.5																																								■	■	■	■	■	■	■					7	1576
11	Karnali	258																																								■	■	■	■	■	■	■					7	135
12	Karnali	259.1																																								■	■	■	■	■	■	■					7	179
13	Karnali	259.2																								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					21	4420
14	Karnali	269.5																													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					15	NA
15	Karnali	283.3																																									■	■	■	■	■	■					6	NA
16	Karnali	286										■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						34	811
17	Karnali	289.95																												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					17	2557
18	Karnali	290					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																									21	2924
19	Karnali	330			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					42	1924
20	Karnali	339.5									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																	25	662
21	Karnali	340			■	■	■	■	■	■																																										6	NA
22	Karnali	350														■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					31	3527
23	Karnali	360		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					43	5072
24	Karnali	363																																								■	■	■	■	■	■	■					7	78
25	Karnali	364																																								■	■	■	■	■	■	■					7	54
26	Karnali	375																																											■	■	■	■					4	NA
27	Karnali	387.5																																								■	■	■	■	■	■	■					7	NA
28	Karnali	390		■	■	■	■	■	■																																											6	554
29	Narayani	403.5																																												■	■	■	■	■	■	■	7	NA
30	Narayani	405														■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	35	NA

31	Narayani	406																																											■	■	■	■	4	NA
32	Narayani	406.5													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	35	642
33	Narayani	410		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																32	7109
34	Narayani	415		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																				28	418
35	Narayani	415.1																																				■	■	■	■	■	■	■	■	■	■	■	11	NA
36	Narayani	419.1																																	■	■	■	■	■	■	■	■	■	■	■					11	NA
37	Narayani	419.5																																											■	■	■	■	4	NA
38	Narayani	420		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	47	12234
39	Narayani	428												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	37	124
40	Narayani	430		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																											21	590
41	Narayani	439.3																					■	■	■	■	■	■	■	■	■	■	■	■	■																13	133
42	Narayani	439.35																																				■	■	■	■	■	■	■	■	■	■	■	11	NA
43	Narayani	439.7																								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	24	3937
44	Narayani	439.8												■	■	■	■	■	■	■	■	■	■	■	■	■																									13	NA
45	Narayani	440		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	47	309
46	Narayani	445		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					43	3968
47	Narayani	446.8									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																25	154
48	Narayani	447															■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					30	4643
49	Narayani	448							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					38	630
50	Narayani	449.91		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	47	NA
51	Narayani	449.95																																											■	■	■	■	4	NA
52	Narayani	450	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					44	32099
53	Narayani	460	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					44	471
54	Narayani	465		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					43	426
55	Narayani	470		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							41	169
56	Narayani	485		■	■	■	■	■	■	■	■	■																																							9	NA
57	Bagmati	505	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	48	17
58	Bagmati	507	■	■	■	■	■	■	■	■	■																																								9	NA
59	Bagmati	510	■	■	■	■	■	■	■	■	■																																								9	NA
60	Bagmati	536.2							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																										17	NA
61	Bagmati	540	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																															18	NA
62	Bagmati	550	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																															18	NA
63	Bagmati	550.05																														■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					15	607

64	Bagmati	560		■	■	■	■	■	■	■	■	■	■	■	■	■																																						13	NA
65	Bagmati	565														■	■	■																																		3	NA
66	Bagmati	570	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																																			15	NA
67	Bagmati	581																																					■	■	■	■	■	■	■					7	NA
68	Bagmati	589																	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					28	2922
69	Bagmati	590			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																																			15	NA
70	Koshi	600.1																							■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					21	25447
71	Koshi	602												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					33	409
72	Koshi	602.5												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					33	110
73	Koshi	604.5													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					32	27241
74	Koshi	606																								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					20	29532
75	Koshi	610			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					42	2388
76	Koshi	620		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					43	594
77	Koshi	627.5																											■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					17	113
78	Koshi	630		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					43	4904
79	Koshi	640		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																								25	69
80	Koshi	647									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					36	2948
81	Koshi	650		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					43	330
82	Koshi	652						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					39	10141
83	Koshi	660		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					43	921
84	Koshi	668.4																								■	■	■	■	■	■																				6	823
85	Koshi	668.5																								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					20	NA
86	Koshi	670		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					43	3650
87	Koshi	680				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																											21	17593
88	Koshi	681																													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					16	NA
89	Koshi	684																																	■	■	■	■	■	■	■	■	■	■	■					11	NA
90	Koshi	690			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					42	5948
91	Koshi	695															■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					30	53689
92	Koshi	728																					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					24	404
93	Koshi	730				■	■	■																																											3	107
94	Koshi	795										■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					35	1178

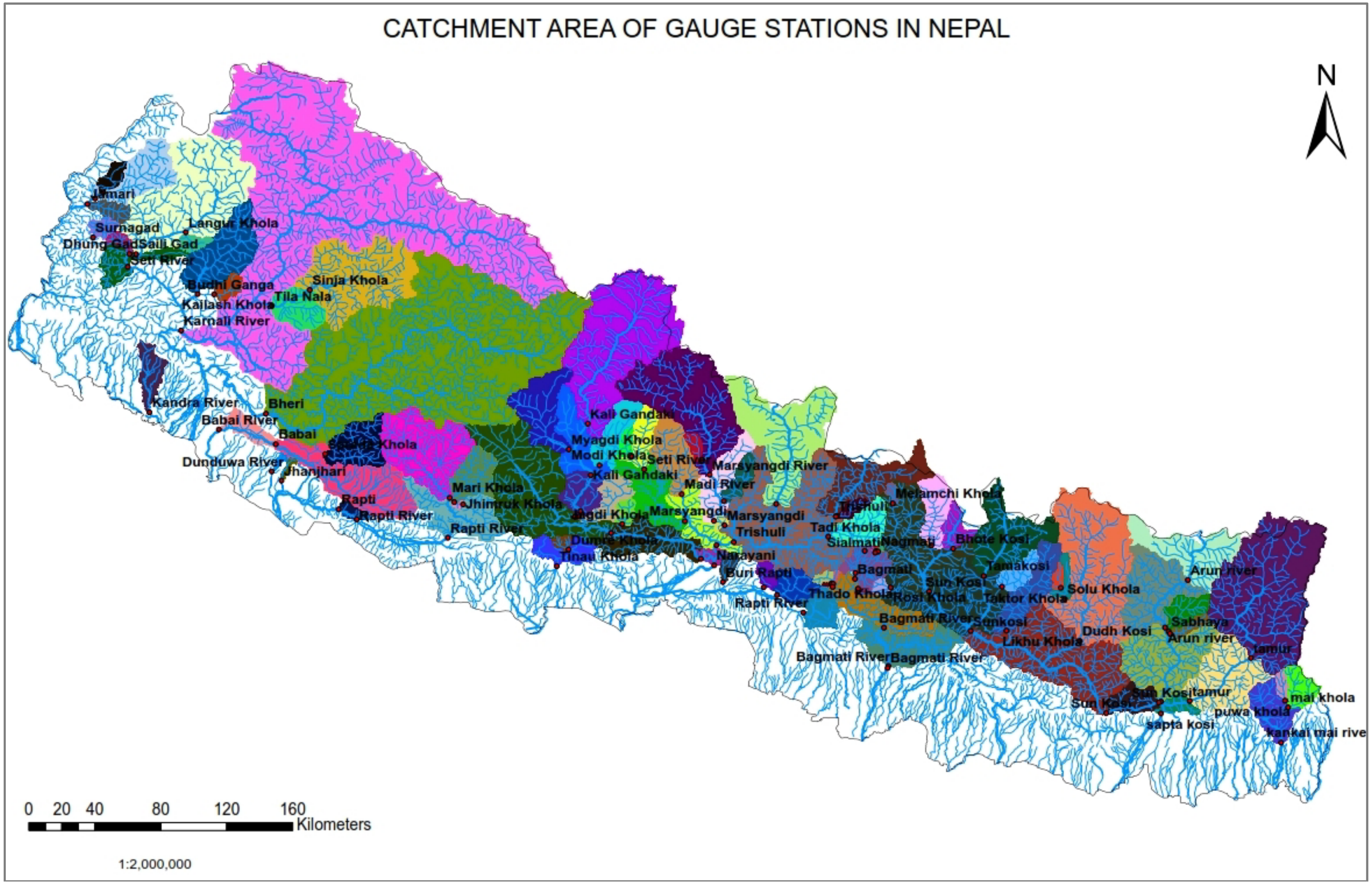

Figure 4-1: Catchment areas at gauge station of rivers in Nepal

4.2.1 Catchment Area Delineation

Department of Hydrology and Meteorology (DHM) provide catchment areas of hydrometric stations. However, most of the intake locations of hydropower projects are not close to DHM stations. In this situation, it is necessary to calculate the basin area using topographic map. From the available topographic map of the study area, basin boundary is delineated and basin area is calculated. This task can be easily accomplished if GIS (Geographic Information System) package is available as shown in Figure 4-1. The DEM (Digital Elevation Model) is required for automatic delineation of basin in GIS. Here, the DEM data is collected from the DHM which is only available for within boundary of Nepal.But, some of the basins of Nepalese Rivers lay beyond the Nepal border. The catchment area of these gauge stations were collected from the DHM and other available sources.

4.2.2 Filling in Missing Data

The missing data break the continuity of the data series. Unfortunately, records of hydrological processes are usually short and often have missing observations. The existence of data gaps might be attributed to a number of factors such as interruption of measurements because of equipment failure, effects of extreme natural phenomena such as hurricanes or landslides or of human-induced factors such as wars and civil unrest, mishandling of observed records by field personnel, or accidental loss of data files in the computer system.

There are different methods of filling missing data for examples Regression analysis, Time series analysis, Interpolation approach, rainfall-runoff modeling etc. The advanced techniques can be applied based on the availability of data and model. However, simple techniques such as catchment area ratio can be used in absence of other options. The equation for this approach is:

$$\frac{Q_2}{Q_1} = \left(\frac{A_2}{A_1}\right)^n$$

Where,

Q1= monthly discharge at gauge station 1 in m^3/s

Q2 = monthly discharge at gauge station 2 in m^3/s

A1 = catchment area at gauge station 1 in Km^2

A2 = catchment area at gauge station 2 in Km^2

n = exponent

4.2.3 Building Hydrological Series at Hydropower Stations

The hydrological data for hydropower stations are generated from actual data if available. In case of ungauged location, data at intake site is generated from different ways, such as using the calibrated rainfall-runoff model, regression analysis, catchment area ratio method etc.

4.2.4 Checking Consistency of Hydrological Data

Double mass curve is used for checking consistency of hydrological data of a particular station. If the curve is straight, the data from a particular station is consistent. Correlation of the data from upstream and downstream location can also be checked. Trend of flow can be compared by the visual plot of data of upstream and downstream location/neighbouring basin.

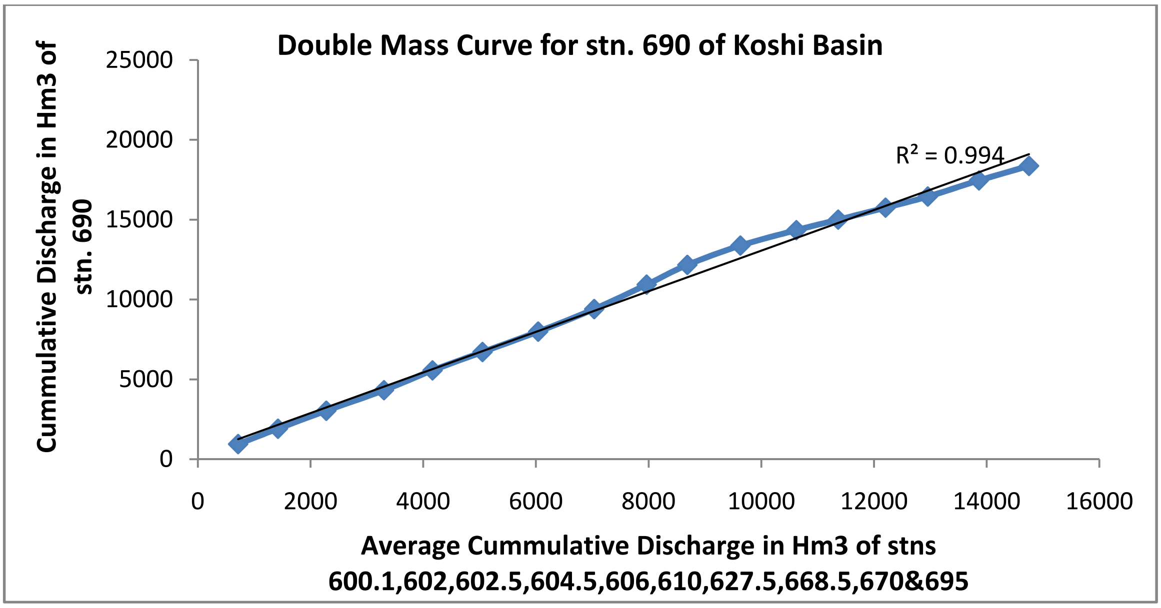

Figure 4-2: Double Mass Curve for stn. 690 of Koshi Basin

4.2.5 Flow Duration Curve (FDC)

FDC is a curve which shows the relationship between flow and the percentage of time the flow is equaled or exceeded. The curve is useful for computing the flow of certain probability of exceedednce e.g. 65% (Q65), 40% (Q40). Hence, FDC is helpful in evaluating the characteristics of the hydropower potential of the river.

The following is the procedure to construct FDC.

- Arrange flow data in a descending order and assign rank. (Use class intervals if the number of data is very large, note down number of values/frequency in class interval and compute cumulative frequency which is rank).
- Compute plotting position

  $$P_p = \frac{m}{n+1}$$

  Where,
  m = order of number of the discharge/rank (cumulative frequency for class interval),
  N = total number of data points,
  P_p = % probability of the flow magnitude being equaled or exceeded.
- Plot discharge Q vsP_p

The design discharge for the power plant can be selected or optimized based on this FDC.

4.2.6 Parameters Computation of Level-Volume Function for Reservoir

In VALORAGUA, four parameters are used for defining the level-volume function of the reservoir. The level (Z)-volume (V) function is given as:

$$Z(V) = \gamma + \alpha(V - \varphi)^{\beta}$$

where γ = level corresponding to volume φ, which is (dead volume), α, β = other parameters

From the available storage volume and corresponding elevation data of a reservoir, these parameters can be estimated using regression techniques. An auxiliary tool called LEVEL is available in VALORAGUA to estimate these parameters.

4.3 PROCESSING OF LOAD DATA

4.3.1 Load Forecasting

In Nepal, load is forecasted by NEA which is considered to be authentic. In general, following are the commonly used methods for load forecasting.

4.3.1.1 Sectional methods or load survey methods

In this approach, loads are grouped under different categories such as residential, domestic, commercial, industrial etc. Data on demand and its growth rate, duration and time of occurrence of load and the energy requirements are collected for each category and mathematical equations are developed to forecast load and energy.

4.3.1.2 Time series analysis models

In this method, time series data (historical) on load is collected. The seasonality effect of the time series is removed. The trend of the residual series is fitted by regression techniques, which is extrapolated for load forecasting. Alternatively, a time series model can be fitted from which load is forecasted.

4.3.1.3 Mathematical methods (Regression)

Data on past consumption of energy is collected and a linear/exponential/parabolic curve is fitted for finding the rate of change of energy consumption. The curve is extrapolated for load forecasting.

4.3.1.4 Mathematical methods using economic parameters

The power consumption depends on economic factors, such as specific gross investments, industrial production, GDP, raw energy consumption etc. A cause effect relationship is developed between energy/load and economic parameters. For example, a simple univariate model can be developed relating energy growth and GDP.

4.3.2 Load Duration Curve (LDC) and Its Discretization

LDC displays the plot of load versus the percentage of time the load is equalled or exceeded. It represents the operating conditions of power systems over time. LDC can be constructed using hourly demand data covering a certain period of time. The following are the steps for the preparation of LDC.

- Arrange the data in descending order.
- Assign rank.
- Compute probability of exceedence (P_p). Most widely used formula for P_p is $P_p = \frac{m}{n+1}$
  where m =rank, n = total number of data points
- Plot load versus P_p.

For the VALORAGUA model, the total duration of continuous LDC is divided into discrete steps, called load steps. It is a linear approximation of LDC. Usually 5 load steps are used (this is the limit allowed in the VALORAGUA model). The time duration of each load step and the fraction of peak power is optimized using the auxiliary tool DIAGOPTM available within VALORAGUA model. This is done mathematically by fitting a staircase function to the original LDC. The distance between the two functions, i.e., the continuous function (original LDC) and the staircase function is minimized during optimization. The power demand level of the first load step corresponds to the peak load and the one for the last load step corresponds to the base load. Average monthly LDC or LDC of each month data can be used for this computation.

4.3.3 Coefficients of 5th Order Polynomial of LDC

In WASP, load magnitude and load duration data in discrete form, and/or polynomial equation representing shape of LDC is used as input data for describing the load system.

For polynomial approximation of LDC, input data on LDC's are prepared using the normalized load duration curve of the period, for which load magnitudes are expressed as fractions of the peak load of the period and the respective load duration values as fractions of the total hours of the period. The LDC is approximated by a polynomial equation of 5th order describing the shape of the curve for each period.

$L = a_0 + a_1X + a_2X^2 + a_3X^3 + a_4X^4 + a_5X^5$
Where L =normalized load, X = normalized duration, a_0 to a_5: coefficients
These coefficients are optimized using the auxiliary tool WASPLDC available within VALORAGUA model.

4.4 ESTIMATING COST OF UNSERVED ENERGY (CUE)

Unserved energy measures the expected amount of energy which will not be supplied per year owing to generating capacity deficiencies and/or shortages in basic energy supplies.

CUE estimation techniques:

4.4.1 Production Factor Analysis

In this approach, the following form of relationship among inputs, factors of production and outputs is applied:

$$CUE = \frac{Economic\ index}{Input}$$

Economic index that can be used are valued added/GDP/Wages. Input is usually electric energy consumed (kWh) over the same period as the economic index is measured. Theoretically, this method assumes that normal development of the selected economic index ceases during a service interruption which can be characterized by unserved energy.

4.4.2 Captive Generation Method

Cost of alternative or back-up power generation in place of stand-by power generation provides an estimate of cost of unserved energy. For example, using thermal plant (diesel) instead of hydropower

4.4.3 Empirical Analysis: Customer Surveys

Customer surveys are carried out to estimate the service interruption costs in relation to their impacts on a range of production activities. The customer survey should cover industrial, commercial, agricultural, residential and institutional customers. The data on power demand, number of planned hours of electricity use, number of hours of interruptions, financial information, loss due to interruption, alternative arrangement during power cut etc. are collected and statistical analysis is performed to obtain cost of unserved energy.

4.5 DESCRIPTION OF VALORAGUA FILES

4.5.1 Input File of VALORAGUA

Formatting style

Format identifier: A: text, I: Integer, F: Real, X: space (number before X showing number of spaces)

Number after A/I shows total number of allotted columns.

For real, e.g. in Fn.d, n is the total number of allotted column (including decimal sign) and d is number of digit after decimal.

4.5.1.1 CADIR.DAT

I. Study identification data

Line1: Heading (A72)

Line2: User identification (A48)

Line3: Study title (A18), Study year (I5), First hydro condition (I5), Last hydro condition (I5), Probability hydro condition (I5) (0=equal), no. of load steps (I5), print out flag option1 (I5), print out flag option2 (I5)

Probability hydro condition: 0 =equal for all, 1 = next line defining the probability

In next line, F6.3 for up to 10 conditions in one line

Print out flag option1: 0 = no print, 1 = print the input data independent of hydrocondtion

Print out flag option2: 0 = no print, 1 = print the input reservoir inflows

Line4: Duration of each load steps defined as a fraction of the total duration (F10.5 for each load step)

II. Electric Node

Line1: Heading (A72)

Line2: Identification (ID) of electric nodes (I2)

Line3: Electric node name (A6)

Line 4 onwards: Monthly fraction of the mean power demand corresponding to the each load step in each month (row by row) (F6 for each month)

III. Fixed Demand

Line1: Heading (A72)

Line2: number of fixed demand (I2)

Line3: Code name of fixed demand (A6), ID of associated electric node (I4)

Line 4: Annual energy demand (GWh) (F6)

The energy demand in each month is defined in terms of a percentage of the annual demand (F6 for each month). If this space is not filled in by the user, the program will assume the percentage defined internally as default.

IV. Secondary Demand

Line1: Heading (A72)

Line2: number of secondary demand (I2)

Line3: Code name of demand (A6), ID of associated electric node (I4)

Line 4: Code name of demand (A6), Average selling price (cts/KWh) (F7) and Maximum variation (F7) (for each load step; if same for each load step, one data set is ok.)

Line5: Maximum power supply in each month (MW) (F6 for each month)

Line 6: Minimum power supply in each month (MW) (F6 for each month)

(Line 5 and 6: if same for each month, one data set is ok.)

V. Maintenance Crews

Line1: Heading (A72)

Line2: number of crews (I2)

Line 3 onwards:

Identification name of the maintenance team (A6), No of available team in each month (I5 for each month): Repeat this pattern for all plants

VI. Thermal Power Plants and Imports

Line1: Heading (A72)

Line2: number of plants (I2)

Line 3 onwards for first block of data (prepare for each plant)

First line: ID name of plant (A6), ID of associated electric node (I4), Maximum number of units for maintenance (I3), Maintenance duration (week) (I3), ID of maintenance crew(I3), nominal unit capacity (MW) (F7), Average operation cost (Cts/KWh) (F8), Variation of operation costs (F10), Unit technical minimum (MW) (F5), Forced outage rate (F5), Internal consumption fraction (F5)

Second line: Coefficient of maximum utilization of nominal capacity in each load step (F4 for each load step)

Second block of data (prepare for each plant)

First line: ID name of plant (A6), Number of units in service in each month (I5)

Second line: ID name of plant (A6), Plant maintenance outage rate (by month) (F5 for each month)

VII. Reservoir

Line1: Heading (A72)

Line2: number of reservoirs (I2)

Line 3 onwards

for first block of data (prepare for each reservoir, row by row)

ID name of reservoir (A6), ID number of the reservoir (I4), Storage capacity (106m3) (F10), Fraction of the storage capacity defining the maximum operational storage (F5), Fraction of the storage capacity defining the minimum operational storage (F5), Parameters defining the level/ volume function of the reservoir (four parameters) (F10 for each parameter)

Second block

Storage bounds (if data available)

Number of reservoir (I3), heading (A32)

ID number of the reservoir (I4), Minimum operational final storage (in 106m3 by month) (F6 for each month)

ID number of the reservoir (I4), Maximum operational final storage (in 106m3 by month) (F6 for each month)

(similar pattern for each reservoir)

Third block data

Evaporation heights (if data available)

Number of reservoir (I4), heading (A32)

ID number of the reservoir (I2), Evaporation heights (mm by month) (F5 for each month) (row by row for each reservoir)

Fourth block data

Water releases (if data available)

Number of reservoir (I4), heading (A32)

ID number of the reservoir (I4), Mandatory water releases (in 106m3 by month) (F5 for each month) (row by row for each reservoir)

If data on storage bounds, evaporation and water releases are not available, just write down the heading part with 0 as number of reservoirs.

VIII. Spillways

Line1: Heading (A72)

Line2: number of spillways (I2)

Line 3 onwards (for each spillway)

Identification name of the spillway (usually equal to the name of associated reservoir) (A6), Identification number of the upstream hydraulic node (reservoir) (I4), Identification number of the downstream hydraulic node (reservoir) (I5)

IX. Hydro Turbine Plants

Line1: Heading (A72)

Line2: number of plants (I2)

Line 3 onwards (for each plant)

First block

Identification name of the turbine plant (A6), Identification number of upstream reservoir (I4), Identification number of downstream reservoir (I5), Identification number of the associated pumping plant (I3), Identification number of associated electric node (I2), Head loss at nominal flow (m) (F5), Internal consumption fraction (F5), Average global efficiency (F7), Forced outage rate (F7), Technical minimum (m3/s) (F7), Nominal head (m) (F7), Nominal flow (m3/s) (F7), Minimum tail water level (m) (F7)

Second block

ID name of plant (A6), Maximum flow capacity ((m3/s) by month) (F5 for each month)

ID name of plant (A6), Plant maintenance outage rate (by month) (F5 for each month)

Number of turbine plants for which a technical minimum is defined (I4)

Identification number of the turbine plant (I4), Technical minimum ((m3/s) by month) (F5 for each month)

X. Pumped Storage Plants (Pumping Units)

Line1: Heading (A72)

Line2: number of plants (I2)

Line 3 onwards (for each plant)

First block

Identification name of pumped storage plant (A6), Identification number of downstream reservoir (I4), Identification number of upstream reservoir (I5), Identification number of associated electric node (I2), Head loss at nominal flow (m) (F5), Internal consumption fraction (F5), Average global efficiency (F7), Forced outage rate (F7), Technical minimum (m3/s) (F7), Nominal head (m) (F7), Nominal flow (m3/s) (F7), Minimum tail water level (m) (F7)

Second block

ID name of plant (A6), Maximum flow capacity ((m3/s)by month) (F5 for each month)

ID name of plant (A6), Plant maintenance outage rate (by month) (F5 for each month)

[for peaking ROR/storage, maximum flow capacity = design discharge for each month; for ROR if monthly flow is less than design flow, keep the monthly flow, else keep design flow]

XI. Hydro Cascades

Line1: Heading (A72)

Line2: number of plants cascades (I2)

ID name for reservoirs (A12), Number of reservoirs (by hydro cascade) (I3 for each)

ID name for turbine plants (A12), Number of turbine plants (by hydro cascade) (I3 for each)

ID name for spillways (A12), Number of spillways (by hydro cascade) (I3 for each)

ID name for pumped storages (A12), Number of pumped storage plants (by hydro cascade) (I3 for each)

XII. Transmission Lines

Line1: Heading (A72)

Line2: number of lines (I2)

Line 3 onwards

Code name of transmission line (A6), Identification number of the first electric node (I4), Identification number of the second electric node (I5), Transmission capacity (MW) (F7), Line Reactance(Ohm) (F10), Line Resistance(Ohm) (F10), Line operating voltage (KV) (F10), Forced outage rate (F10), Maintenance outage rate (F10)

4.5.1.2 INFLOW.DAT

Line 1: Initial hydro condition (year) of the available water inflows (I5), Final hydro condition (year) of the available water inflows (I5)

For each station

Identification name of the reservoir (A6)

Tributary water inflows to the reservoir for each hydro condition (year of inflow) (by time period e.g. month in 106m3) (F6 for each month)

4.5.1.3 VALAGP.DAT

Line1: Heading (A72)

Line 2: year of study (I5), starting year (I5), ending year (I5), key for medium and short term solution (I5) (1: yes, 0: no), no of states of reservoir (I3), initial storage key 1 (I3) (0 means initial storage = 50% of max. available storage, 1 means defined value), initial storage key 2 (I3), (0 means initial storage at next time= final storage of previous time, 1 means defined value), first cascade ID (I3), last cascade ID (I3), key for hydrocascades (I3) (0: all, 1: specified only)

Line3: Heading (A72)

Line 4: initial marginal value of reservoir for each state of reservoir (Cts/Kwh) (F6 for each state)

Line5: Heading (A72)

Line 6 onwards

Fractions of maximum available volume for the definition of initial storage of each reservoir (10 in one row. For same value, one value in each row is ok) (F6 for each reservoir)

4.5.1.4 MAINT.DAT

Line1: Heading (A72)

Line 2: year of study (I5), key for phase1 (I5) (feasible solution: 0 means exist, 1 means determine), key for phase 2 (I5) (sequential cost minimization, 0 means no, 1 means determine)

Line 3: print out flags (1 or 0: yes or no) for following items (I5 for each item)

Maintenance by thermal plant, maximum available capacity, Maintenance outage rate, hydro and thermal power allocation, expected generation costs

Line4: Heading (A72)

Line 5: No. of hydroconditions to be considered individually (I5), No. of hydroconditions to be considered in average (I5)

Line 6 onwards: years for considering conditions of line 5 (I5 for each year)

4.5.1.5 RESEX.DAT

Line1: Heading (A72)

Line 2: ID for type of printed output (I5) (1 = annual result for average of hydroconditions, 2= annual results for a set of hydro conditions, 3 = monthly and annual results for a set of hydro conditions, 4 = monthly results (average of hydro conditions), 5 = all monthly and annual results)

Set of hydroconditions for option 2 or 3 (for average of all put dummy value) (I5 up to 13 years)

Line 3: ID for printing of results of following components (0: no print, 1, 2: print) (I5 for each item)

Electric node, secondary demand and exports, thermal power plants and imports, reservoirs, hydro turbine plants, pumping plants, transmission lines

Line 4: ID for printing monthly results (1: print, 0: no print) (I5 for each month)

4.5.1.6 RESIM.DAT

Line1: Heading (A72)

Line 2: ID of component for which output is to be printed (I2), ID of plant for which printed output is required (I2)

Line 3: print out flags (1: print, 0: no print); 7 items for hydroplants on load step basis (I5) and 12 items independent of load steps (I1)

Up to five load steps print out for Water flow, head loss, net head, power output, volume discharged through turbine, energy generation, value of energy generation

12 items: discharged volume, energy generation, value of discharged water, value of energy generation, net benefit, unitary benefit, marginal value of water, utilization factor, gross head, average energetic coefficient, average net head, maximum available power

ID of components in VALORAGUA to be specified as first data of line2

02 -secondary demand and export

03 -thermal power plant and import

04 -hydraulic node -reservoir

05 -hydro turbine plant

06 -pumped storage plant (pumping units)

07 -transmission line

4.5.1.7 VWASP.DAT

Line 1: Number of period in each year (I5)

Line 2: ID name of periods (A12 for each period, if more than 6 periods, write in 2 lines)

Line 3: number of load steps (I5), load step number to compute peak characteristics (I5)

Line 4: Number of hydroconditions to be considered in WASP (I5)

Line 5 onwards (for each hydrocondition)

First line: ID name (A10), number of years (I5)

Second line: corresponding years (I5) (up to 10 year in 1 line)

4.5.2 Output Files of VALORAGUA

In the tabular output, the headings with unit are displayed in the output files.

4.5.2.1 CADIR.PRN

If format of all data entered in CADIR.DAT and INFLOW.DAT are correct, CADIR.EXE runs successfully, and CADIR.PRN is generated. This file lists all the data entered in CADIR.DAT and INFLOW.DAT in tabular format.

4.5.2.2 VALAGP.PRN

VALAGP.EXE is optimization module of VALORAGUA. The output of the model lists medium term and short term options.

Medium term iteration

For each period and corresponding to each state of the equivalent reservoir, the output lists the marginal value of water (FVW), the associated standard deviation (S.D.) and the total accumulated value of the reservoir energy contents (ACV). For each period, the minimum equivalent reservoir contents (RMI) and maximum equivalent reservoir contents (RMA), and incremental energy contents (DR) is displayed.

Short term

For each time period and each hydrological condition, the total system operating costs, maximum error in marginal cost and marginal cost by load step is displayed.

4.5.2.3 RESEX.PRN

By running RESEX.EXE, the summary output of all hydroplants are generated in RESEX.PRN. The file lists the following outputs:

Power balance equation - marginal costs of electric node

Secondary demand system: summary report of power generation, cost and benefit

Thermal power system: summary report of power generation, cost and benefit

Hydraulic nodes (reservoirs): water balance equation - water values

Hydroelectric power plants: summary report of power generation, cost and benefit

4.5.2.4 RESIM.PRN

RESIM.EXE module generates output for a particular hydro plant, which is saved in RESIM.PRN. The file lists the following components for each month for each year for specified load step: Water flow, head loss, net head, power output, volume discharged through turbine, energy generation, value of energy generation.

4.5.2.5 MAINT.PRN

MAINT.PRN generated after running MANT.EXE lists the following information:

Maintenance scheduling (week) program for the average of all hydro conditions

Number of units in maintenance

Maximum available capacity of thermal power plants

Monthly maintenance outage rates

Power allocation by generation subsystem

Expected generation costs

4.5.2.6 VWASP.PRN

VWASP.EXE creates data for WASP module, which is saved in VWASP.PRN. For each period of each hydrocondition, the file shows the following:

MWB: Base capacity

MWC: Available capacity

EA: Inflow energy

EMIN: Minimum requirements for base load generation

4.5.3 Description of WASP Files

4.5.3.1 Input files of WASP

The data input modules are CCD, LOADSY, FIXSYS and VARSYS. Three modules CONGEN, MERSIM and DYNPRO running in sequence produce the optimal solutions. The output of DYNPRO displays optimal solution. The input/output in the form of report is generated by REPROBAT.

I. LOADSY.DAT

Title of study (A60)

Type A record: Number of periods per year (I4), Number of cosine terms in Fourier approximation of Load Duration Curve (LDC) (I4), printout option (I4) (0: default, 1: extended)

Type B record: Annual peak load (F8), year (I6)

IDs (I4): 1: end of data for the year, 2: type 2 record follows, 3: type 3 record follows, 4: type 4 record follows

Type 2 record: Ratio of the peak load in each period expressed as a fraction of the annual peak (F8 up to 10 numbers per line)

Type 3 record: coefficients of fifth order polynomial representation of LDC (F12 for each)

Type 4 record

Number of periods for which load duration curve data are changed from the preceding year (I4), index of periods (I4 for each)

Number of points representing the LDC of the period (I4), index option (I4)

[Index option 0: next data, 1: LDC of current = LDC of previous]

Load magnitude (as a fraction of the period peak load) of each point on the LDC (F10), Load duration (as a fraction of total hours of the period) of LDC (F10)

Note: Put load in descending order (firs duration, peak load = 1.0; last duration, peak load = minimum)

II. FIXSYS.DAT

Title of study (A60), number of thermal plants (I4), print option (optional) (I4)

For each thermal plant: Thermal plant fuel type number (0 to 9) (I4, 1X), Code name for this fuel type (A4, 1X), short description (A20)

For each composite type hydroelectric plant: Code name of hydroelectric plant (5X, A4, 1X), description (A10)

Next line: First year of study (I4), Number of periods per year (maximum 12) (I4), Number of thermal plants in FIXSYS (I4), Number of hydro-conditions (maximum 5) (I4, 2X), Code name of hydroelectric plant type A (A4), Fixed operating and maintenance costs of hydroelectric plant type (F6, 2X), Code name of hydroelectric plant type B (A4), Fixed operating and maintenance costs of hydroelectric plant type B (F6), Probability of hydro-conditions (F6 for each).

Thermal plants data

First line: Code name (A4), Number of identical units (I3), Minimum operating level of each unit (MW) (F5), Maximum unit generating capacity (MW) (F5), Heat rate at minimum operating level (kcal/kWh) (F7), Average incremental heat rate between minimum and maximum operating levels (kcal/kWh) (F7), Domestic fuel costs (c/106 kcal) (F5), Foreign fuel costs (c/106 kcal) (F5), Plant type number (0,1,2, .. 9) (I3), Unit spinning reserve as % of MWC (I2), Unit forced outage rate (%) (F5), Number of days per year required for scheduled maintenance of each unit (I3), Maintenance class size (MW) (F5, 7X), Fixed component of non-fuel operation and maintenance cost ($/kW-month) of each unit (F5), Variable component of non-fuel operation and maintenance cost ($/MWh) of each unit (F5)

Second line: heat value of the fuel used by plant (kcal/kg) (F10), percentage of polluting emission first material (default: SO2) (F10), percentage of polluting emission second material (default: NOx) (F10)

Next part of thermal

Number of group limitations (I2), index for change of both default penalty factors (I2) [1 = content of next two fields replaces defaults ,0 = content of next two fields ignored], penalty factor for the loss-of-load probability when determining the optimal mix of strategies (F10) [default = 0.0], penalty factor for the unserved energy when determining the optimal mix of strategies (F10, 1X) [default =1.0], name of first emitted material (A3, 1X) [default: SO2], name of second emitted material (A3) [default: NOx], index number defining type of limit (I2 for each)

[index numbers: 1 = corresponding limit concerns the fuel used for energy generation, 2 = emitted first material is limited, 3 = emitted second material is limited, 4 = used heat is limited, 5 = generation is directly limited]

Next part of thermal

Number of plants for real emission (I4) [0 means not active, = number of thermal plants means all plants]

Index of plant taking role in the real emission (I4 for each)

Keys used in hydropower data (I4)

[Keys description, 1: process current year data and proceed to read data for next year, 2: hydro project data type 2 follows , 3: one type-3 record follows, 4: indicates that description of pumped storage project] [use appropriate keys]

Type 2 record: Hydropower data

First line: Name of hydroelectric project (2X, A4, 2X), Code name of hydroelectric plant type (A4), installed capacity (MW) (F6), energy storage capacity (GWh) (F6)

For each period and each hydrocondition (put in one row for all hydroconditions): Period inflow energy (GWh) of the hydro project (F5), Minimum generation in base in the period (GWh) (F5), Available capacity in period (MW) of the project (F5)

Type 3 record

Number of the thermal plant in which one or more units are to be added or retired (I4), Number of units to be either added (+) or retired (-) in plant IP (I4)

Type 4 record for each project: pumped storage project

First line: Name of the pumped storage project (2X, A4), Installed capacity (MW) of the pumped storage project (F6), Cycle efficiency of the pumped storage project (%) (F6), Fixed operating and maintenance cost of the pumped storage project ($/KW-month) (F6)

Next line: Pumping capacity (MW) of pumped storage project for the period (F5), Generating capacity (MW) of pumped storage project for the period (F5), Maximum feasible energy generation (GWh) of pumped storage project for the period (F5).

III. VARSYS.DAT

Title of study (A60, 5X), print option (optional) (I4)

Number of periods per year (maximum 12) (4X, I4), Number of thermal plants in VARSYS (I4), Number of hydro-conditions (maximum 5) (I4, 2X), Code name of hydroelectric plant type A (A4), Fixed operating and maintenance costs of hydroelectric plant type (F6, 2X), Code name of hydroelectric plant type B (A4), Fixed operating and maintenance costs of hydroelectric plant type B (F6), Probability of hydro-conditions (f6 for each), Number of candidate hydro projects of hydro plant type A (maximum 30) (I3), Number of candidate hydro projects of hydro plant type B (maximum 30) (I3), Number of pumped storage projects used as system expansion(maximum 30) (I3)

Thermal plants data

First line: Code name of thermal plant (A4, 3X), Minimum operating level (MW) (F5), Maximum operating level (MW) (F5), Heat rate at minimum operating level (kcal/kWh) (F7), Average incremental heat rate between minimum and maximum operating levels (kcal/kWh) (F7), Domestic fuel costs (c/106 kcal) (F5), Foreign fuel costs (c/106 kcal) (F5), Plant type number (0,1,2, .. 9) (I3), Spinning reserve as % of MWC (I2), Unit forced outage rate (%) (F5), Number of days per year required for scheduled maintenance (I3), Maintenance class size (MW) (F5, 6X), Fixed component of non-fuel operation and maintenance cost ($/kW-month) of each unit (F5), Variable component of non-fuel operation and maintenance cost ($/MWh) of each unit (F5)

Second line: heat value of the fuel used by plant (kcal/kg) (F10), percentage of polluting emission first material (default: SO2) (F10), percentage of polluting emission second material (default: NOx) (F10)

Next part of thermal

Number of group-limitations (I2, A23), name of first emitted material (A3, 1X) [default: SO2], name of second emitted material (A3) [default: NOx], index number defining type of limit (I2 for each)

[index numbers: 1 = corresponding limit concerns the fuel used for energy generation, 2 = emitted first material is limited, 3 = emitted second material is limited, 4 = used heat is limited, 5 = generation is directly limited]

Next part of thermal

Number of plants for real emission (I4) [0 means not active, = number of thermal plants means all plants]

Index of plant taking role in the real emission (I4 for each)

Keys used in hydropower data (I4)

1: Process current year data and proceed to read data for next year

2: Hydro project data type 2 follows

3: Indicates that description of pumped storage project

Type 2 record: Hydropower data

First line: Name of hydroelectric project (2X, A4, 2X), Code name of hydroelectric plant type (A4), installed capacity (MW), energy storage capacity (GWh) (F6), First year the project is available to be considered as expansion candidate (I6)

For each period and each hydrocondition (put in one row for all hydroconditions): Period inflow energy (GWh) of the hydro project (F5), Minimum generation in base in the period (GWh) (F5), Available capacity in period (MW) of the project (F5)

Type 4 record for each project: pumped storage project

First line: First line: Name of the pumped storage project (2X, A4), Installed capacity (MW) of the pumped storage project (F6), Cycle efficiency of the pumped storage project (%) (F6), Fixed operating and maintenance cost of the pumped storage project ($/KW-month) (F6), First year the project is available to be considered as expansion candidate (I6)

Next line: Pumping capacity (MW) of pumped storage project for the period (F5), Generating capacity (MW) of pumped storage project for the period (F5), Maximum feasible energy generation (GWh) of pumped storage project for the period (F5)

IV. CONGEN.DAT

Title of study (A60, centered to columns 30-31), print option (I4) [option 1: print from fixsys and Varsys)

Keys used (I4)

Keys: 1, 2, 3, 4

1: end of data

After keys 2, 3, 4 and 8, following data are entered.

After 2: minimum number of sets (0 to 14) for each thermal plant and hydroplant type (I4 for each)

After 3: tunnel width (addition to minimum number, total representing maximum number) for each thermal plant and hydroplant type (I4 for each)

After 4: Minimum (F10) and maximum (F10) permissible reserve margin (% of peak load) in critical period

After 8: Number of the hydro condition for which critical period and reserve margins are to be calculated (default =1) (I4)

V. MERSIM.DAT

Title of study (A60, centered to columns 30-31), print option (I4) [option 1: print from fixsys and Varsys), key (I4) (0: extensive or 1: general for optimization option)

Index used

1: End of data

2: Type 2 records follow

4: Type 4 record follows

5: Type 5 record follows

7: Type 7 record follows

Type 2 record

Loading order instructions (F5), Multiplier of period peak load (PKMW) for calculating the required spinning reserve (F5), loading order calculation option (I5) [0: plant basis, 1: unit by unit basis]

Type 4 record

Output option (I4) (0: minimum, 1: intermediate, 2: maximum outputs)

Type 5 record

Number of Fourier coefficients (I4)

Type 7 record

Domestic fuel consumption by unit (TON/GW•h) (F8 for each unit up to 9 in one line)

Foreign fuel consumption by unit (TON/GW•h) (F8 for each unit up to 9 in one line)

Domestic fuel stock by unit (TON) (F8 for each unit up to 9 in one line)

Foreign fuel stock by unit (TON) (F8 for each unit up to 9 in one line)

Type 8 record

Number of thermal plants for which the annual maintenance schedule is changed (I5)

Plant order number in the combined FIXSYS plus VARSYS set of plants (I5), Number of fixed maintenance days for each unit of thermal plant (I4 for each unit)

Type 9 record

Index number of group-limitation to be overwritten (I4), index of individual period group limits (I4) [0: default, 1: distribute], modified upper bound value of constraint (F10), ratio of group limitations (F5 for each period)

VI. DYNPRO.DAT

Line 1: Title of study (A60, centered to columns 30-31), print option (I4) [1 to print the VARSYS file, 0 no file printing], Special printing option (I4) [1 to print all states, 2 to print debug information, 0 prints neither information]

Line 2: Base year for cost discounting calculation (I5), Base year for cost escalation calculation (I5), First year of study (I5), Number of years to be considered for the economic comparison (I5)

Line 3: Single domestic discount rate (%/year) (F10), Single foreign discount rate (F10)

Record key

1: end of data, 2 to 17: data of different type

Type 2 record

Depreciable domestic capital cost ($/kW) of expansion candidate plant IP (IP is the number of the plant in VARSYS) (F8), Depreciable foreign capital cost ($/kW) (F8), Plant life (in years) (F8), Non-depreciable domestic capital cost ($/kW) (F8) (leave blank for hydro or Pumped storage P-S), Non-depreciable foreign capital cost ($/kW) (F8) (leave blank for hydro or P-S), Interest during construction (F8), Construction time (in years) (F8), name of project (A4)

Type 3

Factor by which all foreign costs will be multiplied (default value 1.0) (F8)

Annual escalation ratio of domestic capital cost of VARSYS plant IP (default =1) (F8)

Type 4

Annual escalation ratio of foreign capital cost of VARSYS plant IP (8X, F8)

Type 6

Maximum number of units (sets) of the expansion candidate IP (plant number in the VARSYS list) which can be added per year (default value 50) (I4 for each)

Type 7

Minimum number of units (sets) of each expansion candidate which must be added per year (default value is 0) (I4 for each)

Type 9

Annual escalation ratios of plants of “fuel” type (I) to be applied to the domestic (1st record) and foreign (2nd record) operating costs (default values 1.0) (F6 for each)

Type 11

Coefficients of the 2nd order polynomial of the incremental cost of unserved energy ($/kWh) as a function of the unserved energy (expressed as a fraction of total annual energy) (default values 0.0).(F8 for each)

Type 12

Critical value of annual loss-of-load probability (in %) (default value 100) (F8)

Type 13

Number of best solutions to be reported; values from 1 to 10 (default value 1) (2X, I2)

Type 16

Salvage value option (0 (default value) calls for linear depreciation; 1 calls for sinking fund depreciation) (I4)

Type 17

Escalation ratios by type of ("fuel") plant for domestic (1st record) and foreign (2nd record) fuel costs (default values = 1.0) (F6 for each)

(Note: type 3 to 17 records can also be entered through GUI.)

VII. REPROBAT.DAT

Line 1: Title of study (A60, centered to columns 30-31)

Line2: Initial year of study (same as in FIXSYS) (I5), Last year of study (same as in FIXSYS) (I5), First year of planning period (I5), Last year of planning period (I5)

Keys: 1 to 8 (1: end of data, others: data type that follows) (I4)

Type 2 data

Eight printout options (1: print, 0: no print) (I4 for each)

load system description (LOADSY), fixed system description (FIXSYS), variable system description (VARSYS), constraints in configuration generator module (CONGEN),optimum solution(DYNPRO), economic parameters and additional constraints (DYNPRO), expected cost of operation (MERSIM), cash flow of construction and fuel inventory costs

Type 3 data

Three sub-options to optimum solution (1: print, 0: no print) (I4 for each)

Detailed output of cash flows by year and plant, Calculation and output of IDC, Listing of capital and IDC costs combined

Type 4 record

Sub-option to optimum solution (I4)

0: no report (default)

1: only weighted values are reported (and not by hydro-condition)

2: maximum output

Type 5 record

N indicating the type of record used to specify the contents of the footnote of the cover (A1, 3X), Date (A20), Text 1 (name of the author(s) or any other text (A6)

N (A1, 3X), text 2 (A60)

Type 6 record

N (A1, 3X), text 3 (any additional info) (A60)

Type 7 record

Line 1: Name of thermal plant unit, hydro or P-S project of the FIXSYS plant to be considered in the REPROBAT report (A4, 1X), Plant Fuel type (I2, 2X), Key to control input of fuel inventory data (I1, 1X) (Leave blank for hydro or P-S), First year of service of the plant (I4), Number of years of construction (maximum = 10) (I5)

Line 2: Domestic total pure construction cost (million $) (F10), Annual distribution of domestic pure construction cost (%) (F6 for each year of construction)

Line 3: Foreign total pure construction cost (million $) (F10), Annual distribution of foreign pure construction cost (%) (F6 for each year of construction)

Line 4: Domestic total fuel inventory cost (million $) (F10), Annual distribution of domestic fuel inventory cost (%) (F6 two entries)

Line 5: Foreign total fuel inventory cost (million \$) (F10), Annual distribution of foreign fuel inventory cost (%) (F6 two entries)

Line 6: Foreign total interest during construction (million \$) (F10), Annual distribution of foreign interest during construction (%) (F6 for each year of construction)

Type 8 record

Line 1: Thermal plant name, hydro or P-S plant type name (has to be equal to VARSYS name) (A4, 1X), Hydro or P-S project name (A4) (must be equal to VARSYS name) (Leave blank for thermal), Key to control input of fuel inventory data (I1) (Leave blank for hydro or P-S), Annual distribution of domestic pure construction costs (%) (F6 for each year of construction)

Line 2: Annual distribution of foreign pure construction costs (%) (10X, F6 for each year of construction)

Line 3: Annual distribution of domestic fuel inventory cost (%) (10X, F6 for each year of construction)

Line 4: Annual distribution of foreign fuel inventory cost (%)(10X, F6 for each year of construction)

4.5.4 Output Modules of WASP

4.5.4.1 Loadsy.rep

Displaying data on Energy demand, load factor

4.5.4.2 Fixsys.rep

Displaying data of Fixsys.dat (both thermal and hydro plant) in tabular form, displaying base capacity, peak capacity, peaking energy, and hours per day for individual plant; base and peak capacity, available energy for peaking and total available capacity of the composite hydro plant

4.5.4.3 varsys.rep

Displaying similar data as Fixsys for variable expansion case

4.5.4.4 Congen.rep

Displaying entered data in CONGEN.DAT, capacity from FIXSYS.DAT, year by year configurations

4.5.4.5 Mersim2.rep

Displaying Cost, LOLP, configurations, Energy not served (ENS)

Other outputs in Mersim1.rep and Mersim3.rep

4.5.4.6 Dynpro1.rep

Displaying entered data in DYNPRO.DAT, objective function, the number of the state in the preceding year connected to the sub-optimum path, variable alternatives by year with following information.

CONCST (Construction cost)

SALVAL (Salvage value)

OPCOST (operation cost)

ENSCST (Energy not served cost)

Total cost

Objective function (cumulative)

LOLP (Loss-of-load probability)

Configurations

4.5.4.7 Dynpro2.rep

Displaying all states

4.5.4.8 Reprobat1.rep

Reports of WASP including input and output (summary report for Loadsy, Fixsys, varsys, Congen, Mersim and Dynpro), expected cost of operation

Chapter 5

Optimization Framework

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5. OPTIMIZATION FRAMEWORK

The optimization framework of power system is setup by using the VALAROGUA and WASP models. The optimization framework using the VALAROGUA-WASP model is described as below:

5.1 DESIGN OF HYDRAULIC NETWORK

The power system is modeled in VALORAGUA as electric network comprising nodes connected by transmission lines, each node encompassing all the thermal and hydroelectric power plants in the region. The hydroelectric plants are represented as a hydraulic network, where each plant is represented as a reservoir, with or without storage (run-of-river), connected to other plants in a cascade by waterways. Each reservoir gets natural inflow from river, if first in the cascade or incremental or intermediate inflows for downstream reservoirs. Water from one reservoir to another in the downstream flows either through turbines, thereby generating power or through spills, in excess of design flow or when the turbine is shut off. The last reservoir in the cascade discharges into sink. All hydraulic nodes having influence from upstream inflows are kept in one cascade.

5.2 INPUT DATA FILES PREPARATION

Following data are assembled in EXCEL for VALORAGUA

Basic

- Year of simulation period
- First and last year of hydrological condition (year)
- Probability of hydroconditions
- Number and duration of load steps

Electric node

- Fraction of mean power demand for each month in a load step
- Annual energy demand
- Maximum and minimum secondary energy demand
- Data on selling price

Reservoir

- Data on Storage capacity of reservoir
- Fraction of storage capacity at Full supply level and minimum operating level
- Parameters defining level/volume function
- Minimum and maximum operation storage
- Evaporation and mandatory release

Hydropower plant data

- Head loss at nominal flow
- Internal consumption fraction
- Average global efficiency
- Forced outage rate
- Technical minimum
- Nominal head
- Nominal flow

- Minimum tail water level

Data of thermal power plant

- Maintenance teams
- Average operation cost
- Variation of operation costs
- Unit technical minimum
- Forced outage rate
- Internal consumption fraction

Hydrological data

- Mean monthly inflows data

5.2.1 Preparation of Input Data File Format for VALORAGUA

All data files of VALORAGUA are in ASCII format. Hence, any text editor can be used to prepare data files. As CADIR.DAT and INFLOW.DAT contain large amount of data, it will be easy to prepare these files by writing code in high level programming, such as MATLAB. Collecting all data in EXCEL sheets and running MATLAB code will generate these data files in proper format.

5.2.2 Preparation of Input Data File Format for WASP

Like VALORAGUA, all input files of WASP are in ASCII format, which can be prepared by using any text editor. However, for making the task less time consuming, the data files can be generated by writing program in MATLAB.

LOADSYS.DAT: Data on forecasted load is obtained from NEA and coefficients are estimated from load curve. All data are assembled in EXCEL. A MATLAB code can be written to generate data file in proper format. Alternatively, as the size of the file is small, it can be prepared directly using text editor.

FIXSYS.DAT: The output of VWASP is opened in EXCEL, and the data on period inflow energy (GWh) of the hydro project, minimum generation in base in the period (GWh), available capacity in period (MW) of the project for all hydroconditions and all periods of each existing hydropower plant is prepared in separate sheets. A MATLAB code can be prepared to generate the data file in proper format.

VARSYS.DAT: The output of VWASP is opened in EXCEL, and the data on period inflow energy (GWh) of the hydro project, minimum generation in base in the period (GWh), available capacity in period (MW) of the project for all hydroconditions and all periods of each hydropower plant considered for future expansion candidate is prepared in separate sheets. A MATLAB code can be prepared to generate the data file in the required format.

Except above three file, other remaining files are of small size, which can be directly prepared using text editor.

5.3 MODELING USING VALORAGUA AND WASP

First, module CLEARD must be run in order to initialize the direct access file G14 for the particular VALORAGUA study. This is followed by a run of CADIR in order to prepare all the basic characteristics of the power system configuration(s), including the necessary hydro data. For the first run, VALAGP is run with a year of good quality data to check if there are any errors. Finally, a run of VALAGP for all the years of study will provide the required optimization of the operation of the system in the selected years. After VALAGP has been run, RESEX is executed to get overall results of simulation and RESIM is executed to obtain more details for a particular hydroplant. Next, MAINT module is run in order to optimize the maintenance schedule of the thermal power plants for each given configuration and probably a new sequence of runs of CADIR and VALAGP could be undertaken in order to try to improve the results of the previous simulation in terms of operating costs. It should be noted, however, that the CLEARD program is only run at the beginning of the process since any subsequent run of this program will erase any previous information contained in the direct access file G14.

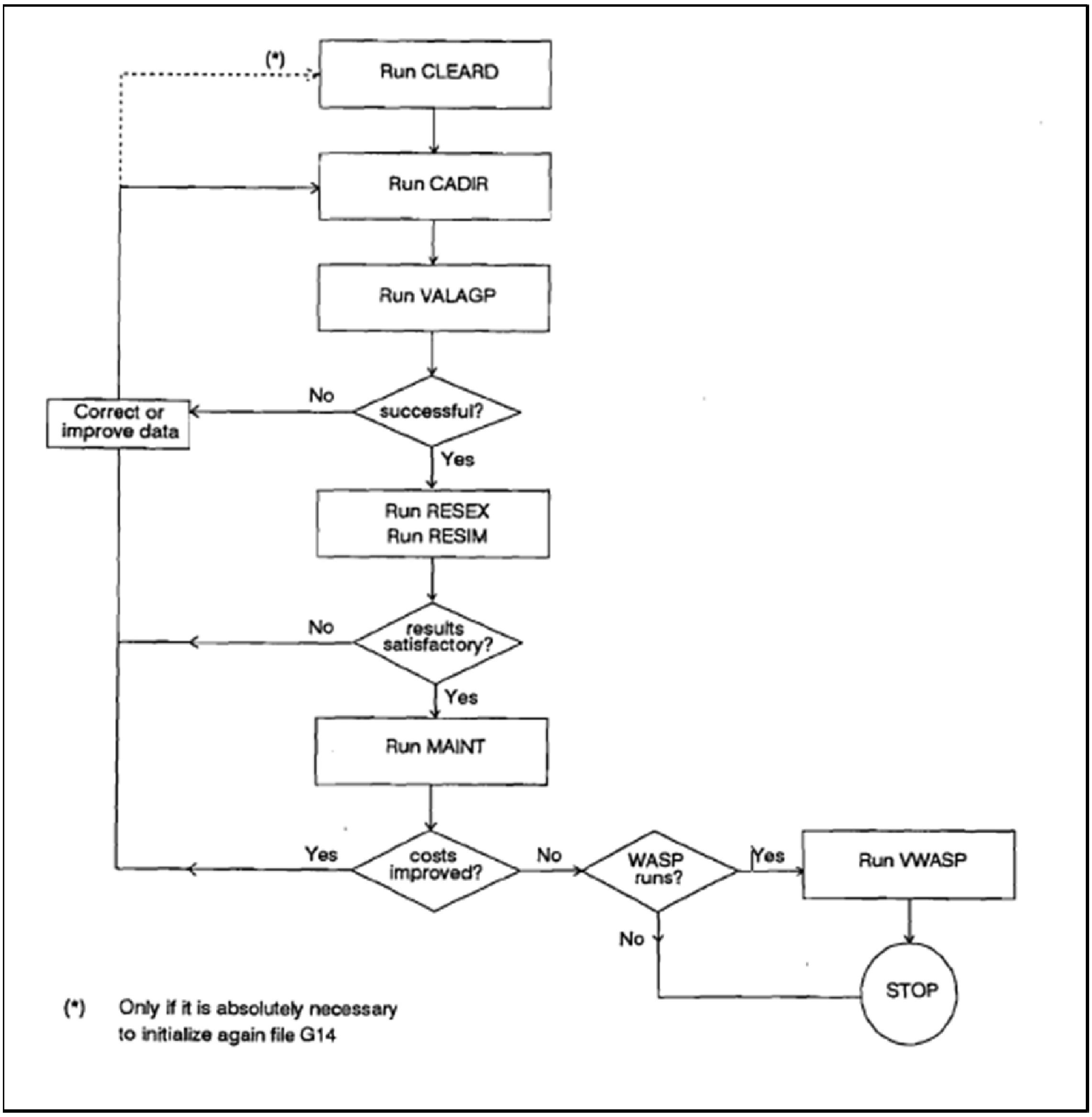

Figure 5-1: Sequence for running VALORAGUA

5.3.1 Sequence for Running VALORAGUA

If the purpose of the VALORAGUA study is to iterate with optimization runs of the WASP program, the VWASP module can be run to produce the hydro data for FIXSYS.DAT and VARSYS.DAT. If optimization of expansion is not the goal, the user may take the VALORAGUA end-results and do the analysis of results.

5.3.2 WASP Running Sequence

LOADSY, FIXSYS and VARSYS are data pre-processing modules, which can be run independent of each other. The data obtained from these modules are used for optimization. For optimization of expansion plan, CONGEN, MERSIM and DYNPRO are run in sequence. The DYNPRO module gives the final optimum solution.

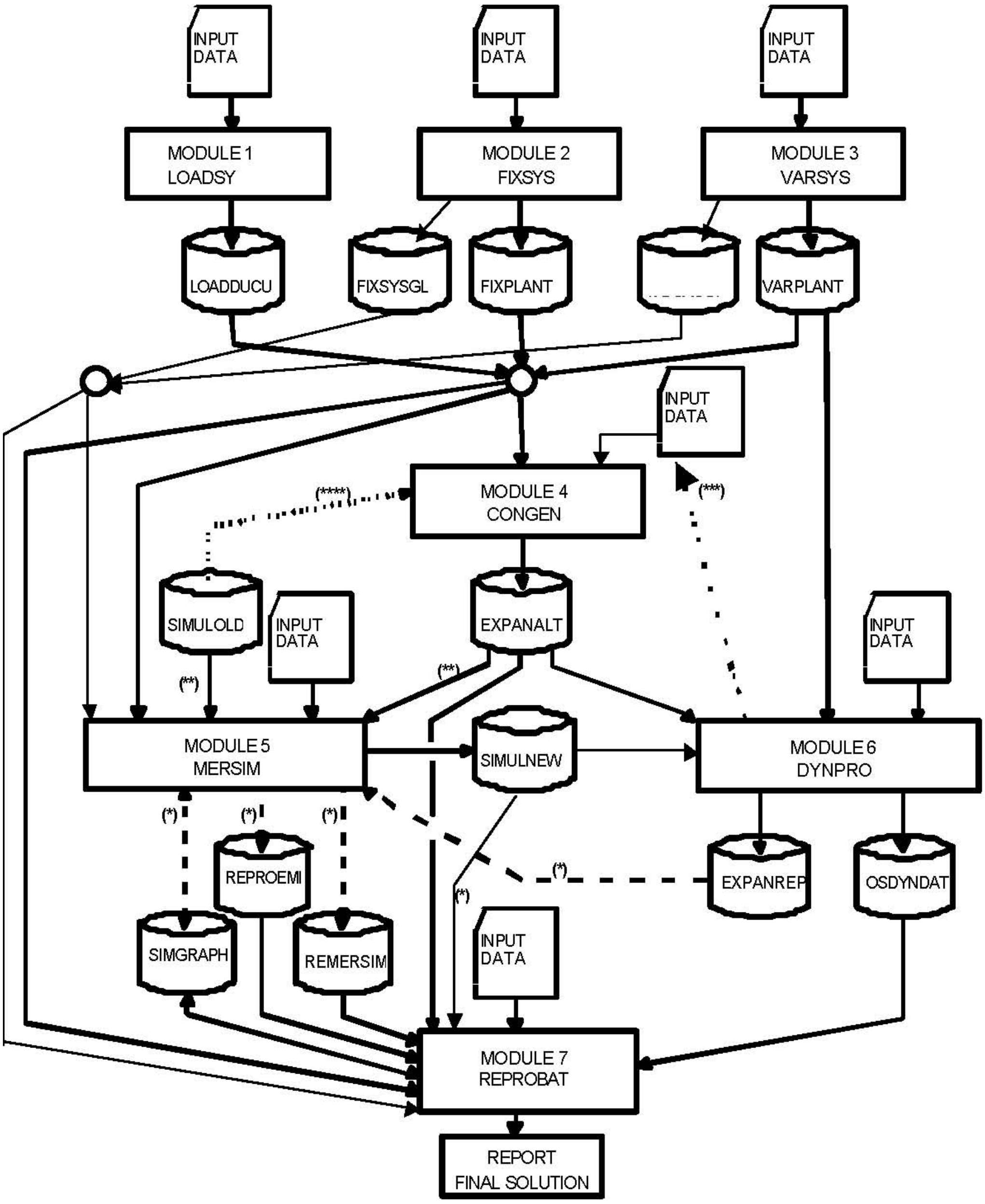

Figure 5-2: Simplified Flow Chart of WASP-IV Model

Notes: (*) For resimulation of best solution only; (**) ommit for resimulation of best solution; (***) iteration pattern if best solution still constrained; (****) for check of configurations already simulated

5.3.3 Analysis of Output Data

Analysis of the output of VALORAGUA model is carried out from the output data saved in VALAGP.prn and RESEX.prn or RESIM.prn for individual plant. VALAGP.prn displays the information on optimization.

VALAGP.prn gives the following:

Solution of medium term problems

Following variables for each state and each month

- RMI/RMA = minimum/maximum equivalent reservoir contents
- DR = incremental energy contents
- FVW = marginal value of water at each state of the equivalent reservoir

- S.D. = associated standard deviation
- ACV. = accumulated value of the reservoir's energy contents

Solution of short term problems

- Marginal cost by load step

RESEX.prn gives the following:

Electric node

Power balance equation - marginal costs

- Fixed power demand
- Secondary power demand
- Thermal power output
- Hydroelectric power output
- Pumping power consumption
- Net transported power
- Power excess
- Marginal cost of generation
- Value of generation

Secondary demand

- Supplied demand, utilization factor, cost and benefit

Thermal

- Power generation, utilization factor, cost and benefit

Hydraulic nodes (reservoirs)

Water balance equation

- Initial storage
- Upstream turbined volume
- Downstream pumped volume
- Upstream spilled volume
- Tributary inflow
- Downstream turbined volume
- Upstream pumped volume
- Downstream spilled volume
- Evaporation
- Mandatory release
- Final storage
- Marginal value of water
- Value of inflow

Hydroelectric power plants

- Net head
- Average energetic coefficient
- Turbined volume

- Energy generation
- Utilization factor
- Marginal value of water
- Value of water
- Value of generation
- Net benefit
- Unitary benefit
- Power output and water flow by load step

RESIM.prn displays the output for a particular plant. For example, for a hydroplant the following output are generated: water flow, gross head, head loss, net head, power output, turbined volume, energy generation, value of generation, net benefit for a plant in each month of all hydroconditions.

The analysis of output data is carried put in WASP from the output data saved in Dynpro1.rep and Reproba1.rep.

Dynpro1.rep provides the objective function and the number of the state in the preceding year connected to the sub-optimum path, and variable alternatives by year with following information.

- CONCST (Construction cost)
- SALVAL (Salvage value)
- OPCOST (operation cost)
- ENSCST (Energy not served cost)
- Total cost
- Objective function (cumulative)
- LOLP (Loss-of-load probability)
- Year by year configurations

Reprob1.rep provides summary of input data from LOADSY, FIXSYS, VARSYS, CONGEN, MERSIM and DYNPRO.

5.3.4 Long Run Marginal Cost (LRMC) Computation

Marginal cost refers to the increase in total cost for producing one additional unit of product. Derivative of long run cost function gives LRMC.

LRMC=dc/dq = Change in total cost/change in output

5.3.4.1 Perturbation approach for LRMC

I. Forecast peak demand or average demand over a future time horizon of, say, 20 years.
II. Obtain a least cost generation capacity expansion that ensures that supply can satisfy demand using WASP.
III. The base case long term generation expansion plan to cover at least twenty years ahead is optimized. This plan is the most likely scenario out of all the different scenarios that may be modelled, and this should be the long-term generation expansion plan that is recommended for implementation and accepted.
IV. Increase forecast average and/or peak demand by a small but permanent amount and recalculate the least cost generation capacity expansions needed to equate demand and supply using WASP.
V. Compute LRMC as

LRMC= (NPV2-NPV1)/(Demand2-Demand1)

NPV2 = net present value of step II

NPV1 = net present value of step I

5.3.5 Monetary Value of Hydropower Plants

After determining the reference optimized expansion plan and reference LRMC, monetary value of different sets of candidate hydropower plants will be determined. While evaluating the monetary values of such sets, different conditions will be imposed mutually inclusively or exclusively in possible combinations.

Chapter 6

Optimization of Power System

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6. OPTIMIZATION OF POWER SYSTEM

6.1 LOAD FORECAST MODEL

Load Forecast is the basis for generation plan, transmission and distribution system plan, and Long run Marginal Cost (LRMC) analysis. Different techniques are available for load forecasting.

a) Sectional method: The approach followed by NEA is based on sectional method. Different sectors considered for Load Forecast by NEA are:

- Domestic
- Industrial
- Commercial
- Irrigation
- Other Sectors
- Export

Following are the demand models used by NEA, which can be adopted by refining the parameters.

Model for Domestic sector

$$D_t = D_{t-1}(1 + a_t b)(\Delta P_t/\Delta CPI_t)^c + 0.5\Delta N_{t-1}d_{t-1}(1 + a_t b)(\Delta P_t/\Delta CPI_t)^c + 0.5\Delta N_t d_t$$

Where,

D_t = Electricity consumption, period t

ΔP_t = Change in price of electricity, period t

CPI_t = Change in consumer price index, period t

ΔN_t = New consumers connected, period t

a_t = Real income growth rate, period t

b = Income elasticity for electricity

c = Price elasticity for electricity for households

d_t = Average consumption for new consumers, period t

Industrial Demand Model

$$D_t = D_{t-1}[1 + (a_t/100)b](1 + P_t/100)^c + \Delta L_t$$

Where,

D_t = Electricity consumption, period t

a_t = Industrial GDP growth rate, period t

b = Income elasticity for electricity

P_t = Percentage increase in price of electricity in real terms, period t

c = Price elasticity for electricity

ΔL_t = Consumption by large new industries, period t

Commercial and Other Sectors Demand Model

$D_t = D_{t-1}[1 + (a_t/100)b](1 + P_t/100)^c$

Where,

D_t = Electricity consumption, period t

a_t = GDP growth rate for the sector, period t

b = Income elasticity for electricity

P_t = Percentage increase in price of electricity in real terms, period t

c = Price elasticity for electricity

Irrigation Demand Model

$$D_t = D_{t-1}(1 + a/100) + \Delta L_t$$

Where,

D_t = Electricity consumption, period t

A = Growth rate for electricity consumption

ΔL_t = Consumption by large new irrigation load, period t

Export

$$D_t = D_{t-1}(1 + a/100)$$

Where,

D_t = Electricity consumption, period t

a = Growth rate for electricity consumption

Assumptions made for forecast until 2027

Overall GDP growth rate = 4.4%

Industrial GDP growth rate = 8.2%

Commercial GDP growth rate = 8.2%

Other GDP growth rate = 6.5%

Population growth rate = 2.1% per annum

Annual growth rate for export = 5%

Income elasticity

- Fiscal year 2010-2014= 1.4
- Fiscal year 2017-2025= 1.3

Price elasticity= -0.4

Long run price elasticity for industry= -0.3

b) Load forecast based on historical data

Statistical techniques can be applied if historical time series data of sufficient duration (usually 20-30 years) are available. Following are some examples of such techniques.

Time Series analysis method

Fitting time series model, such as ARMA (autoregressive moving average) model

Example: ARMA (1, 1)

$$L_t = aL_{t-1} + e_t - be_{t-1}$$

Where,

L_t = Load at time t

a, b = parameters of model

e_t = random component with mean zero

Parameters are found by optimization.

Regression analysis

Fitting regression equation and extrapolation

Form of equation

$e = at+b$

$e=at^b$

$e=at^2+bt+c$

Where,

e = consumption of energy

t = time

a, b, c = parameters

6.2 LOAD FORECASTING

The first step in any power system optimization starts from load forecasting. The data on peak load forecast for the planning horizon should be obtained from an authentic source or prepared using techniques presented in section 3.3.1. As a sample case, peak load forecast made by NEA for 2011-2027 and extrapolated up to 2030 is shown in Figure 6-1.

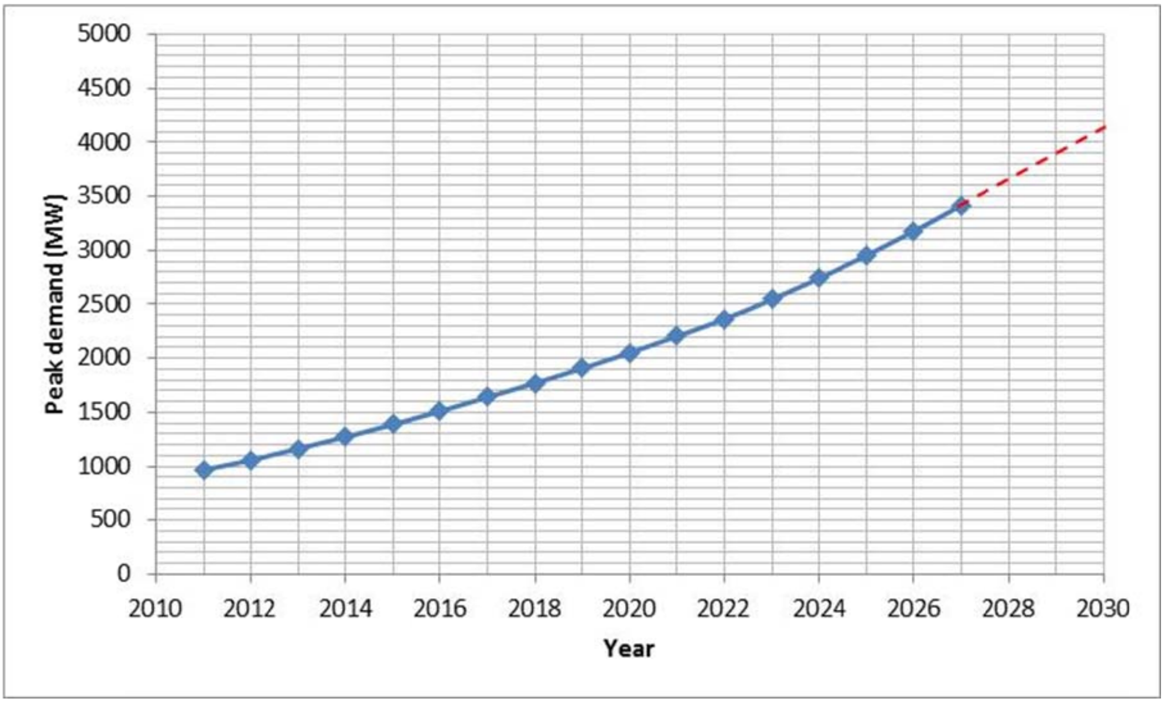


Figure 6-1: Peak Load Forecast

6.3 LOAD DURATION CURVE (LDC)

Average monthly LDC or LDC of each month will be used for processing the data related to load. The LDC is discretized into load steps (maximum 5). The time duration of each load step and the fraction of peak power should be determined using DIAGOPTM auxiliary tool. The coefficients of fifth order polynomial equation representing the LDC are found out by using WASPLDC auxiliary tool. The duration and magnitude of load in discrete form can be directly obtained from the curve.

As a sample case, the LDC data covering 2012 August to 2013 July of Nepal is taken here. The LDC is discretized into 5 steps. The following is the result of DIAGOPTM for the LDC data.

- Optimized time duration (%) of each load step: 4, 11, 18, 30, 37
- Fraction of peak of each load step: 1, 0.82, 0.70, 0.64, 0.58

A sample plot for January is shown below. Such curves are prepared for all months.

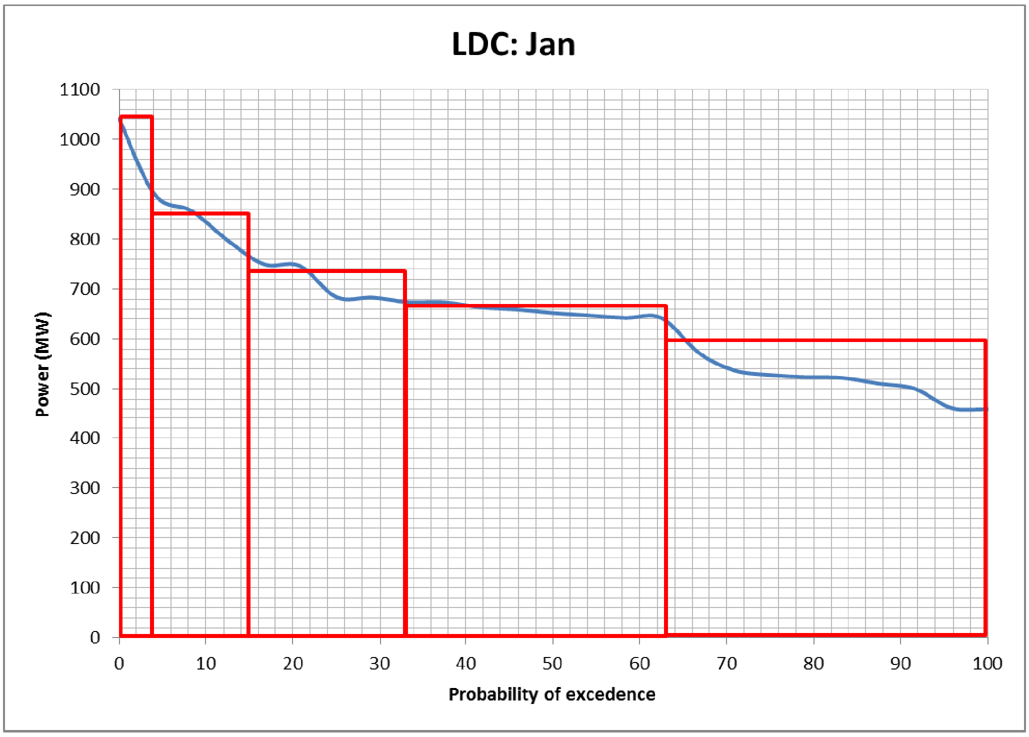


Figure 6-2: Discretization of LDC for January

The following is the coefficients of the fifth order polynomial equation obtained from WASPLDC for the LDC data.

Table 6-1: The coefficients of the fifth order polynomial equation obtained from WASPLDC

Month	A0	A1	A2	A3	A4	A5
Jan	1.0000	-2.8852	9.5950	-15.3243	10.8350	-2.7618
Feb	1.0000	-1.2649	2.0056	-3.3404	4.1922	-2.0569
Mar	1.0000	-1.3636	2.5381	-4.5041	5.3152	-2.4539
Apr	1.0000	-1.7891	5.2904	-9.8477	9.4224	-3.5068
May	1.0000	-1.8388	5.5570	-10.4326	9.9904	-3.7090
Jun	1.0000	-3.1548	11.5001	-20.2684	16.8152	-5.3767
Jul	1.0000	-2.8302	8.2488	-10.5065	5.3813	-0.7455
Aug	1.0000	-3.4718	13.7085	-26.9957	25.1686	-8.8759
Sep	1.0000	-3.2952	11.9500	-22.0191	19.6319	-6.7215
Oct	1.0000	-3.5642	13.5949	-25.7003	23.1841	-7.9710
Nov	1.0000	-3.5642	13.5949	-25.7003	23.1841	-7.9710
Dec	1.0000	-2.2994	5.4637	-6.1302	3.1947	-0.7489

6.4 HYDRONETWORK

6.4.1 Selection of pool of plants

Existing plants

The following existing plants (as of 2013/14) are considered in the power system optimization. Primarily the major plants as well as some small plants for which complete data sets are readily available during modeling works, are selected (refer Table 6-2). However, for long term expansion plan, the smaller plants having capacity less than 5 MW can be ignored or several smaller plants contribution can be lumped together.

Expansion plants

Currently (study year 2013/14), the country is facing shortage of power throughout the year as the demand is surpassing the supply. In order to overcome the loadshedding problem, hydropower plants under construction producing significant power and major planned projects should be considered in the expansion plan. The following plants considered, includes combination of ROR as well as storage plants up to time horizon of 2030. With these plants in place, the forecasted peak demand for the simulation period will be fulfilled.

All the major existing projects and major projects in future expansion should be selected for power system optimization (generally greater than 10 MW projects). There is no need to consider the isolated projects. Basket of projects should be selected in such a way that the power generation would be sufficient to meet the forecasted peak demands.

In VALORAGUA-WASP system, generation subsystem and consumption subsystem is modeled in detail. Basic data pertaining to transmission can be entered (this is optional in VALORAGUA), but transmission-distribution subsystem is not included.

Power system optimization is elaborated here using a sample case for Nepal. In the sample case, all data and parameters are based on the information available in the year 2013/2014.

In the sample case, 18 hydrocascades (maximum limit in VALORAGUA) are considered. Considering 2030 as simulation year, the forecasted peak demand for 2030 is 4155 MW. To fulfill the demands, 20 major existing and 28 major planned/under-construction plants are considered.

Table 6-2: List of hydroplants

Existing plants (20)	**Installed capacity (MW)**	**Under construction/planned projects (28)**	**Installed capacity (MW)**
KALI GANDAKI	144	UPPER TAMAKOSHI	456
MIDDLE MARSYANGDI	70	RASUWAGADHI	111
MARSYANGDI	69	MIDDLE BHOTEKOSHI	102
KULEKHANI-1	60	TRISHULI3A	60
KULEKHANI-2	32	TANAHU STORAGE (SETI)	128
KHIMTI-1	60	BUDHI GANDAKI STORAGE	600
UPPER BHOTEKOSHI	45	DUDH KOSHI STORAGE	300
PUWA	6.2	NALSING GAD STORAGE	400
MAI	15.6	WEST SETI STORAGE	750
PILUWA	3.0	MIDDLE TAMOR	75
SIPRIN	9.6	UPPER TAMOR	415
CHAKU	3	BARAMCHI	4
SUNKOSHI SMALL	2.5	KULEKHANI-3	14
SUNKOSHI	10	LOWER MODI	20
CHILIME	22	CHAMELIYA	30
TRISHULI	24	HEWA	15

DEVIGHAT	15	RAHUGHAT	32
KHUDI	4	PHAWA	5
MODI	15	BALEPHI-A	11
JHIMRUK	12	UPPER SANJEN	15
Total:	**622MW**	IKHUWA	19
		KABELI-A	38
		LOWER CHEPE	8
		MAIWA	14
		LOWER SANJEN	43
		BALEPHI-B	19
		TRISHULI3B	37
		UPPER MARSYANGDI	45
		Total:	**3766 MW**

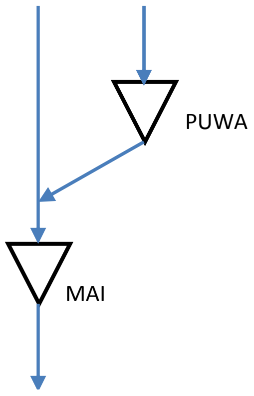
Other identified major projects can also be included in the expansion plan by discarding or lumping the contribution of smaller plants. For example,

Tamor storage: 530MW

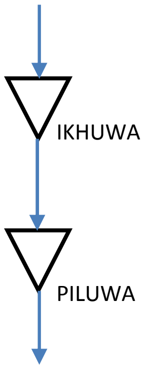
Uttar Ganga storage: 300MW

Upper Arun: 335MW

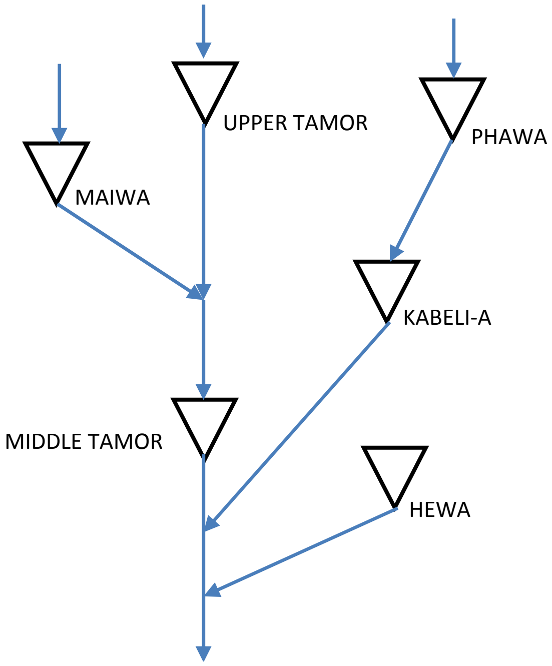
Cascades



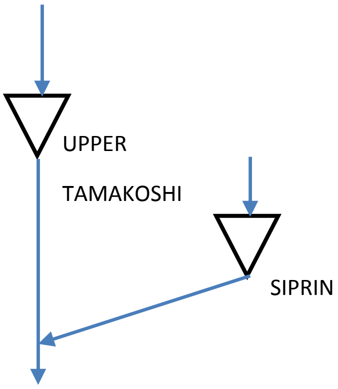
CASCADE 1



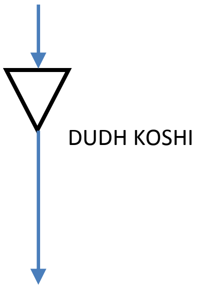
CASCADE 2



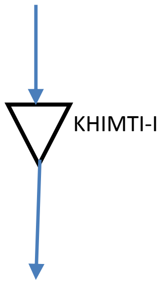
CASCADE 3



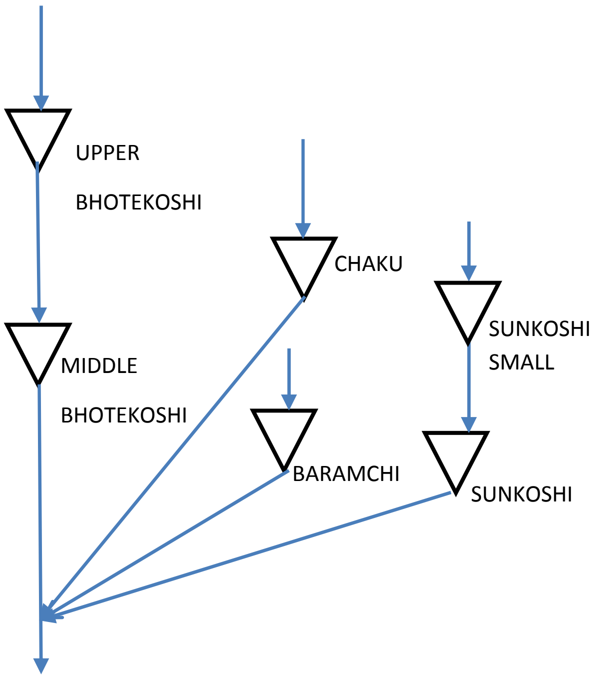
CASCADE 4



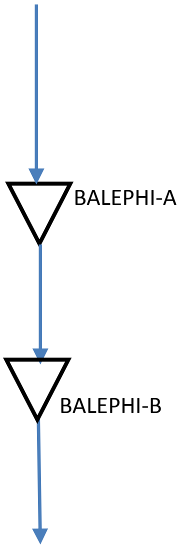
CASCADE 5



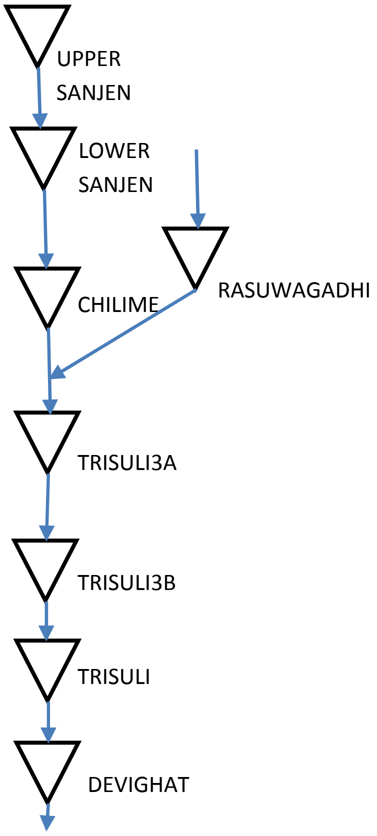
CASCADE 6



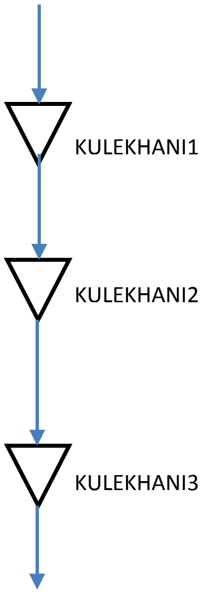
CASCADE 7



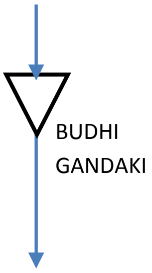
CASCADE 8



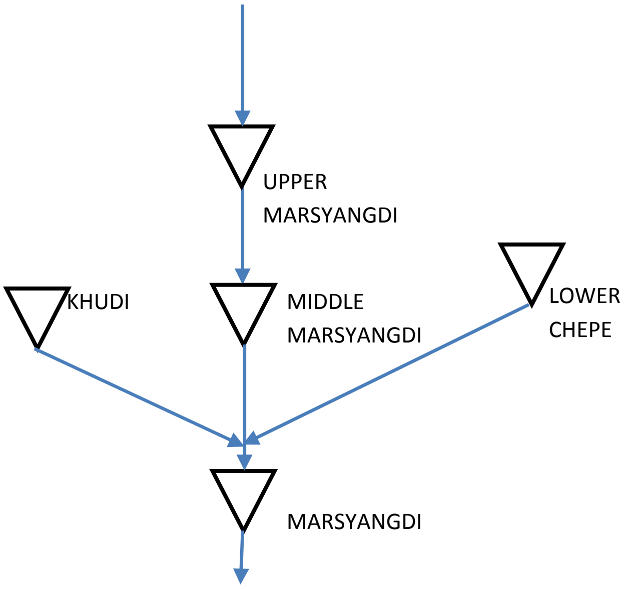
CASCADE 9



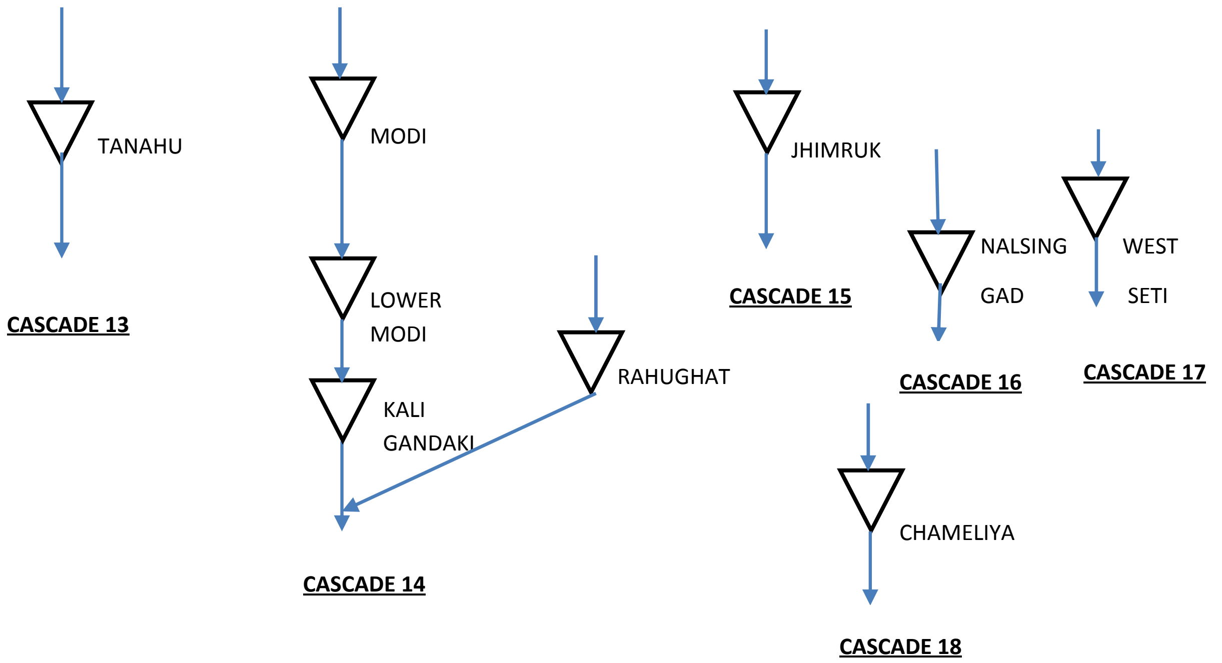
CASCADE 10



CASCADE 11



CASCADE 12



6.5 GENERATION AND CONSUMPTION SUBSYSTEM

Generation subsystem includes hydropower plants and thermal plants. In the sample case, 48 hydropower plants are considered, which include 42 ROR plants and 6 storage types of plants. Two existing thermal plants are also considered for sample case. These are:

- Hetauda: 10 MW
- Duhabi: 39.5

According to this scenario, the total installed capacity will be 4388MW by the end of 2030. The load forecast for 2030 is 4155 MW. Hence, this expansion plan will be sufficient to meet the energy demands for 20 year time horizon.

In consumption (load) subsystem, Nepal is considered as a single electric node. Fixed and secondary power demand for simulation year 2030 is taken in the scenario.

6.6 APPLICATION OF VALORAGUA

The lists of data and format for all the input data files have been described in chapter 4. The data and parameters of the sample case (done in year 2013/2014) is described here.

6.6.1 CADIR.dat

6.6.1.1 Basic data and parameters

- Simulation year considered = 2030
- Starting year of inflow data = 1980, ending year of inflow data = 2009
- Equal probability of all hydroconditions
- Number of load steps = 5 (maximum limit allowed in VALORAGUA)
- Number of electric node = 1 (Nepal as one node)
- Number of system (primary) demand =1, Annual energy demand = 18000 GWh
- Monthly breakdown of energy demand (%): obtained from auxiliary tool DIAGOPTM 8.4 8.4 8.5 8.5 8.7 8.6 8.6 8.2 8.1 8.2 7.8 8.0

- Number of secondary demand = 1, Average selling price = 9 Cts/KWh, Maximum variation = 1%, maximum power supply in each month = 105 MW (About 2.5% of peak demand 4155MW for year 2030)
- Maintenance team considered = 1 team each month for Duhabi and Hetauda

6.6.1.2 Thermal plants and imports data

- Two existing thermal power plant, Hetauda and Duhabi
- Import system: Possibility of 300MW until 2015 and up to 1000MW after the construction of 400kv transmission system, considered 1000 MW in total
- (No thermal addition in expansion)
- Energy not served option of 1000 MW (REST)
- Operation and maintenance (O & M) cost of thermal plants = 40Cents/KWh
- Cost of energy not served (ENS) = 55 Cents/KWh

According to a Report by USAID/SARI (2003), ENS = 0.14 USD/KWh (planned outage), 0.49 USD/KWh (unplanned interruptions)

Cost of using alternative such as diesel plant: about 30-40 cents/KWh (in 2013)

Cost of unserved energy: 30 cents/KWh (previous estimates of NEA) taken as lower range

As per load shedding of about 10 hours, cost of unserved energy = 80 Cents/KWh taken as higher range

Average of these two = 55 Cents/KWh (adopted in the model)

- Import system: Possibility of 300MW until 2015 and up to 800MW after the construction of 400kv transmission system
- O& M cost of import = 10Cents/KWh

Above values are fixed from various references.

6.6.1.3 Reservoir characteristics data and parameters

- For ROR plants, the storage volume of reservoir is considered to be 1 Mm3.
- For ROR project, si = 0, alpha = 0, beta = 1. For storage projects, these coefficients are found by regression from level-volume data.
- Storage bound, Evaporation, and release are set to zero due to unavailability of data.

6.6.1.4 Spillways, hydroplants and cascade definition data

- Design discharge = nominal flow
- Internal consumption fraction = 1%
- Forced outage rate = 5%
- Technical minimum = 0 m3/s
- Nominal head, nominal flow and minimum tail water level: taken from the database of hydroplants
- For PROR and storage plants, maximum discharge of each month is taken as design discharge. For ROR projects, if the mean flow of any particular month is less than design discharge, then the mean monthly flow of that month is taken as maximum flow.
- Components of each cascade is shown in cascade definition data.

6.6.1.5 Glimpses of CADIR.DAT

```
                                 ********* STUDY IDENTIFICATION ********
                DEPT. OF ELECTRICITY DEVELOPMENT
MAJOR PROJECT OPTM   2030 1980 2009    0    5    1    1
   0.04000   0.11000   0.18000   0.30000   0.37000
                         ********* ELECTRIC NODE IDENTIFICATION ********
 1
 NEPAL
 1.434 1.385 1.344 1.371 1.358 1.404 1.425 1.480 1.484 1.498 1.650 1.441
 1.225 1.283 1.275 1.252 1.257 1.286 1.224 1.287 1.290 1.239 1.418 1.310
 1.099 1.167 1.134 1.085 1.050 1.078 1.064 1.043 1.059 1.050 1.134 1.090
 0.941 0.945 0.958 0.988 0.953 0.938 0.934 0.950 0.949 0.961 0.907 0.957
 0.885 0.838 0.850 0.853 0.898 0.883 0.909 0.882 0.874 0.882 0.816 0.851
                             ********* SYSTEM DEMAND DEFINITION ********
 1
 DEM.1   1
18000.   8.4   8.4   8.5   8.5   8.7   8.6   8.6   8.2   8.1   8.2   7.8   8.0
                          ********* SECONDARY DEMAND DEFINITION ********
 1
S.DEM1   1
S.DEM1   9.00   0.01
   105
     0
                                    ********* MAINTENANCE TEAMS ********
 4
DUHABI    1    1    1    1    1    1    1    1    1    1    1    1
HETAUD    1    1    1    1    1    1    1    1    1    1    1    1
   IMP    0    0    0    0    0    0    0    0    0    0    0    0
  REST    3    3    3    3    3    3    3    3    3    3    3    3
                     ********* THERMAL POWER PLANTS AND IMPORTS ********
 4
DUHABI   1  6  6  1    6.5 30.0000 0.0100000    00.2000.100
        1.0 1.0 1.0 1.0 1.0
HETAUD   1  4  4  2    2.5 30.0000 0.0100000    00.2000.100
        1.0 1.0 1.0 1.0 1.0
   IMP   1  0  0  3 800.0  10.0000 0.0100000    00.0000.000
        1.0 1.0 1.0 1.0 1.0
  REST   1  4  8  2 1000.0 55.0000 0.0100000    00.2000.060
        1.0 1.0 1.0 1.0 1.0
DUHABI    6    6    6    6    6    6    6    6    6    6    6    6
DUHABI 0.17 0.17 0.17 0.17    0    0    0    0    0    0 0.17 0.17
```

```
HETAUD    4    4    4    4    4    4    4    4    4    4    4    4
HETAUD 0.25 0.25    0    0    0    0    0    0    0    0  .25  .25
   IMP    1    1    1    1    1    1    1    1    1    1    1    1
   IMP    0    0    0    0    0    0    0    0    0    0    0    0
  REST    4    4    4    4    4    4    4    4    4    4    4    4
  REST    0    0    0    0    0    0    0    0    0    0    0    0
                            ********* RESERVOIR CHARACTERISITCS ********
48
PUWA  01       1.0   1.  .90 .80000+03 .00000+00 .00000+00 .10000+01
MAI  02       1.0   1.  .90 .31660+03 .00000+00 .00000+00 .10000+01
IKHUWA  03       1.0   1.  .90 .15050+04 .00000+00 .00000+00 .10000+01
PILUWA  04       1.0   1.  .90 .75700+03 .00000+00 .00000+00 .10000+01
UTAMOR  05       1.0   1.  .90 .11700+04 .00000+00 .00000+00 .10000+01
MAIWA  06       1.0   1.  .90 .79971+03 .00000+00 .00000+00 .10000+01
MTAMOR  07       1.0   1.  .90 .68400+03 .00000+00 .00000+00 .10000+01
PHAWA  08       1.0   1.  .90 .89200+03 .00000+00 .00000+00 .10000+01
KABE-A  09       1.0   1.  .90 .55640+03 .00000+00 .00000+00 .10000+01
HEWA  10       1.0   1.  .90 .86200+03 .00000+00 .00000+00 .10000+01
UTAMAK  11       1.0   1.  .90 .20065+04 .00000+00 .00000+00 .10000+01
SIPRIN  12       1.0   1.  .90 .10500+04 .00000+00 .00000+00 .10000+01
DUDHK  13     687.0   1.  .36 .53000+03  .2453+03 .93000+00 .60000+00
…………………………………………………………………………………………………………………………………………….
…………………………………………………………………………………………………………………………………………….
   0                 STORAGE BOUNDS
0         HEIGHT EVAPORATION (MM)
   0             WATER RELEASE (HM3)
                                            ********* SPILLWAYS ********
48
  PUWA   1   2
   MAI   2   0
IKHUWA   3   4
PILUWA   4   0
UTAMOR   5   7
 MAIWA   6   7
MTAMOR   7   0
 PHAWA   8   9
KABE-A   9   0
HEWA  10   0
UTAMAK  11   0
SIPRIN  12   0
DUDHK  13   0
KHIM-1  14   0
```

```
U-BHOT  15  17

CHAKU  16  20

M-BHOT  17  20

BARAMC  18  20

SUNKOS  19  20

SUNKON  20   0

BALE-A  21  22

BALE-B  22   0

U-SANJ  23  24

L-SANJ  24  25

CHILIM  25  27

RASGAD  26  27

TRIS3A  27  28

TRIS2B  28  29

TRIS  29  30

DEVIGH  30   0

KULEK1  31  32

KULEK2  32  33

KULEK3  33   0

BUDHIG  34   0

UMARSY  35  36

MMARSY  36  39

KHUDI  37  39

LCHEPE  38  39

MARSYG  39   0

TANA  40   0

RAHU  41  44

MODI  42  43

LMODI  43  44

KGANDA  44   0

JHIMRK  45   0

NALSIN  46   0

WEST  47   0

CHAMEL  48   0
                                   ********* HYDRO POWER PLANTS ********
48

  PUWA   1    2  0 116.00 0.01   0.85   0.05   0.00 320.00   2.50 480.00

   MAI   2    0  0 1 8.89 0.01   0.90   0.05   0.00 121.60  16.00 195.00

IKHUWA   3    4  0 110.00 0.01   0.90   0.05   0.00 605.00   4.00 900.00

PILUWA   4    0  0 1 5.50 0.01   0.91   0.05   0.00 107.00   3.50 650.00

UTAMOR   5    7  0 120.00 0.01   0.90   0.05   0.00 470.00 105.00 700.00

 MAIWA   6    7  0 110.81 0.01   0.91   0.05   0.00 190.09   8.07 609.62
```

```
MTAMOR   7    0  0 1 7.50 0.01   0.86   0.05   0.00  84.00 105.00 600.00
 PHAWA   8    9  0 114.00 0.01   0.90   0.05   0.00 292.00   2.10 600.00
KABE-A   9    0  0 1 5.40 0.01   0.85   0.05   0.00 111.40  37.73 445.00
HEWA  10    0  0 1 5.50 0.01   0.85   0.05   0.00 212.00   8.12 650.00
UTAMAK  11    0  0 122.00 0.01   0.84   0.05   0.00 800.00  66.001206.50
SIPRIN  12    0  0 110.00 0.01   0.85   0.05   0.00 150.00   7.50 900.00
DUDHK  13    0  0 112.50 0.01   0.90   0.05   0.00 249.00 136.00 300.00
.......................................................................
.......................................................................
  PUWA  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5
  PUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
MAI  3.0  2.5  2.4  2.7  4.5 16.0 16.0 16.0 16.0 16.0  6.0  3.6
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UTAMOR105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0
UTAMOR  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 MAIWA  2.2  1.8  1.9  2.6  5.2  8.1  8.1  8.1  8.1  8.1  4.5  2.9
 MAIWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MTAMOR105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0
MTAMOR  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 PHAWA  1.2  1.0  1.1  1.5  2.1  2.1  2.1  2.1  2.1  2.1  2.1  1.6
 PHAWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KABE-A 11.0  9.2  9.3 13.2 26.0 37.7 37.7 37.7 37.7 37.7 22.4 14.2
KABE-A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
  HEWA  3.8  3.0  2.6  4.0  8.1  8.1  8.1  8.1  8.1  8.1  8.1  5.6
  HEWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
UTAMAK 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0
UTAMAK  0.1  0.1  0.1  0.1  0.0  0.0  0.0  0.0  0.0  0.0  0.1  0.1
SIPRIN  1.8  1.6  1.5  1.8  3.2  7.5  7.5  7.5  7.5  7.5  4.0  2.6
SIPRIN  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 DUDHK136.0136.0136.0136.0136.0136.0136.0136.0136.0136.0136.0136.0
 DUDHK 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
.......................................................................
.......................................................................
   0      (MANDATORY TEC. MINIMUM - M3/S)
                                ********* PUMPED STORAGE PLANTS ********
 0
                               ********* DEFINITION OF CASCADES ********
18
```

```
N.RESERVOIRS  2  2  6  2  1  1  6  2  8  3  1  5  1  4  1  1  1  1
N.TURB.PLANT  2  2  6  2  1  1  6  2  8  3  1  5  1  4  1  1  1  1
 N.SPILLWAYS  2  2  6  2  1  1  6  2  8  3  1  5  1  4  1  1  1  1
N.PUMPED STO  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

6.6.2 INFLOW.dat

- Monthly inflow data for 1980-2009 ($10^6 m^3$ (hectometer^3)) for 48 hydroplants

6.6.2.1 Glimpses of INFLOW.DAT

```
1980 2009
TRIBUTARY  INFLOWS  TO  PUWA KHOLA at PUWA (ILAM) ( HM3 )  1980 / 2009
   3.9   2.7   3.6   5.2  11.9  24.7  44.1  45.5  34.5  13.8   7.0   4.6
   3.3   2.3   2.3   4.1   8.1  19.2  44.7  61.4  32.4  12.0   6.2   4.0
   2.9   2.3   2.5   4.6   6.8  18.8  44.7  32.4  21.0   9.7   5.9   3.9
   4.7   3.4   3.0   2.6   5.9  14.4  75.1  36.8  37.2  16.5   7.8   5.2
   4.4   3.1   2.8   3.6   6.0  22.2  66.9  35.8  60.0  16.4   9.8   6.8
   5.0   4.4   3.7   3.7   7.1  13.9  38.5  36.4  36.7  29.4  12.0   7.4
   4.9   3.2   3.1   4.8   7.5  13.0  40.4  30.7  52.4  19.7   8.7   5.6
   3.9   2.9   3.6   4.0   5.9  11.6  55.2 117.7  47.1  26.8  11.2   6.9
   4.9   3.7   4.7   4.1   6.4  15.8  24.5  28.2  49.2  14.0   5.5   5.4
   5.0   3.9   4.2   3.1   8.0  25.3  35.2  28.6  38.9  18.1   7.9   6.0
   4.5   4.1   6.7  11.2  22.9  59.0  56.2  51.0  36.3  20.9   6.2   5.5
   6.8   4.9   5.3   5.5   6.9  25.2  58.2  51.0  44.7  10.8   6.5   4.5
   3.7   3.2   2.7   3.7   8.4   8.6  25.8  21.1  16.4  10.9   6.1   4.5
   4.3   3.0   2.8   5.7   6.6  12.8  25.4  34.6  20.7  13.9   8.5   6.0
20.9  20.1  17.0  10.4   6.5   4.9  66.9  35.8  60.0  16.4   9.8   6.8
   4.8   3.6   3.3   4.1   6.4  13.9  38.5  42.3  47.1  13.2   9.2   5.2
   7.7   2.6   2.5   2.2   4.8   9.4  42.4  43.6  22.4  10.4   4.6   3.3
   2.3   1.9   1.7   2.9   3.9  22.9  22.7 177.3 137.1  64.4  22.6  11.3
   5.5   5.1  11.2  15.5  13.6  22.5 117.7  78.1  87.4  38.0   9.3   6.2
   5.4   4.1   3.4   2.7   7.0  49.3 102.8 101.1  85.0  41.6  14.6   9.7
   9.9   8.1   6.1   7.7  19.5  31.4  41.8  50.6  48.8  29.6  15.0   7.7
   4.8   4.2   3.9   3.6  11.6  20.8  32.7  46.1  57.7  62.0  15.8   8.2
   5.3   3.9   3.5   6.7   6.4  15.8  93.6  36.4  36.7  16.6   6.7   3.2
   1.9   1.7   2.3   2.6   2.3  31.2  90.3  52.9  36.6  26.4   6.5   2.1
   3.6   2.1   2.3   2.6   7.9  25.6  73.0  30.1  43.7  28.3  10.3   5.2
   3.2   2.2   1.6   2.3   3.3   8.8  59.0  70.4  30.7  38.0   9.3   6.2
   5.9   5.3   5.3   7.7   8.5  24.3  52.5  41.4  49.8  21.8   5.7   2.3
   1.9   1.7   2.3   2.6   2.3  31.2  90.3  52.9  36.6  26.4   6.5   2.1
   3.6   2.1   2.3   2.6   7.9  25.6  73.0  30.1  43.7  28.3  10.3   5.2
   3.2   2.2   1.6   2.3   3.3   8.8  59.0  70.4  30.7  38.0   9.3   6.2
Similar format for all other remaining river stations
```

6.6.3 VALAGP.DAT

- Number of states of reservoir = 11,
- Initial storage = 50% of max. available storage
- Initial storage at next time = final storage of previous time
- Initial marginal value= 7-13 Cts/Kwh. The final value will be optimized by the model.
- Initial storage = zero.

6.6.3.1 Glimpses of VALAGP.DAT

```
**************** IDENTIFICATION AND STUDY OPTIONS *********************
 2030 1980 2009    1 11  0  0  1 18   0
 ****************   WATER   VALUE   FUNCTION       *********************
 13.00 12.00  12.00  12.00  11.00  11.00  11.00  10.00   9.00   8.00   7.00
 ****************        INITIAL STORAGES          *********************
  0.00
  0.00
  0.00
  0.00
0.00
```

6.6.4 MAINT.DAT

- Print out for hydro and thermal power allocation (indicated by key 1 in line 3 second value)
- Number of hydroconditions to be considered individually and in average = 0 (0 in this case).

6.6.4.1 Glimpses of MAINT.DAT

```
*****************   OPTIMIZATION AND PRINT OPTIONS   *******************
 2013    1    1                          IFASE1,IFASE2
    0    1    0    0    0
***************** HYDROLOGICAL CONDITIONS OPTIONS **********************
    0    0
 1985 1987
 2001 2002
```

6.6.5 RESEX.DAT

- Printing results of average of all hydroconditions for following components: electric node, secondary demand and exports, thermal power plants and imports, reservoirs, hydro turbine plants, pumping plants
- Printing monthly results

6.6.5.1 Glimpses of RESEX.DAT

```
   OUTPUT   FLAGS
 0001 2014
 0001 0001 0001 0001 0002 0002 0000
 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001
```

6.6.6 RESIM.DAT

- Printing of detail result of hydroplant such as number 09
- Printing output for load step 1 for following items: Water flow (10000 means print for first load step, no print for other load steps), head loss, net head, power output, turbined volume, energy generation, value of energy generation
- Printing output on year by year basis: discharged volume, energy generation, value of discharged water, value of energy generation, net benefit, gross head, average net head

6.6.6.1 Glimpses of RESIM.DAT

```
*++++++++      ITYPE ,IPLANT+++++++

0509

10000100001000010000100001000010000111110001010
```

6.6.7 VWASP.DAT

- Number of periods = 12
- Number of load steps = 5
- Load step number to compute peak characteristics = first
- Number of hydroconditions to be considered in WASP = 3 (wet, dry and mean)

6.6.7.1 Glimpses of VWASP.DAT

```
0012

JANUARY  FEBRUARY     MARCH     APRIL       MAY      JUNE

      JULY   AUAGUST SEPTEMBER   OCTOBER  NOVEMBER  DECEMBER

 0005 0001

 0003

       DRY 0005

 1980 1983 1988 1997 2009

       WET 0005

 1986 1995 1998 2000 2007

      MEAN 0020

 1981 1982 1984 1985 1987 1989 1990 1991 1992 1993

 1994 1996 1999 2001 2002 2003 2004 2005 2006 2008
```

6.6.7.2 MAINT.DAT

- Print out for hydro and thermal power allocation (indicated by key 1 in line 3 second value)
- Number of hydroconditions to be considered individually and in average = 0 (0 in this case).

6.6.7.3 Glimpses of MAINT.DAT

```
*****************   OPTIMIZATION AND PRINT OPTIONS   *******************
```

```
 2013    1    1                         IFASE1,IFASE2
    0    1    0    0    0
***************** HYDROLOGICAL CONDITIONS OPTIONS **********************
    0    0
 1985 1987
 2001 2002
```

6.6.7.4 RESEX.DAT

- Printing results of average of all hydroconditions for following components: electric node, secondary demand and exports, thermal power plants and imports, reservoirs, hydro turbine plants, pumping plants
- Printing monthly results

6.6.7.5 Glimpses of RESEX.DAT

```
 OUTPUT   FLAGS
 0001 2014
 0001 0001 0001 0001 0002 0002 0000
 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001
```

6.6.7.6 RESIM.DAT

- Printing of detail result of hydroplant such as number 09
- Printing output for load step 1 for following items: Water flow (10000 means print for first load step, no print for other load steps), head loss, net head, power output, turbined volume, energy generation, value of energy generation
- Printing output on year by year basis: discharged volume, energy generation, value of discharged water, value of energy generation, net benefit, gross head, average net head

6.6.7.7 Glimpses of RESIM.DAT

```
*++++++++      ITYPE,IPLANT+++++++
0509
10000100001000010000100001000010000111110001010
```

6.6.7.8 VWASP.DAT

- Number of periods = 12
- Number of load steps = 5
- Load step number to compute peak characteristics = first
- Number of hydroconditions to be considered in WASP = 3 (wet, dry and mean)

6.6.7.9 Glimpses of VWASP.DAT

```
0012
JANUARY FEBRUARY     MARCH     APRIL       MAY      JUNE
JULY   AUAGUST SEPTEMBER   OCTOBER NOVEMBER DECEMBER
 0005 0001
 0003
```

```
      DRY 0005
1980 1983 1988 1997 2009
      WET 0005
1986 1995 1998 2000 2007
     MEAN 0020
1981 1982 1984 1985 1987 1989 1990 1991 1992 1993
1994 1996 1999 2001 2002 2003 2004 2005 2006 2008
```

6.6.8 Output of VALORAGUA

6.6.8.1 RESEX output

The main output of the VALORAGUA is depicted in the RESEX. In the output table, the annual values for the average of 30 years period are given. Monthly and yearly results can also be printed by setting different key in RESEX.dat. The salient features of the output are summarized below.

Power balance

The fixed energy demand for 2030 was assigned as 1800GWh in CADIR data file. According to the result of VALORAGUA, 24896.47Gwh will be generated by hydroelectric power and 181.06 GWh by thermal output. Total energy generated is 25077.53GWh. After satisfying fixed and secondary demand, 6341.259 Gwh will be excess. The peak power produced in load step 1 is 2953.55 MW as per LDC. Marginal cost of generation in the hydro-thermal mixed system is 2.53 Cents/Kwh

Water balance

Water balance is computed by

Final storage = initial storage + inflows -outflows – losses

Evaporation loss and mandatory release are not considered in the study. Outflows represent downstream turbined volume and spilled volume. In ROR type project, as inflow is equal to outflow, the initial storage becomes equal to final storage. In storage type projects, inflow is not equal to outflow. Therefore, there is some variation in initial and final storage. For the whole system, the initial storage is 2819.84 Mm3 and final storage is 2842.98 Mm3. The turbined volume of water is 43098.1 Mm3.The marginal value of water for the whole system is 0.167 Cents/m^3.

Hydroelectric power plants

The power generation of each plant as well as other information are shown in the result of power plants. The utilization factor is 58.23%. Energy generated is only 58.23% of maximum operationally feasible energy generation. Average energetic coefficient (ratio of energy generated to water flow) is 0.578 Kwh/m3. The marginal value of water for hydroelectric plant is 1.149 cents/m3.

If the objective is to show the power generated on year by year basis, the key in the input data file RESIM.dat should be changed and the module RESIM should be re-run.

6.6.8.2 RESIM output

RESIM output shows the output for a particular plant on year by year basis, which is useful to analyze the various aspects of individual plant.

6.6.8.3 VWASP output

VWASP output shows the base capacity (MWB), available capacity (MWC), inflow energy (EA) and minimum requirements for base load generation (EMIN). EA, EMIN and MWC are used in WASP model.

6.6.8.4 RESEX.PRN

```
1                                                                                                                     PAGE   1
                   DEPT. OF ELECTRICITY DEVELOPMENT
STUDY : MAJOR PROJECT OPTM
   PROGRAM   RESEX



ANNUAL  VALUES                                                                       YEAR
          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                2030


                                                      ELECTRIC NODE

                                        POWER BALANCE EQUATION - MARGINAL COSTS


                                                          HYDRO                NET
                            FIXED   SECONDARY  THERMAL  ELECTRIC   PUMPING    TRANS              MARGINAL
   ELECTRIC   LOAD          POWER     POWERPOWERPOWERPOWER    PORTED     POWER    COST OF    VALUE OF
     NODE     STEP         DEMAND    DEMAND    OUTPUT    OUTPUT   CONSUMPT.   POWER    EXCESS   GENERATION GENERATION
                             MW        MWMWMWMWMWMW      CTS/KWH    MILL.US$


   SYSTEM       1         2953.55     78.06    -46.06  -3332.31      0.00      0.00  -346.771      2.978     35.255
                2         2625.44     79.80    -37.31  -3168.32      0.00      0.00  -500.392      2.853     88.129
                3         2234.75     82.19    -25.91  -2953.64      0.00      0.00  -662.612      2.709    127.287
                4         1949.21     85.29    -16.85  -2784.63      0.00      0.00  -766.985      2.471    181.912
```

```
                5         1785.40     86.50    -13.52  -2684.35      0.00      0.00  -825.969      2.311    202.106


            TOTAL (GWH)  17997.91    738.37   -181.06 -24896.47      0.00      0.00 -6341.259      2.531    634.690
1                                                                                                                     PAGE   2
                   DEPT. OF ELECTRICITY DEVELOPMENT
STUDY : MAJOR PROJECT OPTM
   PROGRAM   RESEX



ANNUAL  VALUES                                                                       YEAR
          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                2030


                                                 SECONDARY DEMAND SYSTEM

                                                      SUMMARY REPORT



                                                                           UNITARY
           SECONDARY   SUPPLIED  UTILIZATION  TOTAL     TOTAL      NET       NET
            DEMAND      DEMAND     FACTOR    BENEFIT    COST     BENEFIT   BENEFIT
                          GWH         %       M US$     M US$     M US$    US$/KW

           S.DEM1      738.37       80.27    66.128    13.729    52.400   499.05

           TOTAL       738.37       80.27    66.128    13.729    52.400   499.05
1                                                                                                                     PAGE   3
```

```
                   DEPT. OF ELECTRICITY DEVELOPMENT

STUDY : MAJOR PROJECT OPTM

   PROGRAM   RESEX




ANNUAL  VALUES                                                                                   YEAR

          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                            2030




                                         SECONDARY DEMAND


                                   POWER SUPPLIED BY LOAD STEP


           =================================================================

           LOAD STEP                 1        2        3        4        5

DURATION   (HOURS)       350.     964.    1577.    2628.    3241.

TOTAL TIME (HOURS)       350.    1314.    2891.    5519.    8760.

           =================================================================


                      SUPPLIED

           SECONDARY   ENERGY                   POWER SUPPLIED

            DEMAND      GWH                           MW


            S.DEM1    738.369     78.063   79.804   82.187   85.292   86.504


            SYSTEM    738.369     78.063   79.804   82.187   85.292   86.504
```

```
1                                                                                                                     PAGE   4
                   DEPT. OF ELECTRICITY DEVELOPMENT
STUDY : MAJOR PROJECT OPTM
   PROGRAM   RESEX



ANNUAL  VALUES                                                                       YEAR
          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                2030


                                                   THERMAL POWER SYSTEM

                                                      SUMMARY REPORT

            THERMAL   VARIABLE                           TOTAL
             POWER     UNITARY    TOTAL     VALUE OF   VARIABLE     NET    UNITARY  UTILIZATION
             PLANT      COST    GENERATION GENERATION    COSTS    BENEFIT  BENEFIT    FACTOR
                       CTS/KWH     GWH      MILL.US$   MILL.US$  MILL.US$  US$/KW        %

           DUHABI     30.0000       0.00       0.00      0.00      0.00      0.00        0.00
           HETAUD     30.0000       0.00       0.00      0.00      0.00      0.00        0.00
           IMP        10.0000     181.06      18.54     18.16      0.38      0.47        2.58
           REST       55.0000       0.00       0.00      0.00      0.00      0.00        0.00

           SYSTEM     10.0318     181.06      18.54     18.16      0.38                  2.48*

           --------------------------------------------------------------------------------
```

```
             * DOES NOT INCLUDE THE UNSERVED ENERGY   REST

1                                                                                                                     PAGE   5

                   DEPT. OF ELECTRICITY DEVELOPMENT

STUDY : MAJOR PROJECT OPTM

   PROGRAM   RESEX




ANNUAL  VALUES                                                                                    YEAR

          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                            2030




                                       THERMAL POWER PLANTS


                                    POWER OUTPUT BY LOAD STEP



           =================================================================

           LOAD STEP                1        2        3        4        5

DURATION   (HOURS)       350.     964.    1577.    2628.    3241.

TOTAL TIME (HOURS)       350.    1314.    2891.    5519.    8760.

           =================================================================


            THERMAL   ENERGY

POWER  GENERATION                  POWER OUTPUT

             PLANT     GWH                          MW
```

```
            DUHABI      0.000      0.000    0.000    0.000    0.000    0.000

            HETAUD      0.000      0.000    0.000    0.000    0.000    0.000

            IMP       181.061     46.064   37.313   25.908   16.852   13.521

            RESTTH      0.000      0.000    0.000    0.000    0.000    0.000


            SYSTEM    181.061     46.064   37.313   25.908   16.852   13.521
1                                                                                                                     PAGE   6
                   DEPT. OF ELECTRICITY DEVELOPMENT
STUDY : MAJOR PROJECT OPTM
   PROGRAM   RESEX




ANNUAL  VALUES                                                                       YEAR
          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                 2030



                                               HYDRAULIC NODES (RESERVOIRS)


                                   WATER BALANCE EQUATION - WATER VALUES IN MILLION M3


                         UP      DOWN      UP              DOWN      UP      DOWN                               MARGINAL
             INITIAL   STREAM   STREAMSTREAM  TRIBU-   STREAM   STREAMSTREAM  EVAPOR.   MANDATORY  FINAL  VALUE OF VALUE OF
 RESERVOIR   STORAGE  TURBINED  PUMPED  SPILLED   TARY   TURBINED  PUMPED  SPILLED   VOLUME   RELEASES  STORAGE  WATER    INFLOW
                       VOLUME   VOLUMEVOLUME  INFLOW   VOLUME   VOLUMEVOLUME                               CTS/M3  MILL.US$


 PUWA          1.00     0.00     0.00     0.00   240.60   -57.09     0.00  -184.03    0.000      0.00     1.00    0.354    0.853
 MAI           1.00    57.09     0.00   184.03   465.89  -234.56     0.00  -465.06    0.000      0.00     1.00    0.001    0.004
```

……

……

```
SYSTEM     2819.84 14644.27     0.00 73918.05 104019.3 -43098.1     0.00 -148494.    0.000      0.00  2842.98    0.167  321.527
1                                                                                                                     PAGE   7
                   DEPT. OF ELECTRICITY DEVELOPMENT
STUDY : MAJOR PROJECT OPTM
   PROGRAM   RESEX



ANNUAL  VALUES                                                                       YEAR
          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                2030


                                                HYDROELECTRIC POWER PLANTS

                                                    SUMMARY REPORT


  HYDRO   AVERAGE   AVERAGEMARGINAL  VALUEVALUE
  POWER     NET    ENERGETIC TURBINED    ENERGY   UTILIZATION VALUE OF    OFOF       NET    UNITARY
PLANT     HEAD     COEF.    VOLUME   GENERATION   FACTOR     WATER    WATER    GENERATION BENEFIT  BENEFIT
             M      KWH/M3   MILL.M3      GWH          %       CTS/M3  MILL.US$   MILL.US$  MILL.US$ US$/KW

 PUWA      320.00     0.733    57.09      41.85       85.27    1.484     0.85       1.22     1.22    217.90
```

```
 MAI       121.60     0.295   234.56      69.18       94.23    0.002     0.00       0.80     0.80     95.88
```

……

……

```
 SYSTEM    510.30     0.578 43098.10   24896.47       58.23    1.149   495.19     616.15   616.15    126.24
1                                                                                                  PAGE   8
                   DEPT. OF ELECTRICITY DEVELOPMENT
STUDY : MAJOR PROJECT OPTM
   PROGRAM   RESEX



ANNUAL  VALUES                                                                                YEAR
          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                         2030



                                    HYDROELECTRIC POWER PLANTS

                                    POWER OUTPUT BY LOAD STEP

           =================================================================
           LOAD STEP                1        2        3        4        5
DURATION   (HOURS)       350.     964.    1577.    2628.    3241.
TOTAL TIME (HOURS)       350.    1314.    2891.    5519.    8760.
```

```
           =================================================================


                       ENERGY
           TURBINING GENERATION                  POWER OUTPUT
             PLANT      GWH                           MW


            PUWA       41.851      4.908    4.866    4.808    4.762    4.735
            MAIIK      69.180      8.087    8.057    7.989    7.900    7.783
……………………………………………………………………………………………………………………………………………………..
……………………………………………………………………………………………………………………………………………………..



            SYSTEM   24896.47   3332.314 3168.319 2953.642 2784.632 2684.352
1                                                                                                                                    PAGE   9
                   DEPT. OF ELECTRICITY DEVELOPMENT
STUDY : MAJOR PROJECT OPTM
   PROGRAM   RESEX




ANNUAL  VALUES                                                                                    YEAR
          MEAN OF HYDRO CONDITIONS: 1980 - 2009                                                             2030



                                    HYDROELECTRIC POWER PLANTS
```

```
                                      WATER FLOW BY LOAD STEP


           =================================================================

           LOAD STEP                1        2        3        4        5

DURATION   (HOURS)       350.     964.    1577.    2628.    3241.

TOTAL TIME (HOURS)       350.    1314.    2891.    5519.    8760.

           =================================================================


             HYDRO    TURBINED

             POWER     VOLUME                     WATER FLOW

             PLANT    MILL.M3                        M3/S


            PUWA       57.093       1.860    1.844    1.822    1.804    1.794

            MAIIK     234.556       7.616    7.588    7.525    7.440    7.330
```

……

……

```
            SYSTEM   43098.10   1481.032 1442.919 1393.760 1353.363 1329.146
```

6.6.8.5 Glimpses of VWASP output

```
1                                                                                                                                          PAGE   1

                     DEPT. OF ELECTRICITY DEVELOPMENT

STUDY : MAJOR PROJECT OPTM

   PROGRAM   VWASP
```

```
                                                          STUDY YEAR     :      2030
                                                          HYDRO CONDITION:       DRY
                                                          PERIOD         :   JANUARY
                                                          - 1980- 1983- 1988- 1997- 2009
                HYDROELECTRIC POWER PLANTS -- TURBINE UNITS

                         DATA PREPARATION FOR WASP

         HYDRO
         POWER            MWB        MWC         EA       EMIN
         PLANT           (MW)       (MW)      (GWH)      (GWH)

         PUWA            3.73       4.05       2.82       2.72
         MAI             2.33       3.03       1.92       1.70

         IKHUWA          9.40      10.01       7.06       6.86
         PILUWA          2.51       2.51       1.87       1.83

         UTAMOR         88.84     141.90      73.77      64.86
         MAIWA           2.01       2.12       1.51       1.47
         MTAMOR         37.22      39.34      27.97      27.17
```

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

6.7 APPLICATION OF WASP

The VALORAGUA is useful for the short term optimization, in which the focus will not be on long term expansion. If there is a need to optimize the economic expansion plan for power system in the long term (up to 30 years), WASP model will be useful. The model minimizes the present value of the total system cost (capital and running). If the output of the VALORAGUA is linked to the WASP model, then the modeling tasks starts from forecasting load, interpreting LDC, designing hydronetwork, assembling all data required for VALORAGUA; and data of thermal plants, planned configurations for expansion plan, and cost data of hydroplants for WASP. In this case, the power output and energy generation data of hydroplants will be taken from the VWASP output of the VALORAGUA. If WASP model is run as a standalone model, then the power output and energy generation data should be prepared from available data and information.

WASP model for the sample case is described here.

In order to link the outputs, same number of hydroplants as used in VALORAGUA is considered in WASP model. In 48 plants, 20 are existing plants (fixed system) and remaining 28 are considered as candidate plants for expansion. No thermal expansion is considered. Data requirements and formats of all input files are as described in chapter 3.

Following parameters are adopted in the study.

- Discount rate for domestic and foreign cost is 10%.
- Plant life of thermal is considered to be 25 year.
- Plant life of hydro is considered to be 50 year.
- Interest during construction is taken as 10%.
- Depreciation on capital cost for hydro plant is 3% per annum (25% domestic and 75% foreign)
- Critical value of LOLP is taken as 25% as an initial value so that the model runs smoothly even for worse situation. The final value for each year is optimized by model.
- Cost of energy not served is the same value as adopted in VALORAGUA

Data and parameters for different modules of WASP

6.7.1 Loadsys

- Simulation period = 2011-2030 (20 years time horizon)
- Periods per year = 12
- Cosine terms in Fourier approximation = 50
- Annual peak load for 2011-2030
- Ratio of the peak load in each period expressed as a fraction of the annual peak (after key 2)
- Coefficients of fifth order polynomial representation of LDC (after key 3)

```
          Demonstration Case (Variable Expansion)

12  50   0

967.1  2011

   2

   0.951   0.915   0.894   0.906   0.910   0.926   0.928   0.910   0.907   0.934

   0.916   1.000

   3

      1.0000     -2.8852      9.5950    -15.3243    10.83504     -2.7618
```

```
     1.0000     -1.2649      2.0056     -3.3404      4.1922     -2.0569
     1.0000     -1.3636      2.5381     -4.5041      5.3152     -2.4539
     1.0000     -1.7891      5.2904     -9.8477      9.4224     -3.5068
     1.0000     -1.8388      5.5570    -10.4326      9.9904     -3.7090
     1.0000     -3.1548     11.5001    -20.2684     16.8152     -5.3767
     1.0000     -2.8302      8.2488    -10.5065      5.3813     -0.7455
     1.0000     -3.4718     13.7085    -26.9957     25.1686     -8.8759
     1.0000     -3.2952     11.9500    -22.0191     19.6319     -6.7215
     1.0000     -3.5642     13.5949    -25.7003     23.1841      -7.971
     1.0000     -3.5642     13.5949    -25.7003     23.1841     -7.9710
     1.0000     -2.2994      5.4637     -6.1302      3.1947      -.7489
   1
1056.90  2012
   1
 ..............................................................................
 ..............................................................................
4155.62  2030
   1
```

6.7.1.1 Fixsys

- Two thermal plants: HETAUDA and DUHABI
- Two import systems: IMPORT1 (300MW), IMPORT2 (200MW)
- Two composite hydroplants
- HYD1: Plant with capacity less than or equal to 45MW
- HYD2: Plant with capacity greater than 45MW
- Number of periods per year = 12
- Number of hydro-conditions = 3
- Fixed operating and maintenance costs of hydroelectric= 2.1 USD/KW month
- Probability of hydro-conditions = 20% (dry), 20% (wet), 60% (mean)
- Period inflow energy (GWh) of the hydro project, Minimum generation in base in the period (GWh), Available capacity in period (MW) of the project taken from the output of VWASP of VALORAGUA

FIXSYS.dat

```
           Demonstration Case (Variable Expansion)             4
   0 HETU HET THERMAL PLANTS
   1 MULT MULTIFUEL PLANTS
   2 PRC1 PURCHASE1
   3 PRC2 PURCHASE2
     HYD1 HYDRO PLANTS GROUP 1
     HYD2 HYDRO PLANTS GROUP 2
2011  12   4   3  HYD1   2.1  HYD2   2.10.20000.20000.6000
HETU  1   3.  10.  2180.  2010. 240.2160.  0 0  20. 55  10.        5.3  2.6
```

```
        0.        0.        0.
MULT  6   1.  6.5  2180.  2010. 240.2160.  1 0  20. 55  25.        5.3  2.6
        0.        0.        0.
PRC1  1   1. 300. 10000. 10000.   0. 638.  3 0  10. 10  20.         0.   0.
        0.        0.        0.
PRC2  1   1. 200. 10000. 10000.   0. 638.  3 0  10. 10  30.         0.   0.
        0.        0.        0.
 0 0       0.0       1.0 SO2 NOx 1
   0
   0
   2
PUWA  HYD1     6     0
2.8  2.7  4.0  3.5  3.4  4.9  3.3  3.2  4.7
2.0  2.0  3.4  2.8  2.7  4.5  2.5  2.4  4.0
2.2  2.0  3.2  2.8  2.7  4.1  2.5  2.4  3.6
2.5  2.5  3.8  3.5  3.5  5.0  3.0  3.0  4.4
3.6  3.5  5.0  4.0  3.9  5.5  4.2  4.1  5.8
4.5  4.4  6.2  4.5  4.4  6.2  4.3  4.3  6.1
4.6  4.5  6.2  4.7  4.6  6.3  4.5  4.5  6.1
4.6  4.5  6.2  4.7  4.6  6.3  4.6  4.5  6.2
2.7  2.7  3.8  2.7  2.7  3.8  2.7  2.6  3.7
2.2  2.2  3.0  2.0  2.0  2.8  2.5  2.5  3.4
4.4  4.4  6.2  4.3  4.2  6.0  4.3  4.2  6.0
3.9  3.8  5.4  3.7  3.6  5.1  3.6  3.5  5.1
   2
.............................................................................................................................
.............................................................................................................................
JMRK  HYD1    12     0
4.5  4.4  6.0  4.1  4.0  5.8  4.2  4.1  5.9
3.7  3.6  5.8  3.6  3.6  5.9  3.6  3.6  5.8
3.2  3.0  4.5  3.1  3.0  4.5  3.1  2.9  4.5
2.8  2.7  4.4  2.8  2.7  4.4  2.6  2.4  4.4
2.7  2.5  4.3  2.8  2.6  4.3  2.6  2.5  4.1
6.9  6.8  9.5  8.7  8.6 12.0  7.4  7.4 10.9
8.9  8.8 12.0  8.9  8.8 12.0  8.9  8.8 12.0
8.9  8.8 12.0  8.9  8.8 12.0  8.9  8.8 12.0
8.9  8.8 12.0  8.9  8.8 12.0  8.9  8.8 12.0
8.9  8.8 12.0  8.9  8.8 12.0  8.9  8.8 12.0
5.7  5.6  8.6  5.7  5.6  8.6  4.9  4.9  7.7
```

```
5.5  5.4  7.5  5.3  5.1  7.3  4.7  4.6  6.8
   1                    (end of year  2011)
..............................................................................
..............................................................................
   1                    (end of year  2030)
```

6.7.1.2 Varsys

- Thermal addition not considered (with zero capacity for THERM, MULT)
- IMPORT(500MW for expansion) (The import including Fixsys and Varsys is 800MW as specified in VALORAGUA)
- Two composite hydroplants
- HYD1: Plant with capacity less than or equal to 45MW
- HYD2: Plant with capacity greater than 45MW
- Number of periods per year = 12
- Number of hydro-conditions = 3
- Fixed operating and maintenance costs of hydroelectric= 2.1 USD/KW month
- Probability of hydro-conditions = 20% (dry), 20% (wet), 60% (mean)
- Period inflow energy (GWh) of the hydro project, Minimum generation in base in the period (GWh), Available capacity in period (MW) of the project taken from the output of VWASP of VALORAGUA

VARSYS.dat

```
           Demonstration Case (Variable Expansion)
      12   3   3  HYD1   2.1  HYD2   2.10.20000.20000.6000             16 12  0
THRM     10. 000.  3590.  2650. 500.2500.  1 0  20. 37 12.5        2.8  2.6
       0.0       0.0       0.0
MULT     10. 000.  2180.  2010. 240.2160.  3 0  20. 55  20.        5.3  2.6
       0.0       0.0       0.0
PRCH      1. 300. 10000. 10000.   0. 638.  415  10.  0  25.        0.0  0.0
       0.0       0.0       0.0
 0                        SO2 NOx 1
   0
   0
BARA  HYD1     4     0  2015
0.6  0.5  0.8  0.6  0.6  0.8  0.5  0.5  0.8
0.5  0.5  0.8  0.5  0.5  0.8  0.5  0.4  0.8
0.3  0.3  0.4  0.3  0.3  0.4  0.3  0.3  0.4
0.6  0.6  0.8  0.6  0.6  0.8  0.5  0.5  0.8
0.7  0.6  1.2  0.9  0.9  1.3  0.7  0.7  1.2
1.1  1.1  1.7  1.5  1.4  2.0  1.2  1.1  1.7
2.7  2.7  3.7  2.8  2.8  3.8  2.4  2.4  3.4
2.8  2.8  3.8  2.0  1.9  2.6  2.8  2.7  3.7
```

```
2.0  2.0  2.8  2.7  2.6  3.7  2.7  2.6  3.7
1.3  1.3  1.8  0.9  0.9  1.2  1.4  1.4  2.0
0.7  0.7  1.0  0.6  0.6  1.0  0.6  0.6  0.9
0.5  0.4  0.8  0.4  0.3  0.8  0.5  0.5  0.8
KUL3  HYD1    14     0  2015
2.8  2.6  4.5  5.4  5.2  7.8  7.4  7.3 10.3
4.3  4.2  6.8  5.5  5.4  8.7  7.5  7.5 10.9
5.5  5.3  7.8  6.7  6.5  9.3  9.7  9.5 13.0
6.5  6.5  9.4  7.4  7.4 10.7  9.7  9.5 13.0
5.9  5.7  8.3  5.5  5.4  7.7  5.0  4.8  7.3
7.0  7.0  9.7  8.8  8.7 12.2  5.4  5.3  8.4
9.7  9.5 13.0  9.7  9.5 13.0  6.9  6.7  9.6
9.7  9.5 13.0  9.7  9.5 13.0  7.7  7.8 11.0
5.0  5.0  6.9  5.0  5.0  6.9  5.0  5.0  6.9
5.1  5.0  6.9  6.0  5.9  8.1  5.3  5.2  7.2
4.2  4.0  6.9  5.2  5.2  8.1  5.3  5.3  7.9
3.1  2.9  4.8  4.7  4.5  6.9  5.3  5.1  7.6
```

……

……

6.7.1.3 *Congen*

- Minimum and maximum permissible reserve margin (% of peak load) in critical period = -30%, 30% (as initial value).The values are fixed by iterations so that the model configurations of all year are generated.
- Based on addition of plants in varsys, year by year configuration is assigned. 16 type 1 and 12 type 2 pants will be added by 2030.

```
      Demonstration Case (Variable Expansion)            0
4
   -30        30
8
1
2
0   0   0   0   0
3
0   0   0   0   0
1          (END OF YEAR  2011)
2
0   0   0   0   0
3
0   0   0   0   0
1          (END OF YEAR  2012)
2
```

```
   0   0   0   0   0
   3
   0   0   0   0   0
   1           (END OF YEAR  2013)
   2
   0   0   0   0   0
   3
   0   0   0   0   0
   1           (END OF YEAR  2014)
   2
   0   0   0   4   0
   3
   1   1   1   1   0
   1           (END OF YEAR  2015)
   2
   0   0   0   6   0
   3
   1   1   1   0   1
   1           (END OF YEAR  2016)
……………………………………………………………………………………………………
……………………………………………………………………………………………………
2
   2   2   2  16  12
   3
   0   0   0   0   0
   1           (END OF YEAR  2030)
```

6.7.1.4 Mersim

- Data type 2 shows loading order instructions, multiplier of period peak load (PKMW) for calculating the required spinning reserve, and loading order calculation option. Type 5 record shows number of Fourier coefficients, which is 50.

MERSIM.dat

```
          Demonstration Case (Variable Expansion)                0       0
   2
  1.0         0   -1
   4
   0
   5
  50
   1
   1
   1
```

```
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
   1
```

6.7.1.5 Dynpro

- First year of study, base year for cost discounting calculation and cost escalation calculation: 2011
- Single domestic discount rate and foreign discount rate = 10%
- Plant life of thermal = 25 year
- Plant life of hydro = 50 year
- Interest during construction = 10%
- The capital cost of project is obtained from the feasibility study reports, web sites and references. Depreciation on capital cost for hydro plant is 3% per annum (25% domestic and 75% foreign)
- Critical value of LOLP (data type 12) = 25% as an initial value (to be optimized by model)
- Cost of energy not served (type 11) = 55 cents/kwh (similar to VALORAGUA).

DYNPRO.dat

```
           Demonstration Case (Variable Expansion)              0   2
 2011 2011 2011   20
       10.       10.
   2
    100.    900.     25.      0.       0.      10.      3.                THRM
    100.   1400.     25.      0.       0.      10.      3.                MULT
      0.      0.     25.      0.       0.      10.      2.                PRCH
                     50.
    630.   1890.                               10.      5.                BARA
    720.   2170.                               10.      5.                KUL3
…………………………………………………………………………………………………………………………………………..
…………………………………………………………………………………………………………………………………………..
                     50.
```

```
    930.   2780.                          10.      5.               UMSY
    360.   1090.                          10.      5.               UTAK
.........................................................................................
.........................................................................................
  13
  10
  16
   1
  11
    0.55       0       0
  12
    25
   1                                                    (End of year 2011)
   1                                                    (End of year 2012)
.........................................................................................
.........................................................................................
   1                                                    (End of year 2030)
```

6.7.1.6 Reprobat

Following print out options (Type 2 data) are assigned in Reprobat.

Load system description (LOADSY), fixed system description (FIXSYS), variable system description (VARSYS), constraints in configuration generator module (CONGEN), economic parameters and additional constraints (DYNPRO), expected cost of operation (MERSIM)

REPROBAT.dat

```
            Demonstration Case (Variable Expansion)
 2011 2030 2011 2030
   2
   1   2   3   4       6   0   0
   3
   0   0   0
   5
N    3/9/2014
N
   6
   1
```

6.7.2 Base Case Output of WASP

6.7.2.1 Output of optimization module DYNPRO

The output of DYNPRO for sample case is given in the following pages. After the given data part and objective function computation part, the output displays the solution for least cost expansion. The net present worth value of each year is computed from the construction costs, salvage value, operation cost and energy not served cost, LOLP and configuration of each year. The LOLP value for 2015 to 2030 is in the range of 0.016% to 18.709%. From 2011-2014 (past and current year), only 20 existing plants are in place. Therefore, the LOLP increases during this period.

6.7.2.2 Reprobat output

Reprobat shows the summary of data on load, fixed system, variable system, configurations, capital costs, constraints and parameters, and cost of operation. As per load forecast, the energy requirement for 2030 is 22270.6 GWh. Base load and peak load is displayed from the output of fixsys and varsys in the report as per the configuration.

Dynpro output

……………………………………………………………………………………………………….

………………………………………………………………………………………………………..

```
SOLUTION #  1 VARIABLE ALTERNATIVES BY YEAR

  YEAR------ PRESENT WORTH COST OF THE YEAR ( K$ )------  OBJ.FUN.  LOLP  THRM    PRCH    HYD2

CONCST    SALVAL    OPCOST    ENSCST     TOTAL   (CUMM.)    %       MULT    HYD1

  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - -

  2030    149961    136211     42871        25     56646   4129140  0.025   2   2   2  16  12

  2029    590837    487414     43773        15    147211   4072494  0.016   2   2   2  16  11

  2028         0         0     96603     14370    110973   3925282  5.454   2   2   2  16   8-

  2027     76170     49570     91956      6917    125474   3814309  2.854   2   2   2  16   8

  2026    172362    106462     85174      8420    159494   3688836  3.243   1-  1-  2+ 16   8

  2025         0         0     93778      8569    102347   3529342  3.092   1-  1-  2+ 16   7-

  2024         0         0     89627      4368     93995   3426994  1.595   1-  1-  2+ 16   7-

  2023   1285551    593827     85409      2114    779248   3333000  0.810   1-  1-  2+ 16   7

  2022         0         0     93190      2528     95718   2553752  0.894   1-  1-  2+ 16   5

  2021    201832     76750     88467      1312    214862   2458035  0.459   1-  1-  2+ 16   5

  2020     75417     26012    101181      1389    151976   2243173  0.450   1-  1-  2+ 15   3-

  2019     31993     10007     98471      6674    127131   2091197  1.890   1-  1-  1- 13-  3-

  2018    210805     59776     93899      3809    248738   1964066  1.077   1-  1-  1- 11-  3

  2017    686203    162807    103037      3327    629760   1715328  0.915   1-  1-  1-  8-  2-

  2016     62390     14528    143284     19117    210264   1085569  4.169   0   0   1+  6   0

  2015    152442     32151    136433     12443    269167    875305  2.759   0   0   1+  5+  0

  2014         0         0    126322     88367    214689    606138 18.709   0   0   0   0   0

  2013         0         0    115084     51123    166207    391449 11.681   0   0   0   0   0

  2012         0         0     99190     26861    126051    225242  6.348   0   0   0   0   0

  2011         0         0     84474     14717     99191     99191  3.310   0   0   0   0   0
 *****  ALL POSSIBLE PATHS TRACED  *****
```

6.7.2.3 Glimpses of Reprobat output of base case (partial output)

……………………………………………………………………………………………………….

………………………………………………………………………………………………………..

```
PAGE  5


                                          ANNUAL LOAD DESCRIPTION
                                          PERIOD(S) PER YEAR : 12
                  YEAR    PEAKLOAD  GR.RATE  MIN.LOAD  GR.RATE    ENERGY   GR.RATE LOADFACTOR
                             MW        %        MW        %         GWH        %        %


                  2011      967.1      -       421.9      -       5182.8       -      61.18
```

```
                   2012      1056.9     9.3      461.1     9.3      5664.1     9.3     61.18
                   2013      1163.2    10.1      507.5    10.1      6233.8    10.1     61.18
                   2014      1271.7     9.3      554.8     9.3      6815.2     9.3     61.18
                   2015      1387.2     9.1      605.2     9.1      7434.2     9.1     61.18
                   2016      1510.0     8.9      658.8     8.9      8092.3     8.9     61.18
                   2017      1640.8     8.7      715.8     8.7      8793.3     8.7     61.18
                   2018      1770.2     7.9      772.3     7.9      9486.8     7.9     61.18
                   2019      1906.9     7.7      831.9     7.7     10219.4     7.7     61.18
                   2020      2052.0     7.6      895.2     7.6     10997.0     7.6     61.18
                   2021      2206.0     7.5      962.4     7.5     11822.3     7.5     61.18
                   2022      2363.0     7.1     1030.9     7.1     12663.7     7.1     61.18
                   2023      2545.4     7.7     1110.5     7.7     13641.2     7.7     61.18
                   2024      2741.1     7.7     1195.8     7.7     14690.0     7.7     61.18
                   2025      2951.1     7.7     1287.5     7.7     15815.4     7.7     61.18
                   2026      3176.7     7.6     1385.9     7.6     17024.4     7.6     61.18
                   2027      3418.9     7.6     1491.5     7.6     18322.4     7.6     61.18
                   2028      3679.1     7.6     1605.1     7.6     19716.9     7.6     61.18
                   2029      3913.0     6.4     1707.1     6.4     20970.4     6.4     61.18
                   2030      4155.6     6.2     1812.9     6.2     22270.6     6.2     61.18
```

…….

……..

```
PAGE  7

                                                 FIXED SYSTEM
                         SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD1
                                    *** CAPACITY IN MW * ENERGY IN GWH ***
                                      FIXED O&M COSTS : 2.100 $/KW-MONTH
           P      HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
           R  P      PROB.: 0.20       PROB.: 0.20       PROB.: 0.60
           O  E   CAPACITY  ENERGY  CAPACITY  ENERGY  CAPACITY  ENERGY
YEAR  J  R  BASE  PEAK        BASE  PEAK        BASE  PEAK

     2011 15  1   120.    0.   88.  124.    1.   91.  120.    0.   87.
2   107.    0.   78.  109.    0.   79.  104.    0.   76.
3   121.    1.   88.  123.    1.   90.  123.    0.   90.
4   131.    0.   95.  134.    0.   98.  130.    0.   95.
5   159.    0.  116.  154.    0.  113.  158.    0.  116.
6   183.    1.  134.  178.    0.  130.  177.    0.  129.
7   205.    0.  150.  196.    0.  144.  199.    0.  146.
8   206.    0.  151.  200.    0.  146.  197.    0.  144.
9   185.    0.  135.  179.    0.  131.  176.    0.  129.
10   181.    0.  132.  159.    0.  116.  161.    0.  118.
11   164.    0.  120.  147.    0.  107.  157.    0.  115.
12   140.    1.  103.  138.    0.  101.  140.    0.  102.
             INST.CAP.  223.
             TOTAL ENERGY    1391.             1346.             1347.

10    43.    0.   31.   43.    0.   31.   39.    0.   29.
11    25.    0.   18.   25.    0.   18.   25.    0.   18.
12    19.    0.   14.   17.    0.   12.   18.    0.   13.
INST.CAP.   48.
             TOTAL ENERGY     267.              272.              273.
```

…….

……..

```
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                                                VARIABLE SYSTEM  (CONTD.)
                         SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD1
                                    *** CAPACITY IN MW * ENERGY IN GWH ***
                                      FIXED O&M COSTS : 2.100 $/KW-MONTH
           P      HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
           R  P      PROB.: 0.20       PROB.: 0.20       PROB.: 0.60
           O  E   CAPACITY  ENERGY  CAPACITY  ENERGY  CAPACITY  ENERGY
```

```
YEAR   J  R  BASE  PEAK        BASE  PEAK        BASE  PEAK

2015  5  1    19.    0.   14.   26.    0.   19.   27.    0.   20.
2    18.    0.   13.   22.    0.   16.   24.    0.   17.
3    21.    0.   15.   25.    0.   18.   27.    0.   20.
4    25.    0.   18.   31.    0.   22.   31.    0.   22.
5    35.    0.   25.   43.    1.   32.   36.    0.   26.
6    46.    0.   33.   52.    0.   38.   44.    0.   32.
7    59.    0.   43.   50.    0.   36.   54.    0.   40.
8    51.    0.   37.   54.    0.   39.   48.    0.   35.
9    43.    0.   32.   43.    0.   32.   44.    0.   32.
10    43.    0.   31.   42.    0.   31.   42.    0.   31.
11    32.    0.   24.   41.    0.   30.   37.    0.   27.
12    24.    0.   18.   31.    0.   22.   29.    0.   21.
INST.CAP.   83.
             TOTAL ENERGY     303.              335.              323.
```

……

……

6.7.2.4 LRMC for sample case

Perturbation approach is used for computing LRMC. All other data files in WASP are similar to the base case except Loadsy. In Loadsy, the annual peak load of base case scenario is increased by some amount (50 MW each year in the sample case).

The optimization output of perturbation case is given below. As the load is increased, the cost is increased.

DYNPRO output of perturbation case

```
SOLUTION #  1 VARIABLE ALTERNATIVES BY YEAR
  YEAR------ PRESENT WORTH COST OF THE YEAR ( K$ )------  OBJ.FUN.  LOLP  THRM    PRCH    HYD2
CONCST    SALVAL    OPCOST    ENSCST     TOTAL   (CUMM.)    %       MULT    HYD1
  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - -
  2030    149961    136212     44291        33     58074   4317076  0.032   2   2   2  16  12
  2029     29677     24482     45367        23     50585   4259003  0.021   2   2   2  16  11
  2028    617276    462450     43825         7    198658   4208418  0.007   2   2   2  16  10
  2027     76170     49570     94612      8166    129379   4009760  3.274   2   2   2  16   8
  2026         0         0     87799      9963     97762   3880382  3.731   1-  1-  2+ 16   8
  2025    189599    106314     83734      4963    171982   3782619  1.880   1-  1-  2+ 16   8
  2024         0         0     92774      5295     98069   3610637  1.872   1-  1-  2+ 16   7-
  2023   1285551    593827     88739      2640    783104   3512569  0.972   1-  1-  2+ 16   7
  2022         0         0     97497      3176    100673   2729465  1.080   1-  1-  2+ 16   5
  2021    201832     76750     92805      1673    219561   2628792  0.575   1-  1-  2+ 16   5
  2020     75417     26012    106411      1777    157593   2409231  0.565   1-  1-  2+ 15   3-
  2019     31993     10007    103888      8445    134319   2251638  2.319   1-  1-  1- 13-  3-
  2018     85492     24242     99424      4955    165629   2117319  1.343   1-  1-  1- 11-  3
  2017    824047    198234     98153      3132    727099   1951690  0.856   1-  1-  1-  8-  3+
  2016     62390     14528    152837     24015    224713   1224591  5.195   0   0   1+  6   0
  2015    152442     32151    147154     15995    283440    999878  3.359   0   0   1+  5+  0
  2014         0         0    135573    114187    249760    716438 22.366   0   0   0   0   0
  2013         0         0    126358     69913    196271    466677 14.778   0   0   0   0   0
  2012         0         0    112148     38553    150701    270407  8.543   0   0   0   0   0
  2011         0         0     97909     21796    119706    119706  4.839   0   0   0   0   0
 *****  ALL POSSIBLE PATHS TRACED  *****
```

6.8 MODEL RESULTS

Different modules are run in sequence in both VALORAGUA and WASP models. In VALORAGUA, the functions of different modules are:

CADIR: Data processing module

VALAGP: Optimization module

RESEX: Result generating module for all plants (to be taken for analysis purpose)

RESIM: Result generating module for a particular plant (to be taken for analysis purpose

VWASP: Data generating module for WASP from the result of VALORAGUA

The power balance, water balance, cost and benefit etc. generated by VALORAGUA through result generating modules for the designed system is the result of the minimization of the expected value of generation cost under certain constraints.

In WASP, the functions of different modules are:

LOADSY: Data processing module for load

FIXSYS: Data processing module for existing plants

VARSYS: Data processing module for expansion plants

CONGEN: Data processing module for year by year configuration

MERSIM: Module for merging all possible combination and simulating

DYNPRO: Optimization module

REPROBAT: Result in report format

For generating different scenarios, different combinations of expansion plants taking same or slightly different year of commissioning for a plant in common can be considered through VARSYS and CONGEN. The output of optimization module generates year by year output for different costs and LOLP. The LRMC can be computed by perturbation approach in all cases. The expansion plan giving least LRMC can be taken as the optimum one.

The generated energy and the corresponding net present value for both base case and perturbation case is extracted from Reprobat and Dynpro output to compute LRMC. LRMC value obtained with 20 years of output for the hydrothermal system is 4.1 Cents/KWh.

LRMC computation for sample case

E1: Generated energy for base case

E2: Generated energy for perturbation case

NPV1: Net present value for base case

NPV2: Net present value for perturbation case

MC=(difference in cost/difference in energy)

LRMC =average of MC

Table 6-3: LRMC computation for sample case

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)	MC (Cts/Kwh)
2030	22270.6	22538.6	56895	58686	0.7
2029	20970.4	21238.3	48896	50785	0.7
2028	19716.9	19984.8	41293	43126	0.7
2027	18322.4	18590.4	35473	37323	0.7
2026	17024.4	17292.4	28885	30488	0.6
2025	15815.4	16083.4	387787	388554	0.3
2024	14690	14957.9	198328	204985	2.5
2023	13641.2	13909.2	798926	806549	2.8
2022	12663.7	12931.6	119565	128994	3.5
2021	11822.3	12090.3	128037	136181	3.0
2020	10997	11264.9	197944	205269	2.7
2019	10219.4	10487.3	195170	202535	2.7
2018	9486.8	9754.7	160299	167819	2.8
2017	8793.3	9061.3	560235	567592	2.7
2016	8092.3	8360.3	224769	244248	7.3
2015	7434.2	7702.2	276481	293999	6.5
2014	6815.2	7083.2	214689	249760	13.1
2013	6233.8	6501.7	166207	196271	11.2
2012	5664.1	5932.1	126051	150701	9.2
2011	5182.8	5450.8	99191	119706	7.7
				LRMC	**4.1**

6.9 DIFFERENT OPTIONS

6.9.1 Incorporating More than 50 hydroplants

Maximum of 50 hydroplants can be incorporated into VALORAGUA. In WASP, 2 hydroelectric plant types, each one composed of up to 30 projects (60 maximum), can be inserted. Hence, the most important/most significant projects should be selected in case of large number of hydroplants. If there are many smaller projects, the contributions of these projects can be lumped into a single fictitious project, for which the database also need to be revised accordingly. If the hydroplants are in different basins, flowdata and power can be integrated. However, in case of cascade plants, having different design flows, each one should be considered separately.

6.9.2 Selection of ROR and Storage Hydroplants and Thermal plants

For a country like Nepal, the thermal option is much more expensive than hydro option. Therefore, their number should be restricted in expansion plan. For the expansion plan, the type of hydroplants representing the part of load, such as base and peak and the date of commissioning should be considered according to the nature of the project and possibility/feasibility of construction. Expansion plan should be based on the strengths and limitations of specific type of plants, and financial viability for construction.

6.10 APPLICABILITY OF GUIDELINES

VALORAGUA-WASP modeling is a system optimization, not an optimization of a single plant. Therefore, the model is suitable for central planner agency such as WECS, DOED and NEA for system planning. However, the VALORAGUA generates the cost and other factors for each plant, from which the characteristics of individual plant can also be studied. Whenever planning for new plant is finalized, it can be inserted into the developed model, and the least cost expansion plan can be obtained.

Chapter 7

Scenario Analysis

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7. SCENARIO ANALYSIS

Scenarios are generated to study the impact of different alternatives. Analysis of scenarios can be done by taking one reference case and comparing the output of reference case with other alternatives. The limitations of models should be kept in mind while generating scenarios. System optimization will be done for future time. Based on the requirements of that time, the anticipated conditions might change from currently expected. The scenarios may give an idea of advantages or limitations of various options.

The data preparation for scenario generation will be easy once a reference model is set up and run. For a particular scenario to be generated, the database in reference case will be modified or added for specific variables/conditions/plants keeping others same.

VALORAGUA and WASP models are suitable for optimization of mixed hydrothermal system. In these, following scenarios can be generated and LRMC of each scenario can be analyzed.

- A selected case as basic/reference case
- Addition of feasible storage/ROR projects
- Consideration of impact of Seasonal variation
- No addition of thermal or addition of thermal
- Impact of GDP growth (economic change)
- Power optimization for short, medium and long term
- Export option
- Import option

Following scenarios are generated as examples.

7.1 BASIC MODEL-SCENARIO 1

Hydroplants at design flow with Thermal and without export

Maximum number of hydrocascades is set to 18 (maximum limit of VALORAGUA). Based on the availability of data, 46 hydroplants are included within 18 hydrocascades. Among them, 23 are existing plants and remaining are expansion candidates.

Table 7-1: Hydrocascades for Basic Model

Cascade No.	Code Name of plants	No. of plants	Name of plants
1	PUWA, MAI	2	PUWA, MAI
2	IKHUWA, PILUWA	2	IKHUWA, PILUWA
3	UTAMOR, MAIWA, MTAMOR, PHAWA, KABE-A, HEWA	6	UPPER TAMOR, MAIWA, MIDDELE TAMOR, PHAWA, KABELI-A, HEWA
4	UTAMAK, SIPRIN	2	UPPER TAMAKOSHI, SIPRIN
5	KHANI	1	KHANI
6	KHIM-1	1	KHIMTI-1
7	U-BHOT, CHAKU, BARAMC,SUNKOS, SUNKON	5	UPPER BHOTEKOSHI, CHAKU, BARAMCHI,SUNKOSHI (SMALL), SUNKOSHI (NEA)
8	BALE-A, BALE-B	2	BALEPHI-A, BALEPHI-B

9	INDRAW	1	INDRAWATI
10	U-SANJ, L-SANJ, CHILIM, RASGAD, TRIS3A, TRIS2B, TRIS, DEVIGH	8	UPPER SANJEN, LOWER SANJEN, CHILIME, RASUWAGADHI, TRISHULI3A, TRISHULI2B, TRISHULI, DEVIGHAT
11	KULEK1, KULEK2, KULEK3	3	KULEKHANI1, KULEKKHANI2, KULEKKHANI3
12	BUDHIG	1	BUDHI GANDAKI
13	UMARSY, MMARSY, KHUDI, LCHEPE, MARSYG	5	UPPER MARSYANGDI, MIDDLE MARSYANGDI, KHUDI, LOWER CHEPE, MARSYANGDI
14	BIJAYP	1	BIJAYPUR
15	MODI, LMODI, KGANDA	3	MODI, LOWER MODI, KALI GANDAKI
16	ANDHI	1	ANDHI
17	JHIMRK	1	JHIMRK
18	CHAMEL	1	CHAMELIYA

Table 7-2: List of Selected Hydroplants for Basic Model

Existing plants	**Design discharge (m^3/s)**	**Installed capacity (MW)**	**Under construction/to be constructed plants**	**Design discharge (m^3/s)**	**Installed capacity (MW)**
PUWA	2.5	6.2	KHANI	5.1	30
MAI	16	15.6	BARAMCHI	0.9	4.2
PILUWA	3.5	3.0	KULEKHANI-3	16	14
SIPRIN	7.5	9.6	LOWER MODI	29	20
KHIMTI-1	10.8	60	CHAMELIYA	36	30
UPPER BHOTEKOSHI	36.8	45	HEWA	8.1	15
CHAKU	2.7	3	PHAWA	2.1	5
SUNKOSHI SMALL	2.7	2.5	BALEPHI-A	25	10.6
SUNKOSHI	40	10	UPPER SANJEN	11.1	14.6
INDRAWATI	15	7.5	IKHUWA	4	18.5
CHILIME	8.3	22	KABELI-A	37.7	38
TRISHULI	45.3	24	LOWER CHEPE	7.5	8.3
DEVIGHAT	45.3	15	MAIWA	8.1	13.5
KULEKHANI-1	12.1	60	LOWER SANJEN	11.6	42.5
KULEKHANI-2	13.5	32	BALEPHI-B	30	18.5
MIDDLE MARSYANGDI	80	70	TRISHULI3B	51	37
KHUDI	4.6	4	UPPER MARSYANGDI	48.7	45
MARSYANGDI	91.5	69	UPPER TAMAKOSHI	66	456
BIJAYPUR	8.3	4.5	RASUWAGADHI	80	111
MODI	27.5	15	UPPER TAMOR	10.5	415
KALI GANDAKI	134	144	MIDDLE TAMOR	105	75
ANDHI	4.9	9.4	TRISHULI2A	51	60
JHIMRUK	36	12	BUDHI GANDAKI	430	600

Thermal (existing)
Hetauda: 10 MW
Duhabi: 39.5

Total installed capacity of existing hydro plants, expansion candidate plants and thermal existing = 2775 MW

- Consumption (load) subsystem
- Electric code: Nepal as single node
- Fixed Power Demand (primary demand) for simulation year 2030
- Secondary Power Demand

7.1.1 Basic Data and Parameters

Simulation year considered = 2030

Starting year of inflow data = 1980, ending yearof inflow data = 2009

Number of load steps = 5 (maximum limit allowed in VALORAGUA)

Number of electric node = 1 (Nepal as one node)

Number of system (primary) demand =1, Annual energy demand = 18000 GWH (obtained from load forecast data of NEA)

Monthly breakdown of energy demand (%): obtained from auxiliary toolDIAGOPTM provided in NALORAGUA

8.4 8.4 8.5 8.5 8.7 8.6 8.6 8.2 8.1 8.2 7.8 8.0

Number of secondary demand = 1, Average selling price = 9 Cts/KWh, Maximum variation = 1%, maximum power supply in each month = 105 MW (About 2.5% of peak demand 4155MW for year 2030)

7.1.2 Thermal Plants and Imports Data

Two existing thermal power plant, Hetauda (HETAUD) and Duhabi (DUHABI)

Import system: Possibility of 300MW until 2015 and up to 1000MW after the construction of 400kv transmission system, considered 1000 MW in total

One additional thermal plant of 300 MW considered for expansion

Energy not served option of 1000 MW

Operation and maintenance (O & M) cost of thermal plants = 40Cents/KWh

Cost of energy not served = 55 Cents/KWh

Import system: Possibility of 300MW until 2015 and up to 1000MW after the construction of 400kv transmission system, considered 1000 MW in total

7.1.3 Reservoir Characteristics Data and Parameters

For ROR plants, the storage volume of reservoir is considered to be 1 Mm3.

In the basic case, Kulekhani 1 and BudhiGandaki are storage projects, while all other remaining projects are ROR type. For ROR project, si = 0, alpha = 0, beta = 1. For storage projects, these coefficients are found by regression from level-volume data. Storage bound, Evaporation, and release are set to zero due to unavailability of data.

7.1.4 Load Forecast: up to 2030

Number of periods per year= 12, Number of hydro-conditions = 3 Fixed operating and maintenance costs of hydroelectric= 2.1 USD/KW month, Probability of hydro-conditions= 20% (dry), 20% (wet), 60% (mean)

Minimum and maximum permissible reserve margin: -30%, 25%

Discount rate = 10%. Plant life of thermal =25 year and Plant life of hydro= 50 year

Interest during construction = 10%.

Depreciation on capital cost for hydro plant = 3% per annum (25% domestic and 75% foreign). Critical value of LOLP = 25% as an initial value.

7.2 EXPORT OPTION: EXPORT (700MW) OPTION IN BASIC MODEL-SCENARIO 2

7.3 SEASONAL MODEL: SEASONAL BREAKDOWN IN BASIC MODEL -SCENARIO 3

- Dry season: Jan-Apr
- Wet season: May-Dec

7.4 GDP CHANGE: HYDROPLANTS WITH THERMAL AND WITHOUT EXPORT FOR ADOPTED DESIGN FLOW, CONSIDERING 5%, 7.5% AND 10% GDP GROWTH -SCENARIO 4

7.5 STORAGE PROJECTS: HYDROPLANTS WITH THERMAL AND WITHOUT EXPORT FOR ADOPTED DESIGN FLOW ADDING MORE STORAGE PROJECTS IN THE BASIC SCENARIO-SCENARIO 5

7.6 CONSIDERATION OF MAJOR EXISTING, UNDER-CONSTRUCTION AND PLANNED PROJECTS (WITHOUT CONSIDERING THERMAL ADDITION)-SCENARIO 6

7.7 SHORT TERM, LONG TERM AND MEDIUM TERM PLAN-SCENARIO 7

7.8 VALORAGUA DATABASE

Scenarios 1, 2, 3, and 4 contain 18 cascades with 46 hydroplants (23 existing plants and 23 expansion plants). In VALORAGUA, change is done in CADIR file only for different scenarios. Twelve periods are considered for generating VWASP for WASP model. There is no change in the VALORAGUA database for scenario 1, 3, and 4. The change condition in these scenarios is reflected in WASP. In scenario 2, export option of 700MW is added in CADIR file.

In Scenario 5, Khanikhola, Bijyapur and Andhi ROR hydroprojects are discarded from scenario1 and Dudhkoshi, Tanahu and West Seti storage projects are included in the CADIR file. The total number of cascades and hydroplants is same as scenario 1.

In scenario6, major existing projects, major projects under-construction and major planned projects are considered (as discussed in chapter 6). The total number of cascade in this case is also 18. The total number of hydroplants is 48 (20 existingplants and 28 expansion plants).

In scenario 7, database is prepared for three time horizons.

Short term: 2011-2020 (10 years), 23 existing (same as scenario 1), 23 expansion

7.9 EXPANSION PLANTS

Table 7-3: List of Expansion hydroplants for short term scenario

S.N.	**Hydroplants**
1	KHANI
2	BARAMCHI
3	KULEKHANI-3
4	LOWER MODI
5	CHAMELIYA
6	HEWA
7	RAHUGHAT
8	PHAWA
9	BALEPHI-A
10	UPPER SANJEN
11	IKHUWA
12	KABELI-A
13	LOWER CHEPE
14	MAIWA
15	LOWER SANJEN
16	BALEPHI-B
17	TRISHULI3B
18	UPPER MARSYANGDI
19	UPPER TAMAKOSHI
20	RASUWAGADHI
21	MIDDLE BHOTEKOSHI
22	TANAHU
23	TRISHULI2A

7.10 MEDIUM TERM SCENARIO: 2011-2020 (20 YEARS), SAME CASE AS SCENARIO 1

7.11 LONG TERM SCENARIO: 2011-2035 (25 YEARS), 19 EXISTING, 29 EXPANSION

7.11.1 Existing Hydroplants

Table 7-4: List of Existing hydroplants for long termscenario

S.N.	**Hydroplants**
1	MIDDLE MARSYANGDI
2	MARSYANGDI
3	KULEKHANI-1
4	KULEKHANI-2
5	KHIMTI-1
6	UPPER BHOTEKOSHI
7	PUWA
8	MAI
9	SIPRIN

10	CHAKU
11	SUNKOSHI SMALL
12	SUNKOSHI
13	CHILIME
14	TRISHULI
15	DEVIGHAT
16	KHUDI
17	MODI
18	JHIMRUK

7.11.2 ExpansionHydroplants

Table 7-5: List of Expansion Hydroplants long termscenario

S.N.	**Hydroplants**
1	UPPER TAMAKOSHI
2	RASUWAGADHI
3	MIDDLE BHOTEKOSHI
4	TRISHULI3A
5	TANAHU STORAGE (SETI)
6	BUDHI GANDAKI STORAGE
7	DUDH KOSHI STORAGE
8	NALSING GAD STORAGE
9	WEST SETI STORAGE
10	MIDDLE TAMOR
11	UPPER TAMOR
12	UPPER ARUN
13	ARUN 3
14	BARAMCHI
15	KULEKHANI-3
16	LOWER MODI
17	CHAMELIYA
18	HEWA
19	RAHUGHAT
20	PHAWA
21	BALEPHI-A
22	UPPER SANJEN
23	KABELI-A
24	LOWER CHEPE
25	MAIWA
26	LOWER SANJEN
27	BALEPHI-B
28	TRISHULI3B
29	UPPER MARSYANGDI

7.12 COMPARISON OF LRMC

Table 7-6: Summary of LRMC for different scenarios

Scenario	Case	LRMC (Cts/Kwh)
1	Basic	3.9
2	Export	3.8
3	Dry	11.7
	Wet	5.0
4	5.5%GDP	4.2
	7.5%GDP	6.6
	10%GDP	12.7
5	Additional Storage projects to scenario1	3.6
6	Major projects (without thermal addition)	4.1
7	Time horizon	
	Long	3.2
	Medium	3.9
	Short	5.8

After finalizing the least cost expansion scenario from different scenarios, implication of following components can be evaluated.

- Export
- No export
- Import
- No import

7.12.1 Monetary value of Hydropower plants

All the input data are processed by the CADIR module of VALORAGUA. After running the optimization module VALAGP, the output is displayed by executing RESEX module. The first block of output of RESEX module gives the monetary value of the power system considering the power balance. The monetary value is given in terms of marginal cost of generation and value of generation.

Table 7-7: Monitory value of Basic Scenario(Hydroplants with Thermal and without export, design flow)

Load step	**Fixed power demand (MW)**	**Secondary power demand (MW)**	**Thermal power output (MW)**	**Hydroelectric power output (MW)**	**Pumping power consumption (MW)**	**Net transported power (MW)**	**Power excess (MW)**	**Marginal cost of generation (Cts/Kwh)**	**Value of generation (Mill. USD)**
1	2953.55	0	-1015.95	-1937.6	0	0	-0.008	22.11	228.818
2	2625.44	0	-839.47	-1785.97	0	0	-0.008	21.94	555.064
3	2234.75	31.36	-645.22	-1624.35	0	0	-3.47	19.728	705.998
4	1949.21	39.74	-552.17	-1485.04	0	0	-48.254	17.348	928.748
5	1785.4	40.72	-501.1	-1413.41	0	0	-88.377	16.478	1022.508
Total	**17997.91**	**285.87**	**-5257.53**	**-13445**	**0**	**0**	**-418.741**	**18.399**	**3441.136**

Table 7-8: Monetary Value of Export (700MW) option in Basic Scenario

Load step	**Fixed power demand (MW)**	**Secondary power demand (MW)**	**Thermal power output (MW)**	**Hydroelectric power output (MW)**	**Pumping power consumption (MW)**	**Net transported power (MW)**	**Power excess (MW)**	**Marginal cost of generation (Cts/Kwh)**	**Value of generation (Mill. USD)**
1	2953.55	0	-1016.76	-1936.8	0	0	-0.008	22.075	228.458
2	2625.44	0	-840.45	-1784.99	0	0	-0.006	21.9	554.049
3	2234.75	33.35	-644.82	-1623.29	0	0	-0.009	21.673	775.119
4	1949.21	111.4	-552.89	-1507.73	0	0	-0.012	20.656	1118.608
5	1785.4	157.31	-502.62	-1440.12	0	0	-0.019	19.954	1256.433
Total	**17997.91**	**855.23**	**-5264.96**	**-13588.3**	**0**	**0**	**-0.116**	**20.859**	**3932.666**

Table 7-9: Monetary Value of Hydroplants with Thermal and without export for adopted design flow adding more storage projects in the Basic Scenario

Load step	Fixed power demand (MW)	Secondary power demand (MW)	Thermal power output (MW)	Hydroelectric power output (MW)	Pumping power consumption (MW)	Net transported power (MW)	Power excess (MW)	Marginal cost of generation (Cts/Kwh)	Value of generation (Mill. USD)
1	2953.55	61.33	-263.46	-3017.17	0	0	-265.755	4.609	52.984
2	2625.44	62.02	-238.5	-2832.34	0	0	-383.387	4.475	132.409
3	2234.75	63.01	-199.95	-2641.95	0	0	-544.136	4.23	189.56
4	1949.21	63.29	-166.68	-2473.79	0	0	-627.973	3.906	271.02
5	1785.4	63.43	-149.45	-2378.79	0	0	-679.412	3.658	299.745
Total	**17997.91**	**552.51**	**-1559.84**	**-22163.6**	**0**	**0**	**-5172.97**	**3.986**	**945.718**

Table 7-10: Monetary Value of Consideration of major existing, under-construction and planned projects

Load step	Fixed power demand (MW)	Secondary power demand (MW)	Thermal power output (MW)	Hydroelectric power output (MW)	Pumping power consumption (MW)	Net transported power (MW)	Power excess (MW)	Marginal cost of generation (Cts/Kwh)	Value of generation (Mill. USD)
1	2953.55	78.06	-46.06	-3332.31	0	0	-346.771	2.978	35.255
2	2625.44	79.8	-37.31	-3168.32	0	0	-500.392	2.853	88.129
3	2234.75	82.19	-25.91	-2953.64	0	0	-662.612	2.709	127.287
4	1949.21	85.29	-16.85	-2784.63	0	0	-766.985	2.471	181.912
5	1785.4	86.5	-13.52	-2684.35	0	0	-825.969	2.311	202.106
Total	**17997.91**	**738.37**	**-181.06**	**-24896.5**	**0**	**0**	**-6341.26**	**2.531**	**634.69**

Table 7-11: Monetary Value of Long term horizon

Load step	Fixed power demand (MW)	Secondary power demand (MW)	Thermal power output (MW)	Hydroelectric power output (MW)	Pumping power consumption (MW)	Net transported power (MW)	Power excess (MW)	Marginal cost of generation (Cts/Kwh)	Value of generation (Mill. USD)
1	4266.23	69.25	-162.22	-4452.81	0	0	-279.55	3.758	60.77
2	3792.29	69.94	-129.34	-4194.98	0	0	-462.09	3.625	151.048
3	3227.97	71.37	-90.39	-3922.61	0	0	-713.645	3.422	216.557
4	2815.52	73.27	-53.53	-3699.46	0	0	-864.196	3.125	308.181
5	2578.91	74.2	-42.51	-3553.22	0	0	-942.619	2.931	341.607
Total	**25996.96**	**637.23**	**-602.46**	**-33026.6**	**0**	**0**	**-6994.82**	**3.206**	**1078.164**

Table 7-12: Monetary Value of Short term horizon Case

Load step	Fixed power demand (MW)	Secondary power demand (MW)	Thermal power output (MW)	Hydroelectric power output (MW)	Pumping power consumption (MW)	Net transported power (MW)	Power excess (MW)	Marginal cost of generation (Cts/Kwh)	Value of generation (Mill. USD)
1	1401.23	31.61	-175.43	-1286.91	0	0	-29.501	3.987	20.488
2	1245.57	31.94	-138.4	-1233.41	0	0	-94.299	3.863	51.199
3	1060.22	32.29	-97.88	-1175.31	0	0	-180.682	3.645	73.375
4	924.75	32.43	-55.91	-1139.3	0	0	-238.028	3.341	105.221
5	847.03	32.51	-31.2	-1118.19	0	0	-269.849	3.118	116.494
Total	**8562**	**284.15**	**-598.87**	**-10138.7**	**0**	**0**	**-1891.44**	**3.416**	**366.777**

Chapter 8

Sensitivity Analysis

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8. SENSITIVITY ANALYSIS

In power optimization study using VALORAGUA-WASP, some parameters are estimated using available data whereas some parameters are assigned from the prevailing conditions. Sensitivity analysis is a technique for analyzing the impact of change in input or parameters to the output of the model. It reflects the uncertainty in input/parameter. This type of analysis provides an answer to what-if conditions. It is useful for assessing critical variable or parameter, which should be considered in decision making. This technique can be used when there are limited resources or information available. Sensitivity analysis does not require the use of probabilities.

The database preparation for sensitivity analysis is very easy once a base/reference case scenario is generated. For sensitivity analysis, the value of specific parameter or input is changed keeping all other database same as reference case.

Using VALORAGUA and WASP, sensitivity of the following input/parameter on LRMC can be performed.

8.1 CHANGING THE DESIGN FLOW VALUE FOR FUTURE EXPANSION PLANTS

The design flow (called nominal flow in VALORAGUA) is given as input in the CADIR file of VALORAGUA in the hydroplant database part (second last column of first part of data and maximum flow of second part of data). For this, different value of design flow for expansion candidates can be given as input.

8.2 COST OF ENERGY UNSERVED

Cost of energy unserved is changed in the CADIR file of VALORAGUA (in the thermal plant and import database part, considering a fictitious plant) and DYNPRO file of WASP (data type 11).

8.3 LOAD GROWTH

The energy demand for the simulation year obtained from different techniques is changed in the CADIR file of VALORAGUA (system demand data). The growth of load or the load forecast is given as input in the LOADSY file of WASP in yearly basis.

8.4 DISCOUNT RATE

Discount rate is changed in the DYNPRO file of WASP (data in line 3).

8.5 LOLP

Critical value of LOLP is changed in the DYNPRO file of WASP (data type 12).

8.6 RESERVE MARGIN

Maximum and minimum reserve margin is changed in the CONGEN file of WASP (data type 4).

8.7 FUEL COSTS

Fuel costs can be changed in the thermal plant database in the FIXSYS and VARSYS files of WASP.

8.8 EXPORT

The exported value of energy is changed in the CADIR file of VALORAGUA (secondary demand and export part).

8.9 EXAMPLES

1. Reference case (scenario 1 described in chapter 6, having 46 plants: 23 existing+ 23 expansion)

2. Design flow for existing plant and Q25 for expansion candidates
3. Design flow for existing plant and Q30 for expansion candidates
4. Design flow for existing plant and Q40 for expansion candidates
5. Design flow for existing plant and Q50 for expansion candidates
6. Design flow for existing plant and Q60 for expansion candidates
7. Unserved energy cost: 30 cents/kwh, 55 cents/kwh, 80 cents/kwh and 1 USD

Existing plants	Design discharge (m^3/s)	Under construction/to be constructed plants	Q25 (m^3/s)	Q30 (m^3/s)	Q40 (m^3/s)	Q50 (m^3/s)	Q60 (m^3/s)
PUWA	2.5	KHANI	4.95	3.75	2.56	1.39	1.12
MAI	16	BARAMCHI	0.77	0.63	0.45	0.29	0.23
PILUWA	3.5	KULEKHANI-3	15.94	10.65	6.88	5.11	3.84
SIPRIN	7.5	LOWER MODI	58.45	44.65	29.48	17.94	15.13
KHIMTI-1	10.8	CHAMELIYA	49.59	36.69	28.53	20.49	16.67
UPPER BHOTEKOSHI	36.8	HEWA	18.82	16.78	13.42	9.38	7.12
CHAKU	2.7	PHAWA	8.42	6.76	4.46	2.80	2.02
SUNKOSHI SMALL	2.7	BALEPHI-A	11.94	9.13	7.14	3.83	3.20
SUNKOSHI	40	UPPER SANJEN	12.96	10.17	6.71	4.20	3.07
INDRAWATI	15	IKHUWA	12.07	10.17	7.27	4.63	3.31
CHILIME	8.3	KABELI-A	74.23	59.61	39.28	24.64	37.73
TRISHULI	45.3	LOWER CHEPE	23.47	17.64	13.76	7.82	6.26
DEVIGHAT	45.3	MAIWA	14.86	11.94	7.87	4.93	3.57
KULEKHANI-1	12.1	LOWER SANJEN	14.69	11.53	7.61	4.77	3.48
KULEKHANI-2	13.5	BALEPHI-B	65.89	50.42	39.39	21.15	17.66
MIDDLE MARSYANGDI	80	TRISHULI3B	329.5	258.71	170.72	106.92	78.12
KHUDI	4.6	UPPER MARSYANGDI	30.48	22.91	17.87	10.15	8.13
MARSYANGDI	91.5	UPPER TAMAKOSHI	113.69	86.07	58.87	31.93	25.80
BIJAYPUR	8.3	RASUWAGADHI	237.59	186.53	123.09	77.09	56.32
MODI	27.5	UPPER TAMOR	158.93	127.64	84.11	52.77	38.20
KALI GANDAKI	134	MIDDLE TAMOR	177.83	142.82	94.11	59.05	42.73
ANDHI	4.9	TRISHULI2A	327	256.73	169.41	106.11	77.52
JHIMRUK	36	BUDHI GANDAKI	372.23	300.20	197.60	130.02	91.65

8.10 COMPARISON OF LRMC FOR DIFFERENT CASES

Case	Description	LRMC (Cts/Kwh)
1	Reference case	3.9
2	Q25, Qdesign	3.9
3	Q30, Qdesign	3.7
4	Q40, Qdesign	3.7
5	Q50, Qdesign	3.8
6	Q60, Qdesign	3.5
7	ENS 30 Cent	3.1
	ENS 55 Cent	3.9
	ENS 80 Cent	4.5
	ENS 1USD	5.0

Chapter 9

Recommendations

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9. RECOMMENDATIONS

9.1 RECOMMENDED APPROACH FOR PARAMETERIZATION

- Hydrological time series data: Mean monthly discharge data for the period of 20-30 years is recommended for running VALORAGUA for obtaining historical trends.
- Design flow: Discharge corresponding to 25% probability of exceedence (Q25) to 70% probability of exceedence (Q70) is generally adopted.
- Latest Load Duration Curve (LDC) covering a year is required for parameters related to load.
- Cost for optimization in VALORAGUA is given as initial value, such as in the range of 7-20 Cents/KWh. The final cost is optimized by the model.
- Cost of unserved energy is determined by some approach such as customer survey.
- Variability in fuel cost is reflected in the modeling system by performing sensitivity to different costs in WASP.
- Storage-elevation-outflow data for storage projects are required for the determination of storage function parameters.
- Load forecast is based on some mathematical model.
- Reserve margin is given as initial value based on the available power.
- LOLP is given as initial value based on the situation of power supply.
- Economic parameters are based on the data of the country.

9.2 RANGE OF PARAMETERIZATION (BASED ON STUDY YEAR 2013/14)

S.N.	Parameters	Range	Remarks/Justification
1.	Load step	Up to 5	The LDC is based on the available data during 2012-2013 period. The continuous LDC has been discretized into 5 steps to consider large as well as small plants. The peak of the discretized LDC is used in the optimization model.It is better to change the duration of LDC in discrete load step during the forecast period.
2.	Number of electric node	1	Single node for Nepalese power system.
3.	Average selling price of electricity	9 Cents/KWh	Here, considered for base year 2014.
4.	Cost of unserved energy	0.5 to 1USD/KWh	The value of the unserved energy is assigned in such a way the power balance is satisfied. The cost of unnerved energy is based on the available references and prevailing conditions. The cost should be based on research and study. The

			cost of unserved energy can be related to per capita income.Higher the unserved energy cost, higher the LRMC. It is better to keep in lower side. Here, considered for base year 2014.
5.	Initial marginal value of water for optimization in VALORAGUA	2 to 20Cents/KWh	The range of initial marginal value of water is based on the current situation. It is better to take wider range, which covers different types of plants. Low for ROR, highest for reservoir.
6.	Monthly inflow data	30 years data	The quality of hydrological data is checked by visual comparison with different years/nearby stations and by statistical techniques, such as Double Mass Curve (DMC). Inconsistency in data should be checked and corrected if any.
7.	Number of hydrocondtions	3-5	Equal probability of hydrocondition is assumed in the optimization model considering all hydroconditions equally likely. It is better to assign different probabilities and to assess hydrological risk.
8.	Reserve margin Minimum Maximum	 -30% to 25% Up to 100%	The reserve margin is based on power balance under the configurations taken for optimization. It is also better to consider import and export scenario, loss of single largest unit, e.g. 5 to 10 day/year for Nepal. 10% appropriate for Large plants.
9.	LOLP	1% to 25%	Initial value of the LOLP is fixed in such a way that the optimization program runs under all conditions with different configurations year by year. The value of the LOLP should be low, preferably below 5%.
10.	Discount rate	In the range of 10%	Separate discount rate for domestic and foreign can be

			applied.
11.	Interest rate	In the range of 10%	Considered as present practice in Nepalese market.
12.	Interest during construction	In the range of 10%	Present practice in Nepalese context.

9.2.1 Load Duration curve (LDC)

Latest available data should be used for developing LDC. The duration of LDC in discrete load step during 30 years period will be different from prevailing condition, which should be considered while optimizing the duration. The large plants should also be accommodated within the discrete load steps.

9.2.2 Load forecasting

The NEA demand forecast model is econometric type model based on the trend analysis. Other suitable model can also be developed. The load factor with and without load shedding can also be considered, taking into account the future condition.

9.2.3 Probability of hydrocondtion

Different probability of hydrocondtions can be assumed in VALORAGUA and assess hydrological risk.

- Type of hydrocondition: 3 to 5 (Dry, Mean, Wet, Very dry, Very wet)
- Probability of hydro-conditions = based on data availability

9.2.4 Thermal Plants, Import and ExportData

- Operation and maintenance (O & M) cost of thermal plants = 40Cents/KWh (2013/14, to be higher range) and can be based on fluctuation of fuel cost. The price can be fixed from the trend of 5-10 years.
- Cost of energy not served (ENS) = 55 Cents/KWh to 1USD/KWh
- Import system: Possibility of 300MW until 2015 and up to 1000MW after the construction of 400kV transmission system, considered 1000 MW in total
- The export is usually treated as simple demand. If the LRMC is distorted, negative value can also be assigned.

9.2.5 Hydoplants

- Design discharge = nominal flow
- Internal consumption fraction = 1%
- Forced outage rate = 5%

9.2.6 Cost of Hydropower Project

Feasibility report is the basis for the cost of hydropower projects. The cost of project should be taken from detailed study if available.

9.2.7 Commercial Operation Date (COD)

While preparing the configurations for expansion candidate, the commercial operation date should be fixed in model considering delay in project.

9.2.8 Reservoir Characteristics Data and Parameters

- For ROR project, si = 0, alpha = 0, beta = 1

9.2.9 Cost of Unserved Energy (CUE)

Appropriate value of CUE should be fixed based on study and research. One way to estimate is to relate CUE with per capita income.

9.2.10 Initial Marginal value of water

It is better to take wider range, which covers different types of plants (higher for reservoir, lower for ROR).

9.2.11 Reserve Margin

Different factors can be considered while assigning the value of reserve margin.

a. Based on loss of single largest unit in %

b. Based on probabilistic approach, e.g. 5 to 10 day/year for Nepal

c. Negative without import, e.g. -30%

d. Positive with export, e.g. 10%

e. Assessing the impact of gradually decreasing reserve margin from -30% to zero and eventually increasing up to 20% (Sensitivity)

9.2.12 Spilled Hydro-energy

The value of spilled hydro-energy is obtained from the output of WASP. It will be beneficial to consider how to use that energy.

9.2.13 LRMC Computation

Higher incremental value (in perturbation approach) can be considered for large plants. Other methods, such as long run average cost, long run incremental cost can also be applied for LRMC computation.

9.3 RECOMMENDED APPROACH FOR DIFFERENT POSSIBLE CASES

9.3.1 Selecting Pool of Projects for Optimizations

Selection of projects is based on the national importance of the projects. Projects having installed capacity more than 5MW should be given more priority than projects having lesser than 5MW installed capacity. Projects connected to INPS are considered in the system optimization, discarding isolated plants.

9.3.2 More than 50 Plants (Limitations of VALORAGUA)

In VALORAGUA, the maximum 50 number of hydro projects can be input in the model. In WASP, 2 hydroelectric plant types, each one composed of up to 30 projects are allowed (60 maximum). Hence, the most important/most significant projects should be selected in case of large number of hydroplants. If there are many smaller projects, the contributions of these projects can be lumped into a single fictitious project, for which the database also need to be revised accordingly.

9.3.3 ROR and Storage Plants

Continuous load duration curve (LDC) is approximated as a stepped LDC. For the expansion plan, the type of plants representing the part of load, such as base and peak and the date of commissioning should be considered according to the nature of the project and possibility/feasibility of construction. Expansion plan should be based on the strengths and limitations of specific type of plants.

9.3.4 Thermal Limitations

For a country like Nepal, the thermal option is much more expensive than hydro option. Therefore, number of thermal plants in expansion plan should be restricted to a minimum number.

9.3.5 Export and Import Case

Export or import of electricity should be considered in the expansion plan as per the technical possibility and the surplus/deficit of power produced.

9.3.6 Project Cost

VALORAGUA model produces the running cost only, whereas capital cost is also required for WASP model. The cost of project considered as expansion candidate is based on feasibility study. It is better to assign the cost based on detailed study.

9.3.7 Commercial Operation Date

Configuration of expansion candidates is based on the commercial operation date specified in feasibility/detailed study. Delay in the completion of the project should also be taken into account while preparing configurations.

9.3.8 Operation and Maintenance (O & M) Cost of Thermal Plant

The O&M cost of thermal plants is based on the current situation. It is better to consider the fluctuation of fuel cost (especially for diesel plant). The price can be fixed from the trend of 5-10 years.

9.3.9 Cost for Transmission

The cost of transmission of generated electricity to a base station is added in the total estimated cost, which is implicitly considered.

9.3.10 Possibility of Other Softwares

VALORAGUA and WASP are traditional softwares, written in DOS requiring intensive data. Other softwares such as MESSAGE, ProdRisk are recommended for system planning.

9.3.11 Use of Guideline for NEA, DoEDand IPP

VALORAGUA-WASP modeling is a system optimization, not an optimization of a single plant. However, the VALORAGUA generates the cost and other factors for each plant, from which the characteristics of individual plant can also be studied. This outcome is useful for IPP. WASP generates year by year output for the system. The combined output will be useful for policy makers like DoED, NEA and other governmental agencies.

Section B

Section B

Individual Project Optimization

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LIST OF FIGURES

1. INDIVIDUAL PROJECT OPTIMIZATION

1.1 INTRODUCTION

The objective of component optimization of hydropower projects is to adopt the best combination of different components e.g. weir/dam height, settling basin, headrace system, penstock pipe and number of units.

For Run-of-river (RoR) scheme, the component optimization is done for waterways (canal, tunnel, penstock and tailrace) and the number of units. For the storage type hydropower scheme, in addition to above, the dam height including pondage area should be optimized.

In RoR scheme, sizing of components like weir, intake, settling basin, forebay, surge tank, powerhouse are normally governed by hydraulic requirement and hence generally not optimized individually. Cost for access road, land acquisition, and transmission line are independent upon installed capacity and are considered constant for all alternatives. However, structures like canal, tunnel, penstock and tailrace shall be optimized based on the revenue lost due to head loss and cost of construction. The scheme with maximum Internal Rate of Returns (IRR) and Benefit Cost Ratio (B/C Ratio) shall be adopted as the optimum installed capacity.

For storage schemes, the dam height should be optimized based on the storage volume and energy generated with different installed capacity. For each height and installed capacity of the dam, the components like tunnel, penstock should be optimized separately. The installed capacity for which the NPV is the maximum shall be selected as the optimum.

Parameters for Optimization studies

Some of the financial parameters required for optimization study are

- Discount rate
- Period of analysis
- Tariff rate
- Exchange rate
- Debt equity ratio
- Period of analysis

Run-of-river type scheme Optimization

I. Range of Options for Optimization

- Nearly 9 or 10 alternatives with installed capacity corresponding to the plant discharge within the range of 70% to 25% probability of exceedence at an equal increment should be considered.

II. Conceptual layout and sizing

- A conceptual layout of the project for the base case (normally for 40% exceedance) shall be prepared and the components like weir, intakes, settling basin, powerhouse shall be sized accordingly. Layout of other structures like canal, tunnel, forebay/surge shaft, penstock, tailrace shall also be determined.
- Project parameters like canal, tunnel, penstock shall be optimized for each alternatives.
- Project cost for each alternative shall then be determined. The basis for the cost determination shall be the hydraulic requirement and the optimized size of components.

- The installed capacity with maximum benefit and least cost shall be adopted as optimum. Normally, maximum NPV shall be selected as an optimum capacity.

Conditions of optimality

- Condition 1 : Combination of inputs
- Condition 2 : Combination of outputs
- Condition 3 : Level of outputs

Condition 1: Combination of inputs

Optimal production process shall use the least costly combination of inputs to produce any level of output. For instant, sizes of two dams to provide flood control must be selected to achieve the desired level of flood reduction at minimum cost.

Condition 2: Combination of outputs

The optimum combination of outputs achieves a given level of benefits at least cost. For example, with two outputs, such as irrigation and hydropower, the total production must be divided between the two to maximise benefits.

Condition 3: Level of output

This condition determines the optimum level of output, on the assumption that conditions 1 and 2 (combination of inputs and combination of outputs) have already been met.

1.2 INSTALLED CAPACITY OPTIMIZATION

The power generated by a hydropower plant is a function of head and discharge, which is given by the following equation:

$$P = \eta\gamma QH$$

Where P =power, γ = specific weight of water, Q = discharge, H = Head, and η = overall efficiency

Energy = P*time

Revenue = Energy*rate

The power can be calculated for different percentile of available flow. Increasing the percentile of available flow, the design discharge reduces. Decreasing the design discharge, the size of hydropower components such as intake, settling basin, conveyance system, penstock etc. decreases. Hence, the project cost reduces. But, the project capacity as well as energy also reduces due to the decrease in design discharge, thereby decreasing annual revenue. Hence the revenue and cost is traded to get optimum benefit. For this generally, the flow with 25% available to 70% available with certain interval is calculated from the flow duration curve, and power and revenue is calculated. The cost for each option is also calculated and then optimization study is done. The optimum capacity is taken as installed capacity.

1.3 DAM

Dams and weirs are primarily intended to divert the river flow into the water conveyance system leading to the powerhouse. Dams also produce additional head and provide storage capacity.

The choice of dam type depends largely on local topographical and geotechnical conditions. For instance if sound rock is not available within reasonable excavation depth, rigid structures such, as concrete dams are difficult. Conversely, for narrow valleys, it can be difficult to find space for separate spillways, and concrete dams can be the natural choice with their inherent possibilities to integrate spillways and other components in the dam body.

1.3.1 Embankment Dam

The embankment dam may be constructed either as the earth dam or as rockfill dam. They are of three types:

- Homogeneous
- Zoned
- Diaphragm type

1.3.1.1 Design Criteria of Embankment Dam

The basic principle of design is to produce a satisfactory, functional structure at a minimum total cost. Consideration must be given to maintenance requirements so that savings achieved in the initial cost of construction do not result in excessive maintenance costs. Maintenance costs vary with the provisions of upstream and downstream slope protection, drainage features, and the type of appurtenant structures and mechanical equipment. To achieve minimum cost, the dam must be designed for maximum use of the most economical materials available, including materials excavated for its foundations and for appurtenant structures.

An earthfill dam must be safe and stable during all phases of the construction and the operation of the reservoir. To accomplish this, the following criteria must be met:

(a) The embankment, foundation, abutments, and reservoir rim must be stable and must not develop unacceptable deformations under all loading conditions brought about by construction of the embankment, reservoir operation, and earthquake.

(b) Seepage flow through the embankment, foundation, abutments, and reservoir rim must be controlled to prevent excessive uplift pressures; piping; instability; sloughing; removal of material by solutioning; or erosion of material into cracks, joints, or cavities. The amount of water lost through seepage must be controlled so that it does not interfere with planned project functions.

(c) The reservoir rim must be stable under all operating conditions to prevent the triggering of a landslide into the reservoir that could cause a large wave to overtop the dam.

(d) The embankment must be safe against overtopping or encroachment of freeboard during occurrence of the IDF (inflow design flood) by the provision of sufficient spillway and outlet works capacity.

(e) Freeboard must be sufficient to prevent overtopping by waves. Camber should be sufficient to allow for settlement of the foundation and embankment, but not included as part of the freeboard.

(g) The upstream slope must be protected against wave erosion, and the crest and downstream slope must be protected against wind and rain erosion.

An earthfill dam designed to meet the above criteria will prove permanently safe, provided proper construction methods and control are achieved.

1.3.2 Concrete Dam

Concrete dams are categorized according to how they function statically, and fall into one of the following groups.

1.3.3 Gravity Dams

These are dependent on their own mass for stability. Their cross-section is basically triangular in order to provide adequate stability and stress distribution across the foundation plane. The upper part is normally rectangular in order to provide adequate crest width for installation and transportation.

1.3.4 Buttress Dams

These dams consist of a continuous upstream face that is supported by buttresses at regular intervals.

1.3.5 Arch Dams

These dams function structurally as horizontally laid out arches that transfer the water pressure on the upstream face into the abutments rather than into the foundation.

Typical loads acting on concrete dams are as follows.

The horizontal loads

- Lateral water pressure,
- Pressure from soil or deposited sediments,
- Ice pressure,
- Loads from floating objects and debris,
- Downstream water pressure,
- Dynamic acceleration from earthquakes,
- Incremental water pressure during earthquakes.

The vertical loads

- self-weight of the dam,
- Weight of water on inclined upstream surface,
- Uplift pressure from pore water,
- Dynamic load from earthquakes.

Concrete dams are designed for:

Stability against rotation and overturning

Stability against translation and sliding

Over-stress and material failure

1.3.6 Dam Height Optimization

For fixing the dam height, area elevation curve and storage elevation curve can be developed from a contour plan which helps in fixing the maximum operating level of the reservoir and thus fixing the height of the dam. Area between successive contours and elevation of contours is plotted to get area elevation curve. The volume of storage corresponding to different contours can be calculated either by using prismoidal or trapezoidal formula. The optimum or economic dam height is that height, corresponding to which the dam per unit of storage is minimum. This requires the estimation of construction cost for different heights of dam and also corresponding storages in reservoir. A curve for dam height versus construction cost per unit storage is plotted. The lowest point on this curve gives the height of the dam for which the cost per unit of storage is minimum. Alternatively, the cost and benefit from the reservoir is calculated separately for different height of dam, from which net benefit (benefit-cost) can be calculated. A curve for net benefit versus height of dam is plotted. The height of dam having maximum net benefit is the optimum dam height.

1.3.7 Optimization of Gravity Dam Section

The height of the dam is fixed based on the requirements of hydropower energy, size of reservoir and possibility for the acquisition of land. After fixing dam height, the section of dam can be optimized by various optimization techniques, such as

- Dynamic programming
- Genetic programming
- Particle swarm optimization

1.3.8 Cost Based Approach

The costs involved in construction of a dam are that of mass concreting and base excavation. The other costs include making the diversion canal, installing the power generation equipments and transportation costs which do not vary with the section geometry. The objective of optimization is to reduce the cost. Therefore, the objective function represents the total cost and constraints on heights, slope, factor of safety for sliding and overturning, and stress at heel. The constants are listed below: Height of the dam (H), Height of reservoir, Peak ground acceleration and Minimum width of crest

1.3.9 Softwares used for optimization

1.3.9.1 CADAM software

CADAM (Computer Analysis of Gravity Dams) is freely available software which performs the stability analysis of gravity dam (http://www.struc.polymtl.ca/cadam/). The dam geometry, material properties, the various load conditions, cracking options, and load combinations are first specified as input data for subsequent structural analyses. Additional input data such as added masses, floating debris, silts and many more may be included in the model. The following analysis options are currently available:

- Static analysis
- Seismic analysis
- Post-seismic analysis
- Incremental load analysis
- Probabilistic safety analysis

The evaluation of the structural stability of the dam against sliding, overturning and uplifting is performed considering two distinct analyses:

- A stress analysis to determine eventual crack length and compressive stresses,
- A stability analysis to determine the (i) safety margins against sliding alongthe joint considered, and (ii) the position of the resultant of all forces acting on the joint.

The gravity method is based (a) on rigid body equilibrium to determine the internal forces acting on the potential failure plane (joints and concrete-rock interface), and (b) on beam theory to compute stresses. The use of the gravity method requires several simplifying assumptions regarding the structural behaviour of the dam and the application of the loads.

The following geometric elements can be optimized using CADAM: the base width; u/s and d/s slope and crest width keeping the height of the dam constant. The amount of concrete used and the base excavation length are the two main factors on which cost of a dam depends. The section of dam which gives minimum length of excavation and minimum weight of dam will be the most economical. Based on prevalent cost, the optimum section of the dam is worked out on the basis of total cost of excavation and concreting of the dam.

1.3.9.2 Opti-Dam program

Opti-Dam program, developed by Banerjee et al., is a program used for the optimization and safety analysis of gravity dam. The program is based on pseudo static analysis given in IS:6512-2003 (IS 6512, 2003). The Opti-dam program generates optimum dam sections for a particular dam height when subjected to all known of possible loading.

Pseudo Static Analysis as per Indian Standard: A concrete gravity dam section can be analyzed as a block, considering all the forces acting on it. Pseudo static analysis is very simple and effective analysis technique for safety evaluation of a concrete gravity dam.

There are 7 load combinations prescribed to ensure the stability analysis of a dam in Indian Standard. The criteria for load considerations are: Self weight of dam, Upstream reservoir level, Silt pressure, Tail water level, Ice and wave pressure, Uplift pressure, Earthquake load and permissible tensile stress. Optimization of a concrete gravity dam is achieved by minimizing the involved cost of construction. The calculated factor of safety for sliding (F) should be always greater than 1 for a safe section (IS 6512, 2003).

1.3.9.3 ABAQUS: A Finite Element Analysis Package

ABAQUS is a general-purpose Finite Element Analysis (FEA) software package. Finite Element Analysis is a numerical method a complex system is sub-divided into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all, creating a comprehensive explanation of how a system acts as a whole. These results can then be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations. ABAQUS offers a wide range of capabilities for simulation of linear and nonlinear applications. Problems with multiple components are modelled by associating the geometry defining each component with the appropriate material models and specifying component interactions. In a nonlinear analysis ABAQUS automatically chooses appropriate load increments and convergence tolerances and continually adjusts them during the analysis to ensure that an accurate solution is obtained efficiently. Main advantage of ABAQUS is that it can perform both nonlinear static as well as nonlinear dynamic analyses.

1.3.10 Optimization of EarthenDam Section

The safety and economics of an earthen dam depend upon the cross section of the dam. Therefore, designing a dam essentially means the determination of cross sectional parameters of the dam. Of course, the determination of materials and methods to be used in the construction of the dam is equally important for designing the dam. But for the purpose of the optimization problem, it is assumed that these factors are identified and fixed.

The main objective of the problem is to minimize the area of cross section of the dam which is related to minimizing the cost of material for building the dam. The main constraint is that of ensuring the factors of safety. The existing standards are: the upstream factor of safety should be at least 1.3 and the downstream factor of safety should be at least 1.5. The problem of finding the factor of safety of a given design can itself be formulated as a mathematical programming problem.

1.4 SPILLWAY

Spillway is a structure constructed at a dam site for effective disposing of surplus water from upstream to downstream. It is a safety valve for a dam. There is clear difference between dry and wet season flows, flood flows can have catastrophic effects on whatever structure is built in the stream. To avoid damage the excess water must be safely discharged over the dam or weir. For this reason carefully designed overflow passages are incorporated in dams as part of the structure. These passages are known as spillways. Due to the high velocities of the spilling water, some form of energy dissipation is usually provided at the base of the spillway.

The basic purpose of the spillway is to provide a means of controlling the flow and providing conveyance from reservoir to tailwater for all flood discharges up to the spillway design flood (SDF). The spillway can be used to provide flood-control regulation for floods either in combination with flood-control sluices or outlet works, or in some cases, as the only flood-control facility. A powerhouse should not be considered as a reliable discharge facility when considering the safe conveyance of the spillway design flood past the dam. A terminal structure to provide energy dissipation is usually provided at the downstream end of the spillway. The degree of energy dissipation provided is dependent upon the anticipated use of the spillway and the extent of damage that will occur if the terminal structure capacity is exceeded. The standard project flood is a minimum value used for terminal structure design discharge. The designer must keep in mind that damage to the dam structure that compromises the structural integrity of the dam is not acceptable. Acceptance of other damages should be based on an economic evaluation of the extent of damage considering the extremely infrequent flood causing the damage.

1.4.1 Design Consideration of Spillway

- Spillway should be designed properly so as to dispose of the excess water without causing any damage to the dam or any appurtenant.
- Spillway should be structurally and hydraulically adequate.
- Design discharge for spillway should be appropriate (1000yrs return period is taken for design of large dams)

1.4.2 Location of the Spillway

A spillway can be located either within the body of the dam or at one end of it or entirely away from it, independently in a saddle.

1.4.3 Selection of Spillway Size and Type

1.4.3.1 General Considerations

In determining the best combination of storage capacity and spillway capacity to accommodate the selected inflow design flood, all pertinent factors of hydrology, hydraulics, design, cost, and damage should be considered. In this connection and when applicable, consideration should be given to such factors as

- the characteristics of the flood hydrograph,
- the damages that would result if such a flood occurred without the dam,
- the damages that would result if such a flood occurred with the dam in place,
- the damages that would occur if the dam or spillway were breached,
- the effects of various dam and spillway combinations on the probable damages upstream and downstream of the dam (as indicated by reservoir backwater curves and tailwater curves),
- the relative costs of increasing the capacity of spillways, and

- the use of combined outlet facilities to serve more than one function (e.g. control of releases and control or passage of floods.)

The discharge through spillway is calculated by the equation:

$Q=CLH^{3/2}$

Where,

C is the coefficient of discharge,

L is the length of the spillway crest and,

H is the static head.

The coefficient of discharge C is determined by scale model tests; its value normally ranges between 1.66 for broad crested weirs to 2.2 for a weir designed with the optimum profile, when the head equals the design head.

1.4.4 Types of Spillway

- Free Overfall (Straight Drop) Spillways
- Ogee (Overflow) Spillways
- Chute (Open Channel or trough) Spillways
- Side Channel Spillways
- Drop Inlet (Shaft or Morning Glory) Spillways
- Conduit and Tunnel Spillways
- Culvert Spillways

1.5 CANAL

The objective of the design of canal is to determine the size and configuration that meets the criteria for the least cost. The cost determination usually is not limited to construction cost alone but often includes an economic analysis of costs and benefits. The best form of cross-section of a canal is a section which gives maximum discharge for a minimum cross-section i.e. the wetted perimeter should be minimum for economical channel section.

1.6 TUNNEL

For the optimization of diameter of the tunnel, the factors to be considered are: velocity requirement, head loss in tunnel, interest of capital cost of tunnel, annual operation and maintenance charge. The optimization is based on the increment of tunnel cost with respect to the tunnel diameter (sectional area) and the value of energy lost which is a function of the tunnel sectional area. A larger diameter for a given discharge leads to smaller head losses and hence greater will be the net head available to the turbine. Thus the power and energy production will be increased. On the other hand a greater size tunnel means less velocity and greater capital investment. Therefore, a size that will give the least capital cost over the lifetime of the plant is considered to be the optimum diameter / sectional area. A typical curve for the tunnel optimization is presented in Figure 1-1.

The steps for the optimization of tunnel are explained below:

Take different velocities of the flow V1, V2, V3………Vn in the range between minimum permissible velocity and maximum permissible velocity of the flow.
Minimum permissible velocity, V > 0.3 m/s in case of silty water and,

Minimum permissible velocity, V > 0.3-0.5 m/s for water carrying fine sand,
Maximum permissible velocity, V < 2.0-2.5 m/s for unlined tunnels,
Maximum permissible velocity, V < 3.0-5.0 m/s for concrete lined tunnels,
Maximum permissible velocity, V < 4.0-9.0 m/s for steel lined tunnels.

i. Calculate the area (A1, A2, A3……….An) of the tunnel for different velocities of the flow by using relation A=Q/V.
ii. Calculate the equivalent diameter (D1, D2, D3…….Dn) of the tunnel for different tunnel sections.
iii. Calculate the hydraulic radius (R1, R2, R3….Rn) of the tunnel for different tunnel sections.
iv. Calculate the headloss in tunnel using Manning's formula or Darcy's formula whichever gives the maximum headloss.

Manning's Headloss= $h_f = \frac{V^2 n^2 L}{R^{\frac{4}{3}}}$

Darcy's Headloss = $h_f = \frac{fLV^2}{2gD}$

Where,

h_f - Frictional loss

f - Darcy's frictional factor

V - Velocity of water in the tunnel in m/s

L - Length of the tunnel in m

R - Hydraulic radius

n - Rougosity coefficient

For concrete lined tunnel the value of rougosity coefficient *n* varies from 0.012 to 0.018. For unlined tunnel the value of *n* depends upon the nature of rock and the quality of trimming. Recommended values of *n* for various rock surface conditions are given below:

Surface Characteristics	**Minimum value of n**	**Maximum value of n**
Very rough	0.04	0.06
Surface trimmed	0.025	0.035
Surfaced trimmed and invert concreted	0.02	0.03

v. Calculate the energy output of the headloss as below:

Energy= 9.81x Q x h_f x η x 365 x 24

Where, $h_f$is total headloss in the tunnel in meter.

vi. The cost of the energy due to headloss in the tunnel is calculated multiplying energy with current unit cost rate.
vii. The cost of the tunnel is calculated considering the excavation cost and tunnel supports cost. This cost is converted into the annual cost by multiplying the following capital recovery factor:

Capital Recovery Factor = $\frac{i(1+i)^n}{(1+i)^n-1}$

Where,

i = interest rate

n= project life in years

viii. The total cost is calculated adding energy cost and annual cost of the tunnel.

ix. Then, the graph is plotted between the diameter of the tunnel vs cost of the energy loss, cost of the tunnel and total sum of the cost for every diameter as shown in the Figure 1-1. By observing this graph, the optimum diameter of the tunnel will be found out in which total (combined) cost is minimum.

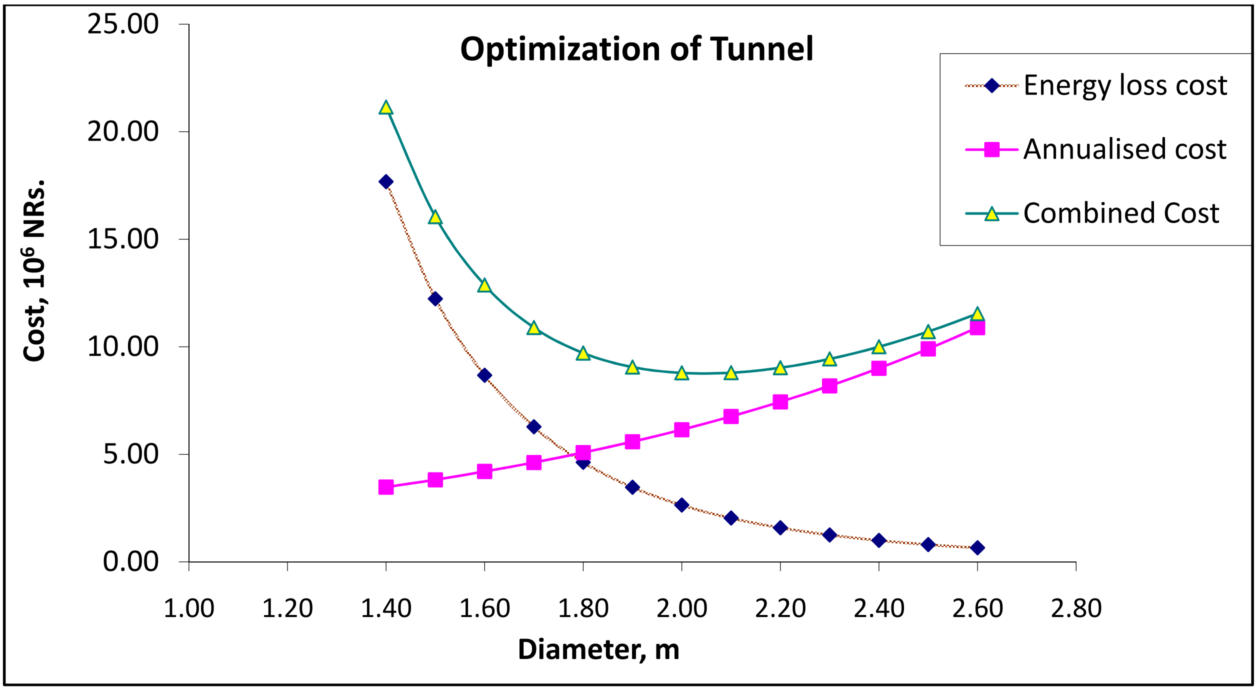

Figure 1-1: Sample curve for Optimization of Tunnel

1.7 PENSTOCK

The inside diameter of penstock should be determined to be economical diameter. The economical diameter is a diameter which minimizes the sum of annual cost of penstock pipe and annual value of power loss due to loss of head.

The diameter can be determined analytically as follows:

The thickness of pipe (t) considering hoop stress (σ) is $t = \frac{PD}{2\sigma}$ where D =internal diameter of penstock.

Volume of penstock = πDtL where L=length of penstock

Volume =$\pi D \frac{PD}{2\sigma} L = \frac{\pi D^2}{2\sigma} PL$

Let Cost of pipe (steel) = a per unit volume

Total cost = $a \frac{\pi D^2}{2\sigma} PL$

Let $\frac{a\pi PL}{2\sigma}$ =X=constant

Total cost of pipe= XD^2

Head loss (h_f)=$\frac{fLV^2}{2gD} = \frac{8fL}{\pi^2 gD^5} Q^2$ where f = friction factor, V = velocity, Q = discharge

Power cost = $\eta\gamma Q h_f = \eta\gamma Q \frac{8fL}{\pi^2 gD^5} Q^2$

Energy = Power*time*rate

Let Rate = b/KW/annum

Total cost = $b\eta\gamma \frac{8fL}{\pi^2 gD^5} Q^3$

Let $Y = b\eta\gamma \frac{8fLQ^3}{\pi^2 g}$

Then total revenue cost (power lost cost) = $\frac{Y}{D^5}$

Total cost (TC) = total cost of pipe + power lost cost = $XD^2 + \frac{Y}{D^5}$

For optimal diameter, $\frac{d(TC)}{dD} = 0$

$$2XD - \frac{5Y}{D^6} = 0$$

$$D = \left(2.5\frac{Y}{X}\right)^{1/7}$$

D is the most economical diameter of the penstock.

Further, economical diameter is also obtained graphically by taking different diameters, computing cost of penstock, cost of energy loss and total cost for each diameter taken, and then plotting these three costs on a graph. The diameter corresponding to minimum total cost is taken as economical diameter. The graphical process of finding the optimum diameter is same as explained in the optimization of the tunnel.

1.8 DESIGN PRINCIPAL FOR SETTLING BASIN

The basic principle of settling is that the greater the basin surface area and the lower the through velocity, the smaller the particles that can settle. The settling basin shall be designed to remove as much of the sediment load in the water as is economically and hydraulically possible. A settling basin must satisfy the following design considerations:

i) Settling capacity

a. The size of the basin must be large enough to allow a large percentage of the fine sediment to fall out of suspension and be deposited on the bottom.

b. The geometry of the inlet and outlet transitions and any other curvatures must be such as to cause minimum turbulence, which might increase the trapping efficiency of the basin.

ii) Storage capacity

The basin should be able to store the settled particles for some time unless it is flush out.

iii) Flushing capacity

The basin should be able to flush all these settled particles along with the incoming flow in the basin by opening flushing gates or valves.

1.9 DESIGN PRINCIPAL FOR SURGE TANK

i. The surge chamber must be so located that pressure variations caused by water hammer are kept within acceptable limits

ii. The chamber must be stable, i.e. the surge resulting from small partial load changes must be naturally damped and must not under any conditions be sustained or amplified

iii. The chamber must be of such size and so proportioned that:

- It will contain the maximum possible upsurge (unless a spillway is provided),
- The lowest down-surge will not allow air to be drawn into the tunnel,
- The range of surges must not be greater enough to cause undesirably heavy governor movements or difficulty in picking up load.

1.10 SELECTION OF TYPES OF TURBINES AND NUMBER OF UNITS

Turbine selection and plant capacity determination requires the detailed information on head and possible plant discharge. The usual practice is to base selection of the annual energy output of the plant and least cost of the energy of the particular scale of the hydropower installation.

Factors to be considered while selecting turbine

I. Available head and its fluctuations

a. Very high head > 350m - Pelton turbine (No other)

b. High head (150 - 350)m - Pelton or Francis (For higher specific speed Francis turbine is more compact and economical than Pelton turbine)

c. Medium head (60 - 150)m - Francis turbine is usually adopted.

d. Low head below 60m - Between 30 - 60 m both Kaplan and Francis turbine can be used. Former is more expensive but yields higher efficiency at part load and over load. Kaplan turbine is generally used under 30m. Propeller turbines are commonly used for head up to 15m. They are adopted only when there is practically no load variation.

II. Specific speed: High specific speed is essential where head is low and output is large because otherwise the rotational speed will be low which means cost of turbo generator and powerhouse will be high. On the other hand, there is practically no need of choosing a high value specific speed for high installation because even with low specific speed high rotational speed can be attained with medium capacity plant.

III. Rotational speed: Rotational speed depends upon specific speed. Also the rotational speed of an electrical generation with which the turbine is to be directly coupled depends on frequency and number of pair of poles. The value of specific speed adopted should be such that it will give the synchronous speed of the generator.

IV. Efficiency: The turbine selected should be such that it gives highest overall efficiency for various operating condition.

V. Deposition of turbine shaft: Experience has shown that the vertical shaft arrangement is better for large sized turbine; therefore, it is almost universally adopted. In case of large size impulse turbine, horizontal shaft arrangement is almost employed.

VI. Conveyance or Maintenance: Maintenance of the reaction turbine is more costly than the impulse turbine.

VII. Water quality: Quality of water is more crucial for reactive turbine than reaction turbine.

1.10.1 Numbers of Turbine

It is most effective to have a minimum number of units at a given installation. Increase in turbine size and number of units increase the efficiency of the plant as shown in Figure 1-2. However, multiple units may be necessary to make the most efficient use of water where flow variation is great.

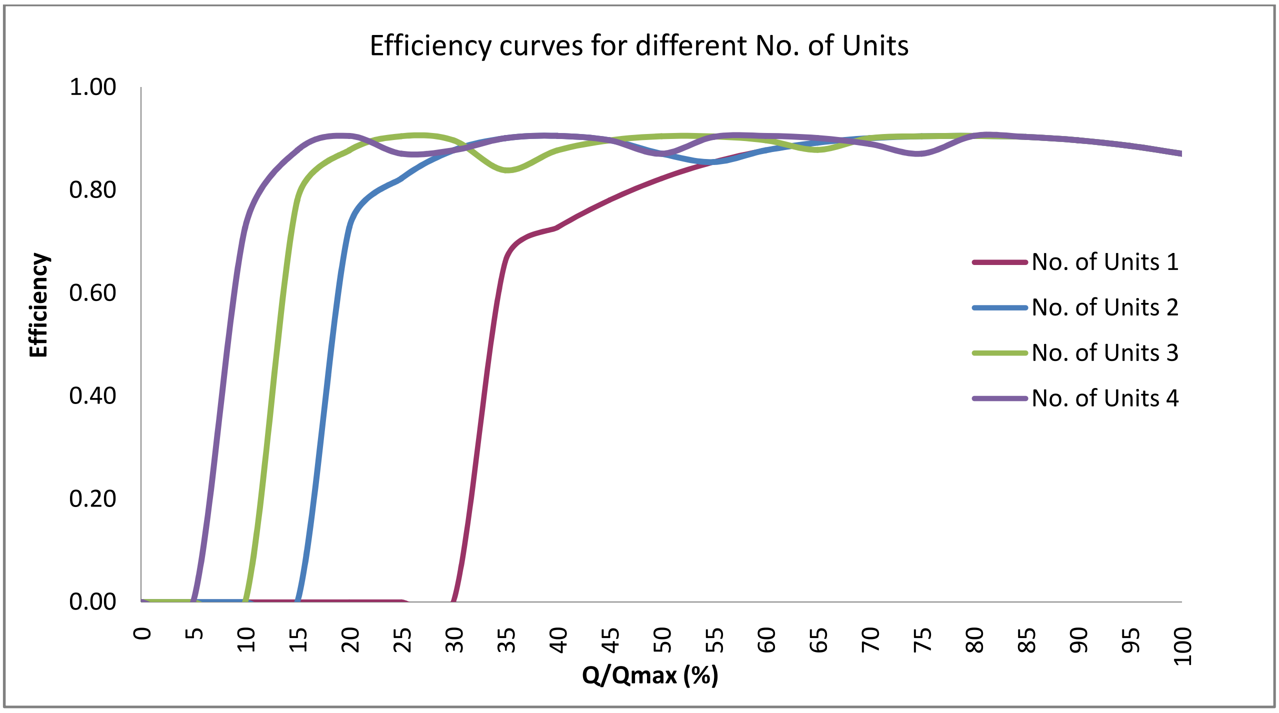

Figure 1-2: Efficiency curves of turbines for different numbers of units

Factors as space limitation by geological characteristics of existing structure may dictate large or small units. The difficulty in transportation or large runners sometimes makes it necessary to limit their size. Isolation system may require more number of units. The percentage of load covered by the plant is another important factor if the contribution of the plant to system is more; the number of units should be more. For the power plant it is better to make the units are identical also somehow dictates the number of plants. If the power generation from the plant is fluctuating, the number of units will be increased and vice versa.

1.11 INDIVIDUAL PROJECT OPTIMIZATION USING WASP

The individual plant can also be optimized by using the WASP model. In this method, the hydro-plant, which has to be optimized, is divided into different installed capacities and prepared the input data for these options similarly as explained in the system optimization part. The least cost expansion of these different options will be estimated by using the model and cost curve is plotted against these installed capacities. By observation of cost curve, the optimized installed capacity of the plant is selected at which the least expansion cost is minimum.

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Appendices

Guidelines for Power System Optimization of Hydropower Projects

December 2015

Appendix -1

Load Duration Curve (LDC)

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Table of Figures:

1. LOAD DURATION CURVE (LDC)

The latest data on hourly values of load of a day of a month having peak demand covering 2012 August to 2013 July is available for preparing monthly load duration curve (LDC). Five steps (maximum allowable steps in VALORAGUA) are considered in LDC for obtaining the data required in the VALORAGUA model. The coefficients of fifth order polynomial equation representing the LDC, the time duration of each load step and the fraction of peak power is optimized using the auxiliary tool WASPLDC and DIAGOPTM available within VALORAGUA model.

1.1 THE FOLLOWING IS THE COEFFICIENTS OF THE FIFTH ORDER POLYNOMIAL EQUATION OBTAINED FROM WASPLDC FOR THE LDC DATA.

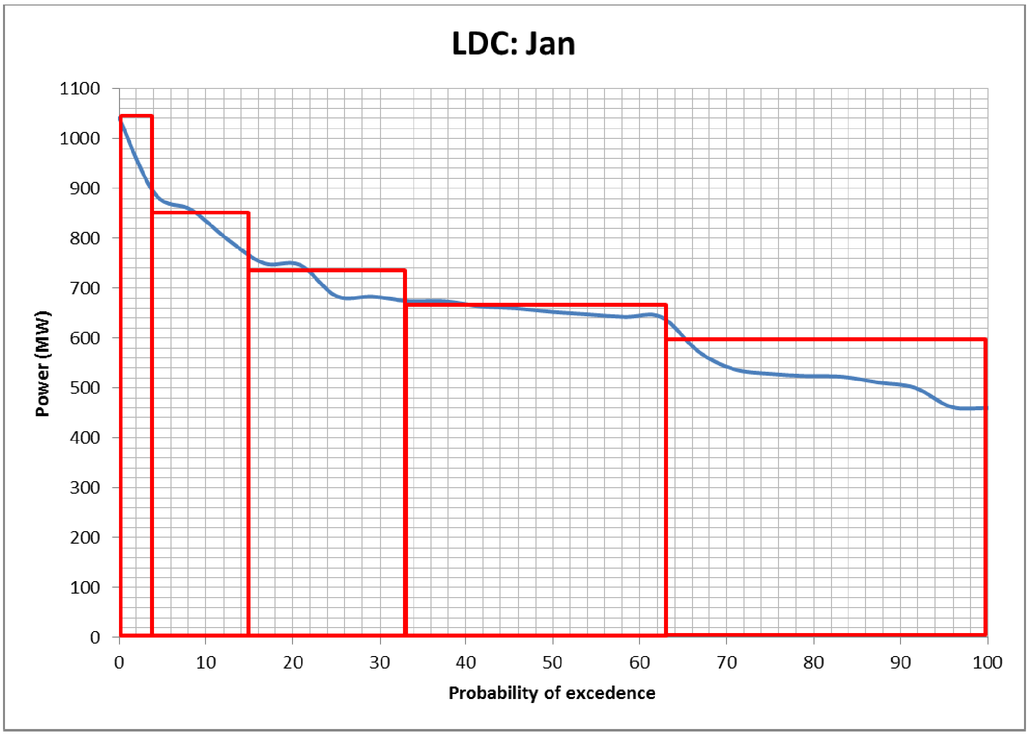
Table 1-1: Coefficients of the fifth order polynomial equation

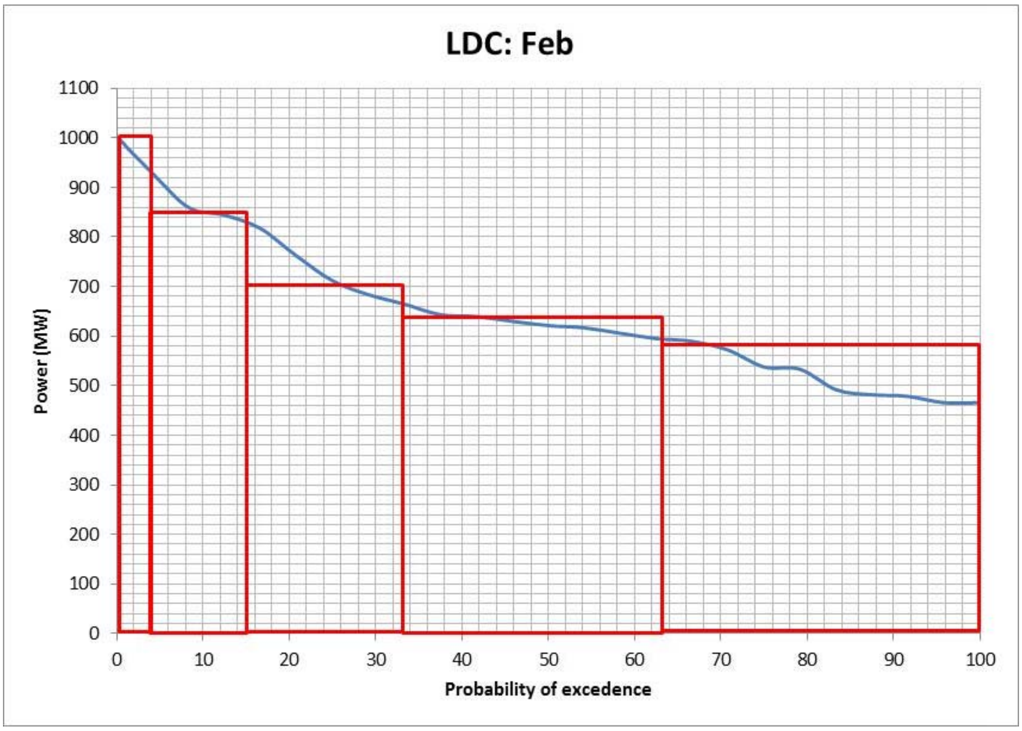
Month	A0	A1	A2	A3	A4	A5
Jan	1.0000	-2.8852	9.5950	-15.3243	10.8350	-2.7618
Feb	1.0000	-1.2649	2.0056	-3.3404	4.1922	-2.0569
Mar	1.0000	-1.3636	2.5381	-4.5041	5.3152	-2.4539
Apr	1.0000	-1.7891	5.2904	-9.8477	9.4224	-3.5068
May	1.0000	-1.8388	5.5570	-10.4326	9.9904	-3.7090
Jun	1.0000	-3.1548	11.5001	-20.2684	16.8152	-5.3767
Jul	1.0000	-2.8302	8.2488	-10.5065	5.3813	-0.7455
Aug	1.0000	-3.4718	13.7085	-26.9957	25.1686	-8.8759
Sep	1.0000	-3.2952	11.9500	-22.0191	19.6319	-6.7215
Oct	1.0000	-3.5642	13.5949	-25.7003	23.1841	-7.9710
Nov	1.0000	-3.5642	13.5949	-25.7003	23.1841	-7.9710
Dec	1.0000	-2.2994	5.4637	-6.1302	3.1947	-0.7489

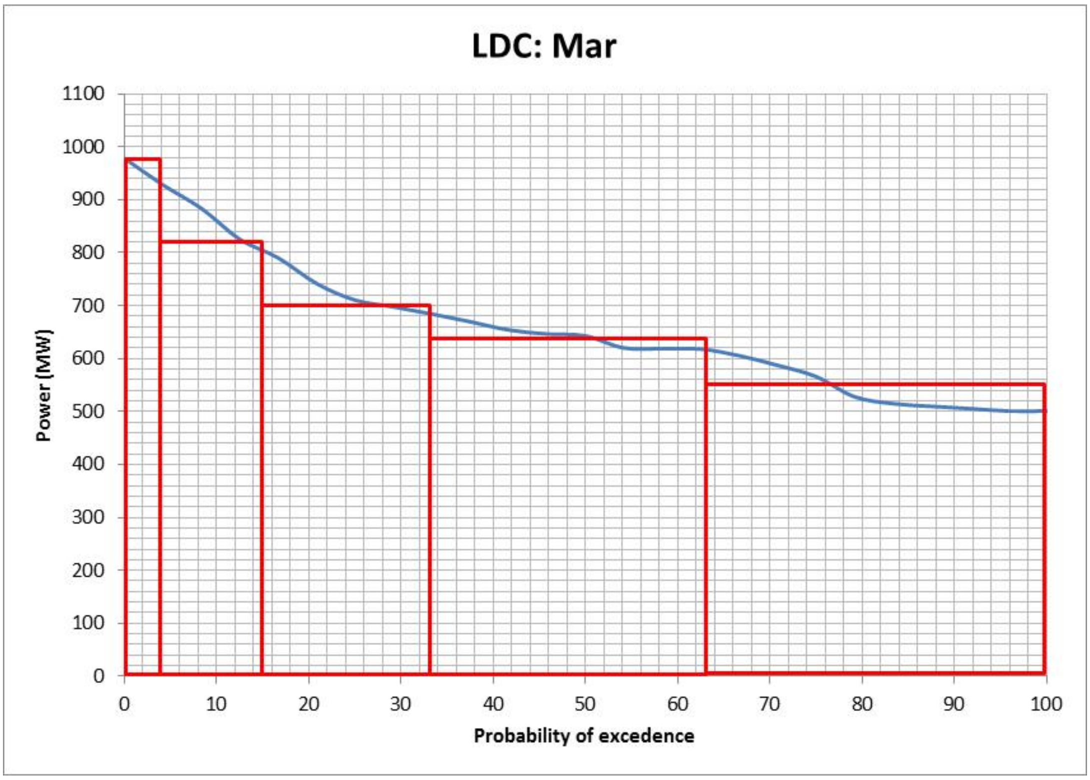
The following is the result of DIAGOPTM for the LDC data.

- Optimized time duration (%) of each load step: 4, 11, 18, 30, 37
- Fraction of peak of each load step: 1, 0.82, 0.70, 0.64, 0.58

Figure 1-1: Load Duration Curve at different months






LDC: Mar
Power (MW)
Probability of excedence
1100
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700
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80
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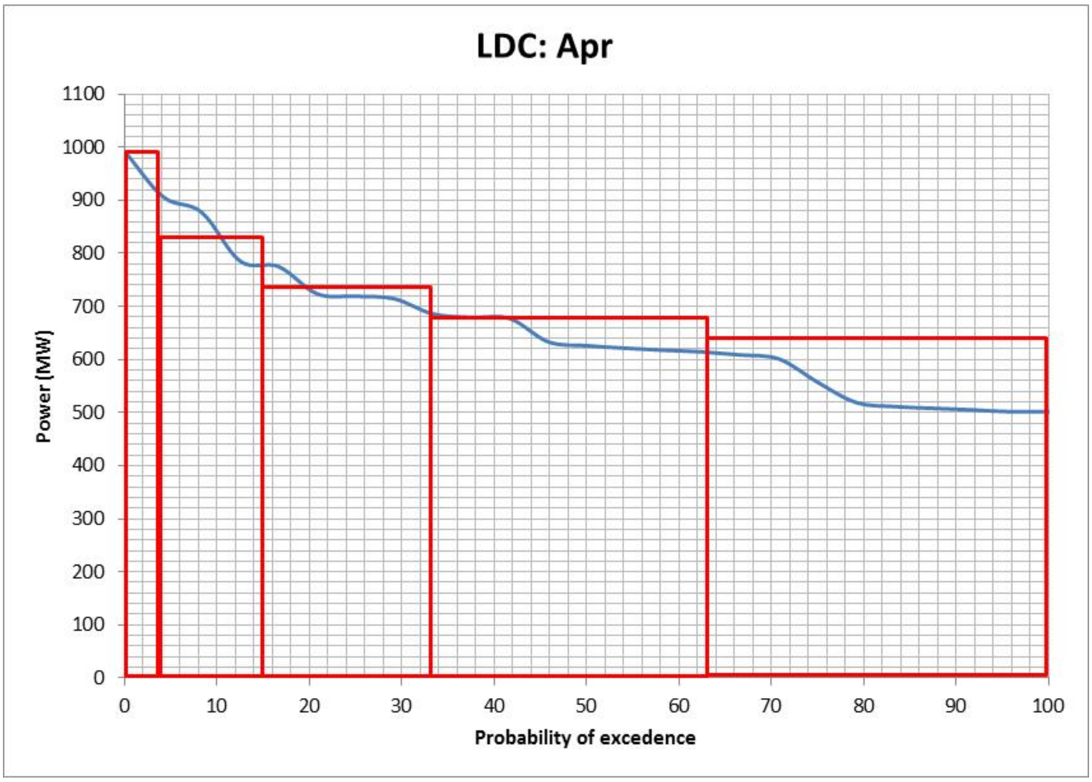
100


LDC: Apr
Power (MW)
Probability of excedence
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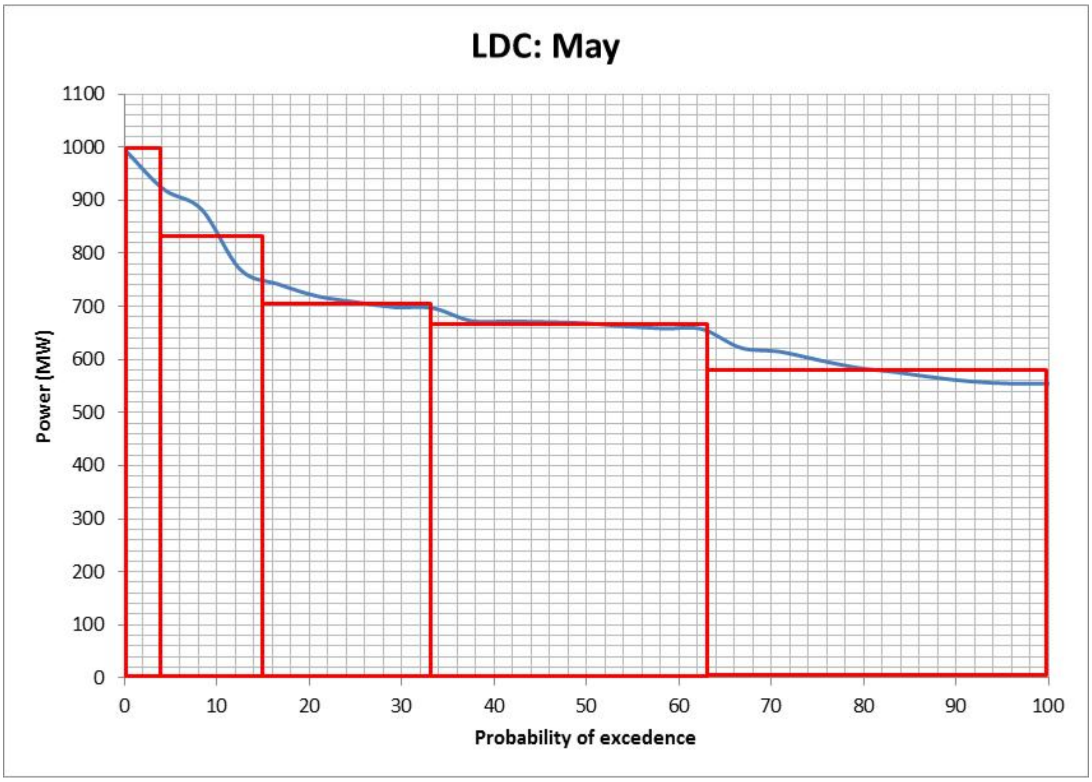
LDC: May
Power (MW)
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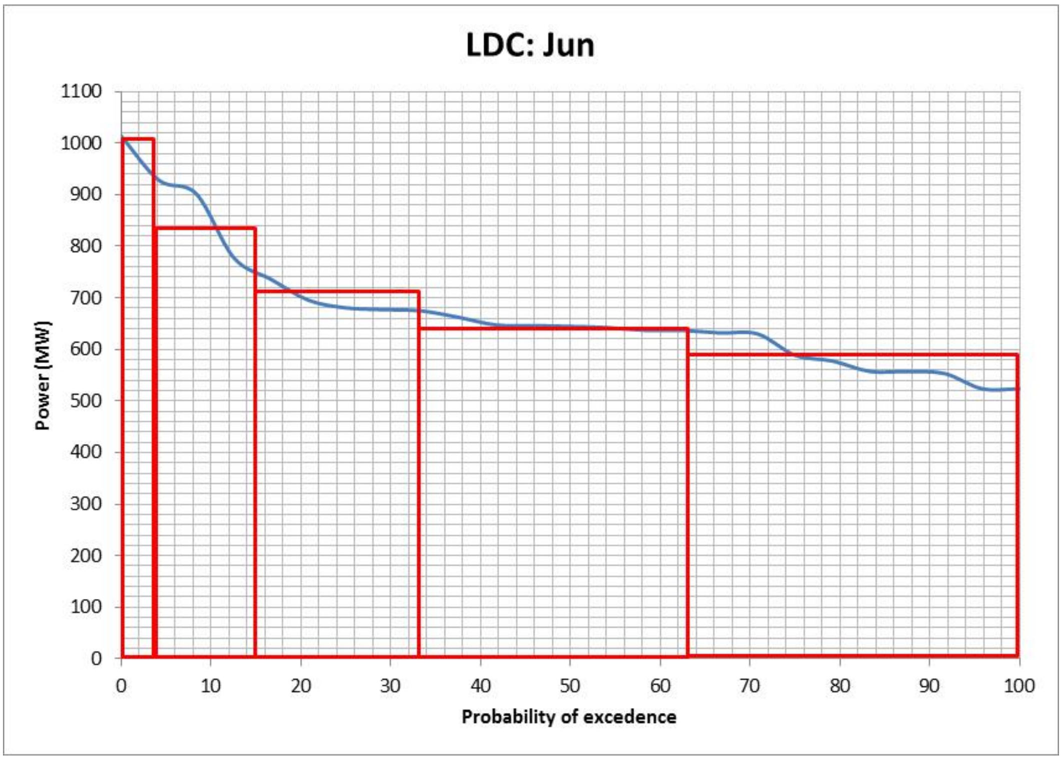
100
Probability of excedence


LDC: Jun
Power (MW)
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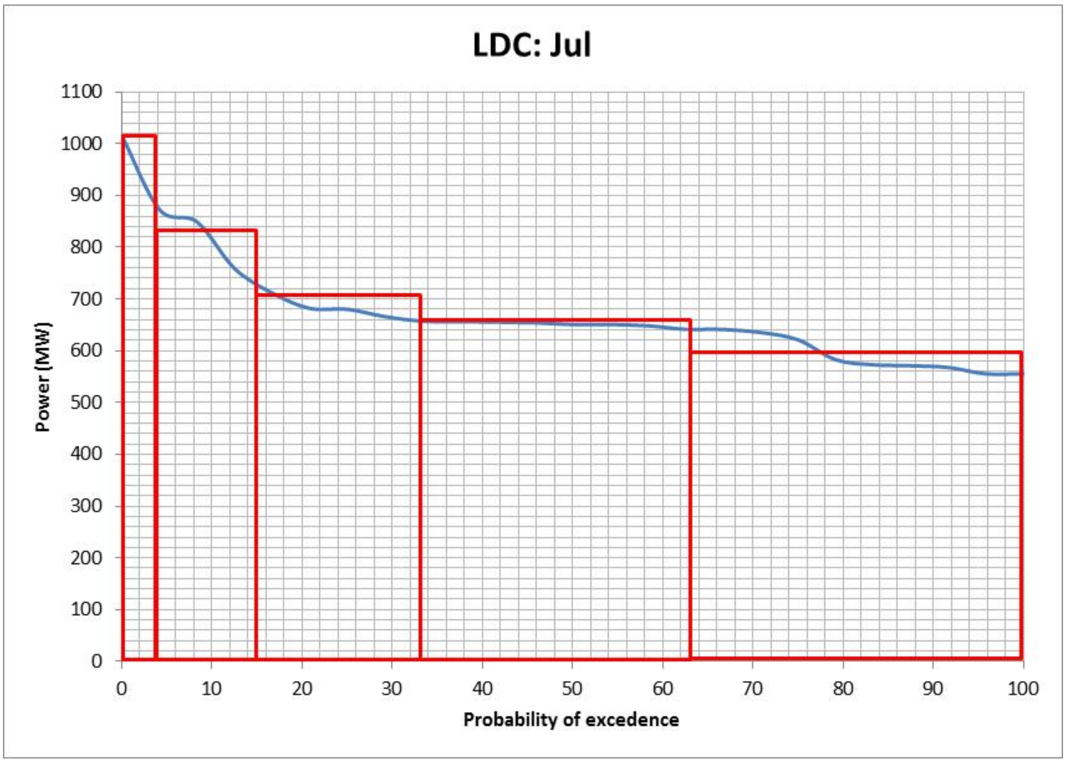
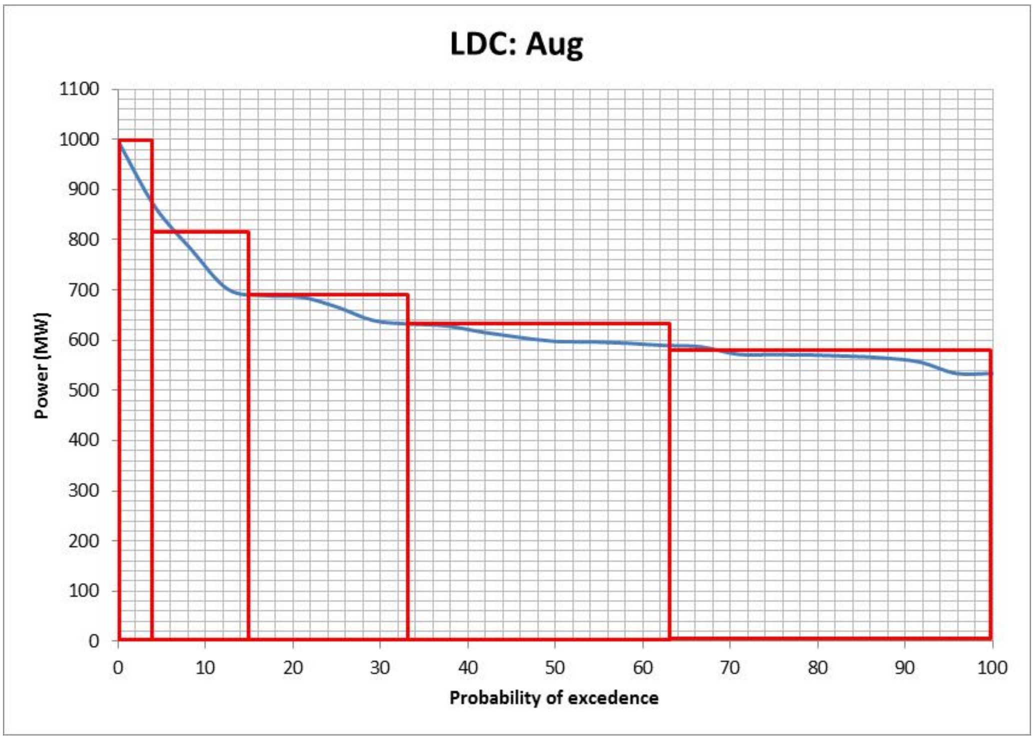
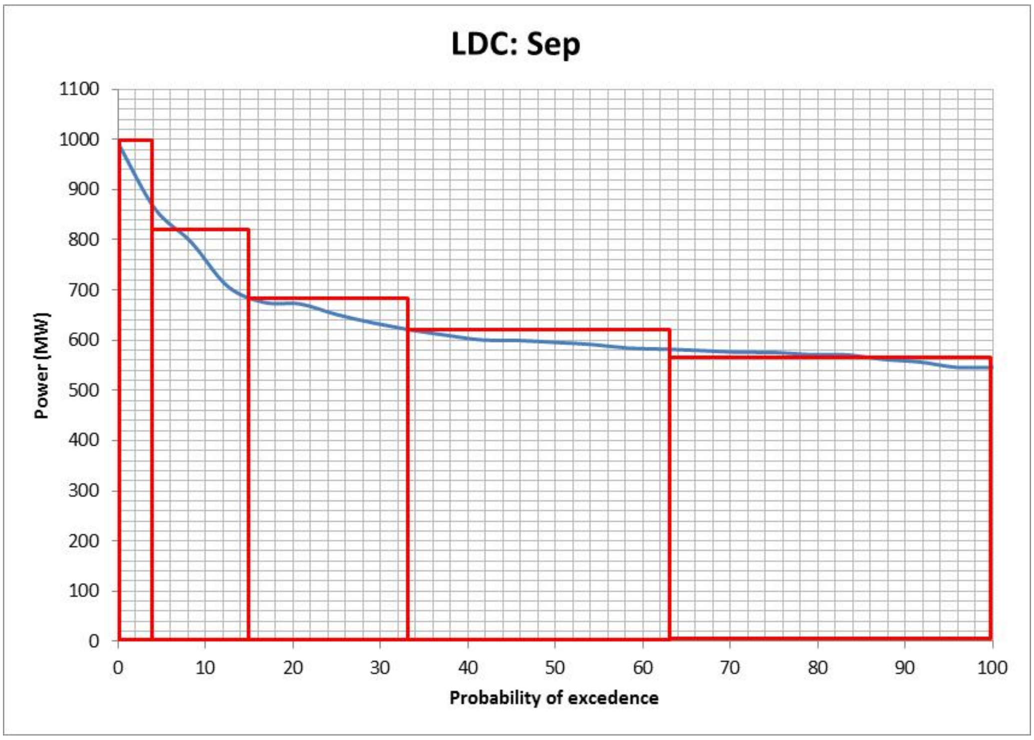
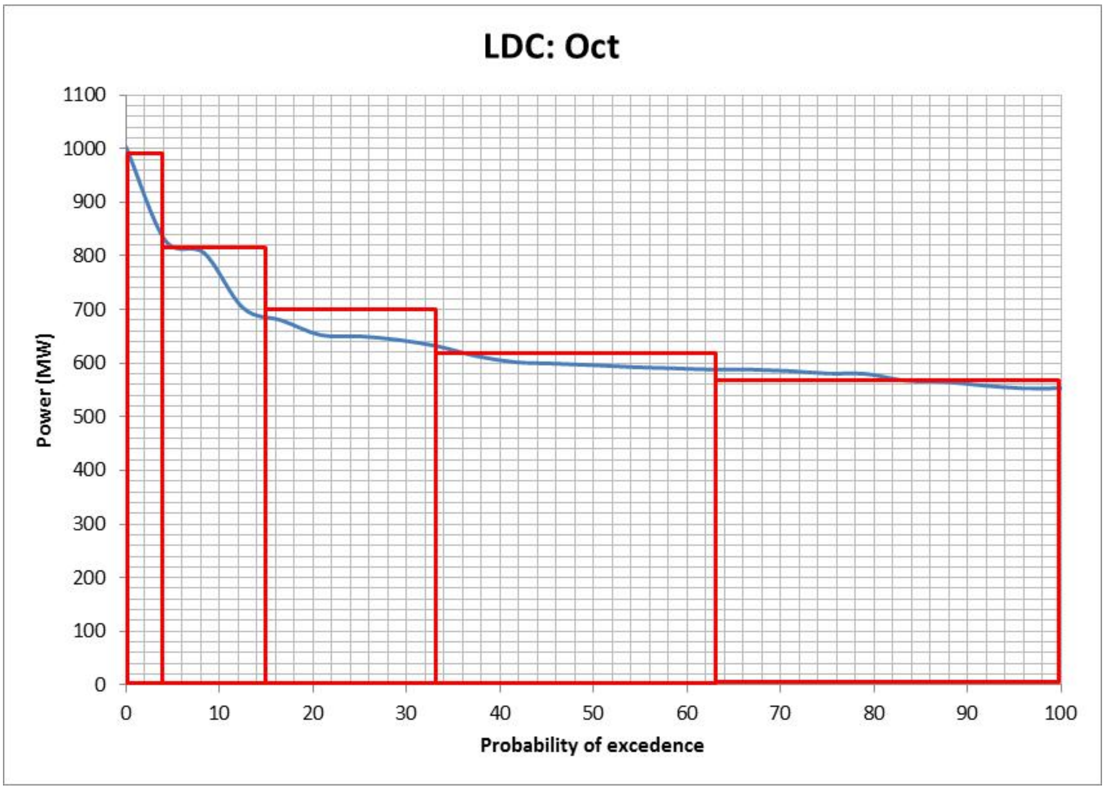
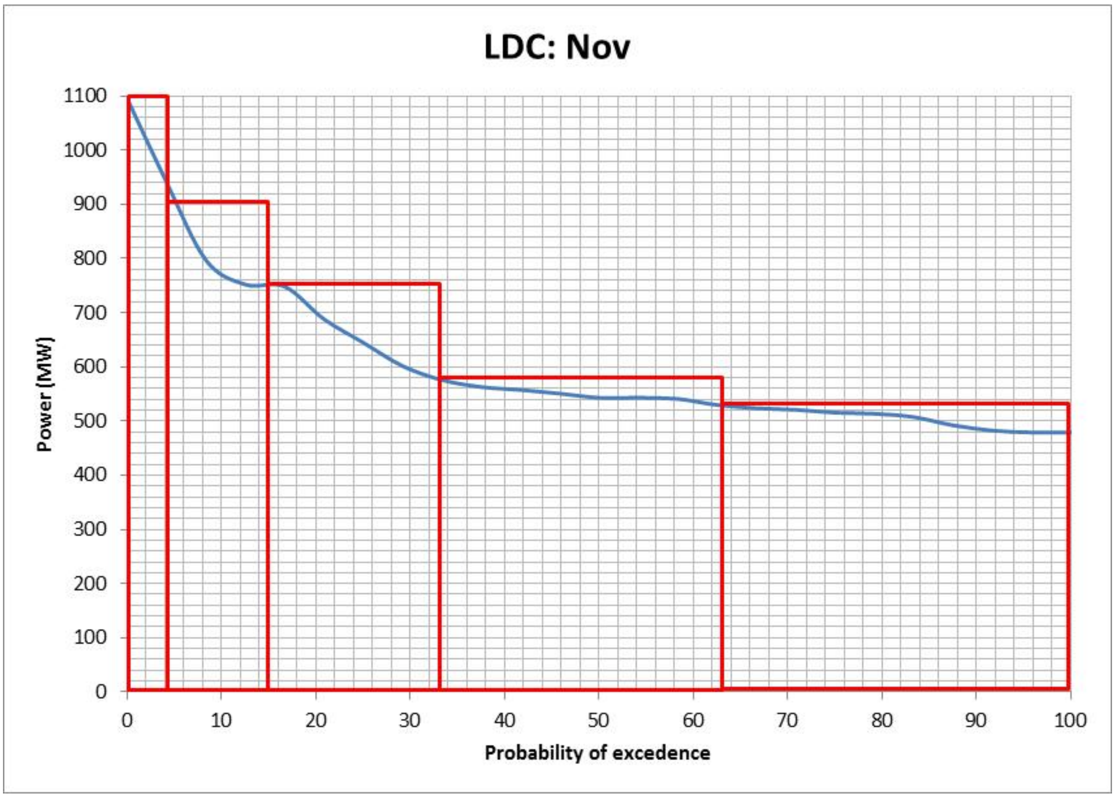
30
40
50
60
70
80
90
100
Probability of excedence

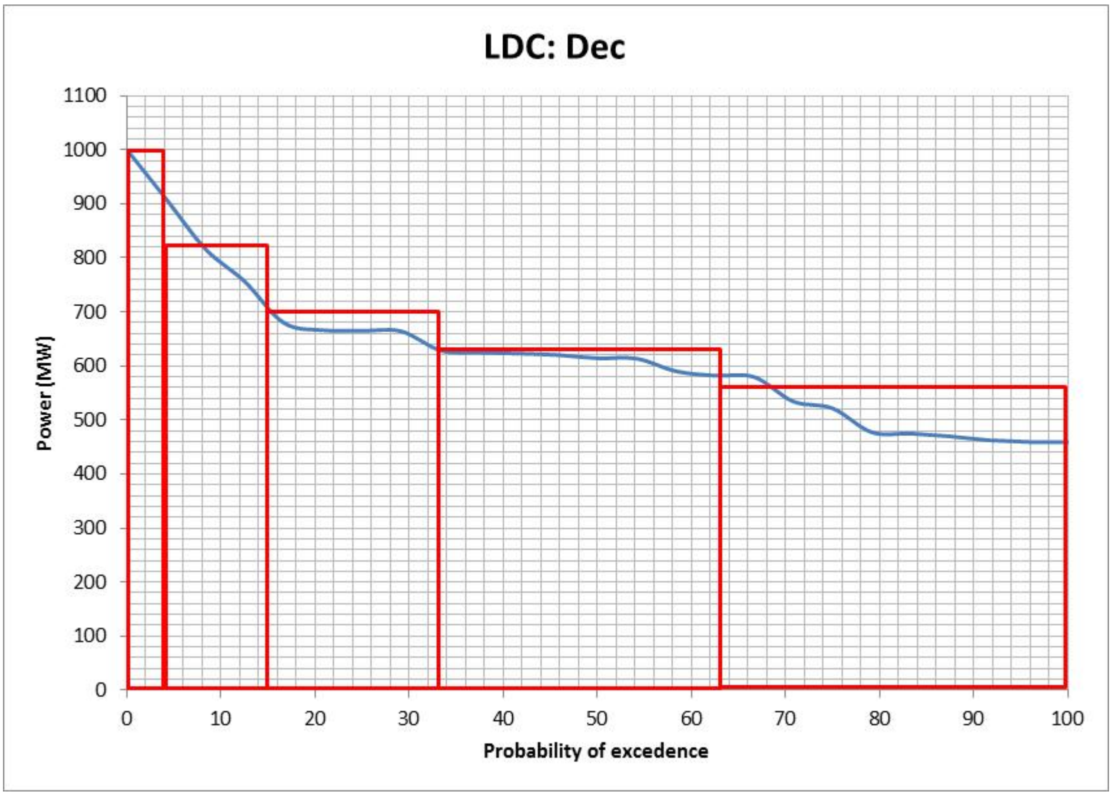

LDC: Jul
Power (MW)
Probability of excedence
0
100
200
300
400
500
600
700
800
900
1000
1100
0
10
20
30
40
50
60
70
80
90
100


LDC: Aug
Power (MW)
Probability of excedence
0
100
200
300
400
500
600
700
800
900
1000
1100
0
10
20
30
40
50
60
70
80
90
100


LDC: Sep
Power (MW)
Probability of excedence
0
100
200
300
400
500
600
700
800
900
1000
1100
0
10
20
30
40
50
60
70
80
90
100


LDC: Oct
Power (MW)
Probability of excedence
0
100
200
300
400
500
600
700
800
900
1000
1100
0
10
20
30
40
50
60
70
80
90
100


LDC: Nov
Power (MW)
1100
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
Probability of excedence


LDC: Dec
Power (MW)
1100
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
Probability of excedence

Appendix -2

Load Forecast

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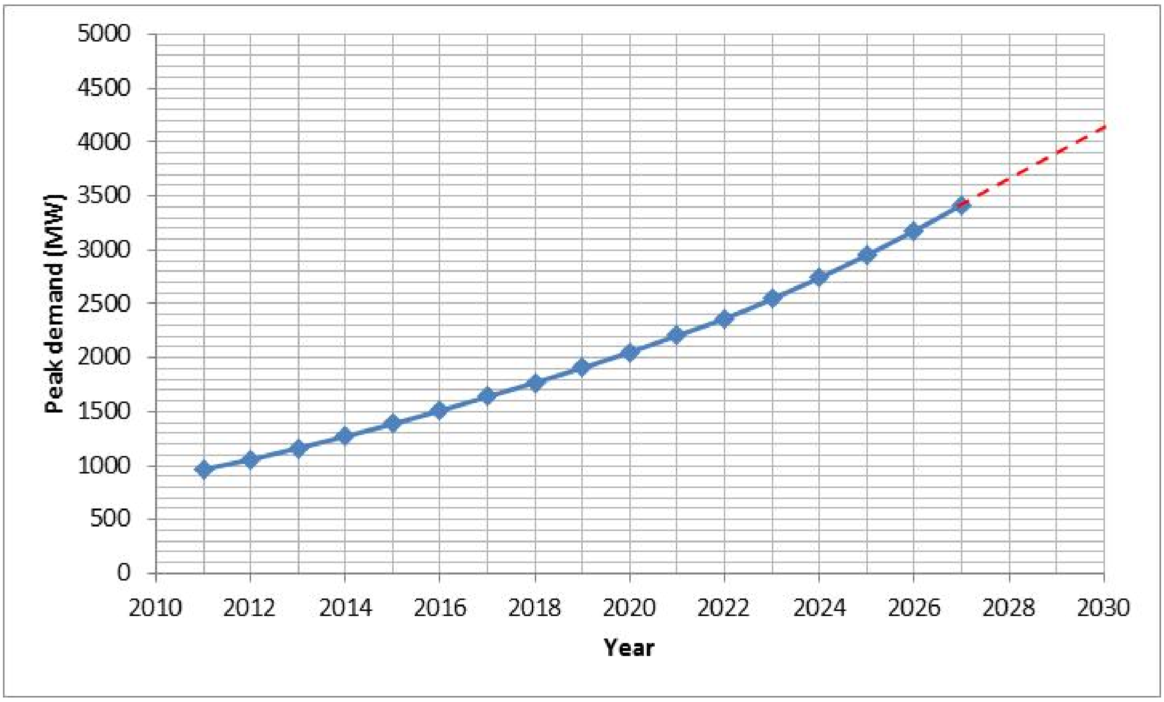
2. LOAD FORECAST

The peak load forecast data of 2011 to 2027 published by NEA is taken in the study. The curve (Figure 2-1) is drawn for this period and extrapolated for the duration of 2028-2030 to get the forecasted peak load values.

Figure 2-1: Peak Load forecast data of 2011-2030



Appendix -3

Application of VALORAGUA

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3. APPLICATION OF VALORAGUA

The objective of power optimization using VALORAGUA is to determine the economically optimal operational strategy for a fixed power system configuration. The optimization is done in terms of power generation. In this study, only generation subsystem and consumption subsystem is modeled in detail. As only one electric node is considered for Nepal, there is no need to consider transmission subsystem separately.

3.1 HYDRO-NETWORK FOR REFERENCE CASE

In the recent version of VALORAGUA, maximum allowable number of hydro plants is 50, and maximum allowable number of hydro cascades is 18. Considering these limitations, maximum number of hydro cascades in all model application of the study is set to 18. Hydro network is designed in such a way that major existing hydro plants and major planned hydro plants from all over Nepal are included in the power optimization (Figures of hydrocascade in Chapter 6). Based on the availability of data, 46 hydro plants are included within 18 hydro cascades. Among them, 23 are existing plants and remaining are expansion candidates.

Table 3-1: Name of plants and cascade

Cascade No.	Code Name of plants	No. of plants	Name of plants
1	PUWA, MAI	2	PUWA, MAI
2	IKHUWA, PILUWA	2	IKHUWA, PILUWA
3	UTAMOR, MAIWA, MTAMOR, PHAWA, KABE-A, HEWA	6	UPPER TAMOR, MAIWA, MIDDELE TAMOR, PHAWA, KABELI-A, HEWA
4	UTAMAK, SIPRIN	2	UPPER TAMAKOSHI, SIPRIN
5	KHANI	1	KHANI
6	KHIM-1	1	KHIMTI-1
7	U-BHOT, CHAKU, BARAMC,SUNKOS, SUNKON	5	UPPER BHOTEKOSHI, CHAKU, BARAMCHI,SUNKOSHI (SMALL), SUNKOSHI (NEA)
8	BALE-A, BALE-B	2	BALEPHI-A, BALEPHI-B
9	INDRAW	1	INDRAWATI
10	U-SANJ, L-SANJ, CHILIM, RASGAD, TRIS3A, TRIS2B, TRIS, DEVIGH	8	UPPER SANJEN, LOWER SANJEN, CHILIME, RASUWAGADHI, TRISHULI3A, TRISHULI2B, TRISHULI, DEVIGHAT
11	KULEK1, KULEK2, KULEK3	3	KULEKHANI1, KULEKKHANI2, KULEKKHANI3
12	BUDHIG	1	BUDHI GANDAKI
13	UMARSY, MMARSY, KHUDI, LCHEPE, MARSYG	5	UPPER MARSYANGDI, MIDDLE MARSYANGDI, KHUDI, LOWER CHEPE, MARSYANGDI
14	BIJAYP	1	BIJAYPUR
15	MODI, LMODI, KGANDA	3	MODI, LOWER MODI, KALI GANDAKI
16	ANDHI	1	ANDHI
17	JHIMRK	1	JHIMRK
18	CHAMEL	1	CHAMELIYA

Table 3-2: List of existing plants

Existing plants	**Design discharge (m^3/s)**	**Installed capacity (MW)**	**Under construction/to be constructed plants**	**Design discharge (m^3/s)**	**Installed capacity (MW)**
PUWA	2.5	6.2	KHANI	5.1	30
MAI	16	15.6	BARAMCHI	0.9	4.2
PILUWA	3.5	3.0	KULEKHANI-3	16	14
SIPRIN	7.5	9.6	LOWER MODI	29	20
KHIMTI-1	10.8	60	CHAMELIYA	36	30
UPPER BHOTEKOSHI	36.8	45	HEWA	8.1	15
CHAKU	2.7	3	PHAWA	2.1	5
SUNKOSHI SMALL	2.7	2.5	BALEPHI-A	25	10.6
SUNKOSHI	40	10	UPPER SANJEN	11.1	14.6
INDRAWATI	15	7.5	IKHUWA	4	18.5
CHILIME	8.3	22	KABELI-A	37.7	38
TRISHULI	45.3	24	LOWER CHEPE	7.5	8.3
DEVIGHAT	45.3	15	MAIWA	8.1	13.5
KULEKHANI-1	12.1	60	LOWER SANJEN	11.6	42.5
KULEKHANI-2	13.5	32	BALEPHI-B	30	18.5
MIDDLE MARSYANGDI	80	70	TRISHULI3B	51	37
KHUDI	4.6	4	UPPER MARSYANGDI	48.7	45
MARSYANGDI	91.5	69	UPPER TAMAKOSHI	66	456
BIJAYPUR	8.3	4.5	RASUWAGADHI	80	111
MODI	27.5	15	UPPER TAMOR	10.5	415
KALI GANDAKI	134	144	MIDDLE TAMOR	105	75
ANDHI	4.9	9.4	TRISHULI2A	51	60
JHIMRUK	36	12	BUDHI GANDAKI	430	600

Thermal (existing)
Hetauda: 10 MW
Duhabi: 39.5
Total installed capacity of existing hydro plants, expansion candidate plants and thermal existing = 2775 MW

Consumption (load) subsystem

- Electric code: Nepal as single node
- Fixed Power Demand (primary demand) for simulation year 2030
- Secondary Power Demand

Inflow data: Data of 30 years from 1980 to 2009 for 46 points

3.2 DATA AND PARAMETERS FOR VALORAGUA MODULES

In this report, the basic scenario is presented in detail. The basic scenario considers 46 hydro plants, 3 thermal plants, 1 import subsystem, and no export option. Design discharge of the power plants is taken as nominal flow. Change in data is done only in CADIR.DAT in VALORAGUA for different scenarios. The inflow data file is same for all scenarios. The input data files for VALAGP, RESEX, RESIM, MAINT and VWASP are also same for all scenarios.

3.2.1 CADIR

CADIR.dat

Basic data and parameters

Simulation year considered = 2030
Starting year of inflow data = 1980, ending year of inflow data = 2009
Equal probability of all hydro conditions
Number of load steps = 5 (maximum limit allowed in VALORAGUA)
Number of electric node = 1 (Nepal as one node)
Monthly fraction of the mean power demand corresponding to the each load step in each month: computed from LDC
Number of system (primary) demand =1, Annual energy demand = 18000 GWH (obtained from load forecast data of NEA)
Monthly breakdown of energy demand (%): obtained from auxiliary tool DIAGOPTM provided in VALORAGUA
8.4 8.4 8.5 8.5 8.7 8.6 8.6 8.2 8.1 8.2 7.8 8.0
Number of secondary demand = 1, Average selling price = 9 Cents/KWh, Maximum variation = 1%, maximum power supply in each month = 105 MW (About 2.5% of peak demand 4155MW for year 2030)
Maintenance team considered = 1 team each month for Duhabi and Hetauda, 3 team each month for the rest

Thermal plants and imports data

Two existing thermal power plant, Hetauda (HETAUD) and Duhabi (DUHABI)
Import system: Possibility of 300MW until 2015 and up to 1000MW after the construction of 400kv transmission system, considered 1000 MW in total
One additional thermal plant of 300 MW considered for expansion
Energy not served option of 1000 MW

Operation and maintenance (O & M) cost of thermal plants = 40Cents/KWh
Cost of energy not served = 55 Cents/KWh (Average of 30 cents/kwh for isolated and 80cents/kwh for current situation of Nepal)
Import system: Possibility of 300MW until 2015 and up to 1000MW after the construction of 400kv transmission system, considered 1000 MW in total
O& M cost of import = 10Cents/KWh
Above values are fixed from various references.

Reservoir characteristics data and parameters

For ROR plants, the storage volume of reservoir is considered to be 1 Mm^3. Parameters defining the level/ volume function of the reservoir (four parameters: gamma, si, alpha, beta) are estimated for storage projects. The level (Z) volume (V) function is given as

$$Z(V) = \gamma + \alpha(V - \varphi)^{\beta}$$

Gamma = level corresponding volume si (dead volume)
In the basic case, Kulekhani 1 and BudhiGandaki are storage projects, while all other remaining projects are ROR type. For ROR project, si = 0, alpha = 0, beta = 1. For storage projects, these coefficients are found by regression from level-volume data. Storage bound, Evaporation, and release are set to zero due to unavailability of data.

Spillways, hydro plants and cascade definition data

The data of spillways shows the connectivity according to designed hydro network. Design discharge is taken as nominal flow. Internal consumption fraction is taken as 1%, forced outage rate is set to 5%, and technical minimum is set to 0m^3/s. Nominal head, nominal flow and minimum tail water level are taken from the database of hydro plants. For PROR and storage plants, maximum discharge of each month is taken as design discharge. For ROR projects, if the mean flow of any particular month is less than design discharge, then the mean monthly flow of that month is taken as maximum flow. Components of each cascade are shown in cascade definition data.

Glimpses of CADIR.DAT

```
                    ********* STUDY IDENTIFICATION ********
           DEPT. OF ELECTRICITY DEVELOPMENT
  BASIC CASE OPTM   2030 1980 2009    0    5    1    1
  0.04000   0.11000   0.18000   0.30000   0.37000
                 ********* ELECTRIC NODE IDENTIFICATION ********
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 NEPAL
 1.434 1.385 1.344 1.371 1.358 1.404 1.425 1.480 1.484 1.498 1.650 1.441
 1.225 1.283 1.275 1.252 1.257 1.286 1.224 1.287 1.290 1.239 1.418 1.310
 1.099 1.167 1.134 1.085 1.050 1.078 1.064 1.043 1.059 1.050 1.134 1.090
 0.941 0.945 0.958 0.988 0.953 0.938 0.934 0.950 0.949 0.961 0.907 0.957
 0.885 0.838 0.850 0.853 0.898 0.883 0.909 0.882 0.874 0.882 0.816 0.851
                   ********* SYSTEM DEMAND DEFINITION ********
 1
 DEM.1   1
18000.   8.4   8.4   8.5   8.5   8.7   8.6   8.6   8.2   8.1   8.2   7.8   8.0
                 ********* SECONDARY DEMAND DEFINITION ********
 1
S.DEM1   1
S.DEM1   9.00   0.01
  105
    0
                     ********* MAINTENANCE TEAMS ********
 5
DUHABI    1    1    1    1    1    1    1    1    1    1    1    1
HETAUD    1    1    1    1    1    1    1    1    1    1    1    1
  ADD    1    1    1    1    1    1    1    1    1    1    1    1
  IMP    0    0    0    0    0    0    0    0    0    0    0    0
 REST    3    3    3    3    3    3    3    3    3    3    3    3
              ********* THERMAL POWER PLANTS AND IMPORTS ********
 5
DUHABI   1  6  6  1    6.5 40.0000 0.0100000    00.2000.100
      1.0 1.0 1.0 1.0 1.0
HETAUD   1  4  4  2    2.5 40.0000 0.0100000    00.2000.100
      1.0 1.0 1.0 1.0 1.0
  ADD   1  1  1  3 300.0  40.0000 0.0100000    00.0000.000
      1.0 1.0 1.0 1.0 1.0
  IMP   1  0  0  3 1000.0  10.0000 0.0100000    00.0000.000
      1.0 1.0 1.0 1.0 1.0
 REST   1  4  8  2 1000.0  55.0000 0.0100000    00.2000.060
      1.0 1.0 1.0 1.0 1.0
DUHABI    6    6    6    6    6    6    6    6    6    6    6    6
DUHABI 0.17 0.17 0.17 0.17    0    0    0    0    0    0 0.17 0.17
HETAUD    4    4    4    4    4    4    4    4    4    4    4    4
HETAUD 0.25 0.25    0    0    0    0    0    0    0    0  .25  .25
  ADD    1    1    1    1    1    1    1    1    1    1    1    1
  ADD    0    0    0    0    0    0    0    0    0    0    0    0
  IMP    1    1    1    1    1    1    1    1    1    1    1    1
  IMP    0    0    0    0    0    0    0    0    0    0    0    0
 REST    4    4    4    4    4    4    4    4    4    4    4    4
 REST    0    0    0    0    0    0    0    0    0    0    0    0
                  ********* RESERVOIR CHARACTERISITCS ********
46
PUWA  01      1.0   1.  .90 .80000+03 .00000+00 .00000+00 .10000+01
MAI  02      1.0   1.  .90 .31660+03 .00000+00 .00000+00 .10000+01
IKHUWA  03      1.0   1.  .90 .15050+04 .00000+00 .00000+00 .10000+01
PILUWA  04      1.0   1.  .90 .75700+03 .00000+00 .00000+00 .10000+01
UTAMOR  05      1.0   1.  .90 .11700+04 .00000+00 .00000+00 .10000+01
MAIWA  06      1.0   1.  .90 .79971+03 .00000+00 .00000+00 .10000+01
```

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MTAMOR  07       1.0   1.  .90 .68400+03 .00000+00 .00000+00 .10000+01
PHAWA  08       1.0   1.  .90 .89200+03 .00000+00 .00000+00 .10000+01
KABE-A  09       1.0   1.  .90 .55640+03 .00000+00 .00000+00 .10000+01
HEWA  10       1.0   1.  .90 .86200+03 .00000+00 .00000+00 .10000+01
UTAMAK  11       1.0   1.  .90 .20065+04 .00000+00 .00000+00 .10000+01
SIPRIN  12       1.0   1.  .90 .10500+04 .00000+00 .00000+00 .10000+01
KHANI  13       1.0   1.  .90 .20760+04 .00000+00 .00000+00 .10000+01
KHIM-1  14       1.0   1.  .90 .12706+04 .00000+00 .00000+00 .10000+01
U-BHOT  15       1.0   1.  .90 .84320+03 .00000+00 .00000+00 .10000+01
CHAKU  16       1.0   1.  .90 .77450+03 .00000+00 .00000+00 .10000+01
BARAMC  17       1.0   1.  .90 .10703+04 .00000+00 .00000+00 .10000+01
SUNKOS  18       1.0   1.  .90 .72550+03 .00000+00 .00000+00 .10000+01
SUNKON  19       1.0   1.  .90 .53210+03 .00000+00 .00000+00 .10000+01
BALE-A  20       1.0   1.  .90 .50800+03 .00000+00 .00000+00 .10000+01
BALE-B  21       1.0   1.  .90 .43000+03 .00000+00 .00000+00 .10000+01
INDRAW  22       1.0   1.  .90 .96000+03 .00000+00 .00000+00 .10000+01
U-SANJ  23       1.0   1.  .90 .23360+04 .00000+00 .00000+00 .10000+01
L-SANJ  24       1.0   1.  .90.216280+04 .00000+00 .00000+00 .10000+01
CHILIM  25       1.0   1.  .90 .14905+04 .00000+00 .00000+00 .10000+01
RASGAD  26       1.0   1.  .90.128848+04 .00000+00 .00000+00 .10000+01
TRIS3A  27       1.0   1.  .90 .85200+03 .00000+00 .00000+00 .10000+01
TRIS2B  28       1.0   1.  .90 .54100+03 .00000+00 .00000+00 .10000+01
TRIS  29       1.0   1.  .90 .20380+03 .00000+00 .00000+00 .10000+01
DEVIGH  30       1.0   1.  .90 .14420+03 .00000+00 .00000+00 .10000+01
KULEK1  31      85.3   1.  .17 .14800+04 .14900+02 .24025+01 .10000+01
KULEK2  32       1.0   1.  .90 .91460+03 .00000+00 .00000+00 .10000+01
KULEK3  33       1.0   1.  .90 .57756+03 .00000+00 .00000+00 .10000+01
BUDHIG  34      3320   1.  .17 .44500+03 .95000+03 .25000+01 .10000+01
UMARSY  35       1.0   1.  .90 .76840+03 .00000+00 .00000+00 .10000+01
MMARSY  36       1.0   1.  .90 .62330+03 .00000+00 .00000+00 .10000+01
KHUDI  37       1.0   1.  .90 .65540+03 .00000+00 .00000+00 .10000+01
LCHEPE  38       1.0   1.  .90 .87000+03 .00000+00 .00000+00 .10000+01
MARSYG  39       1.0   1.  .90 .32960+03 .00000+00 .00000+00 .10000+01
BIJAYP  40       1.0   1.  .90 .95540+03 .00000+00 .00000+00 .10000+01
MODI  41       1.0   1.  .90 .86696+03 .00000+00 .00000+00 .10000+01
LMODI  42       1.0   1.  .90 .68430+03 .00000+00 .00000+00 .10000+01
KGANDA  43       7.7   1.  .60 .66680+03 .00000+00 .00000+00 .10000+01
ANDHI  44       1.0   1.  .90 .10856+04 .00000+00 .00000+00 .10000+01
JHIMRK  45       1.0   1.  .90 .73950+03 .00000+00 .00000+00 .10000+01
CHAMEL  46       7.7   1.  .60 .87830+03 .00000+00 .00000+00 .10000+01
   0                  STORAGE BOUNDS
0        HEIGHT EVAPORATION (MM)
   0            WATER RELEASE (HM3)
                                   ********* SPILLWAYS ********
46
  PUWA   1   2
   MAI   2   0
IKHUWA   3   0
PILUWA   4   0
UTAMOR   5   7
 MAIWA   6   7
MTAMOR   7   0
 PHAWA   8   9
KABE-A   9   0
HEWA  10   0
UTAMAK  11   0
SIPRIN  12   0
KHANI  13   0
KHIM-1  14   0
U-BHOT  15  19
CHAKU  16  19
BARAMC  17  19
SUNKOS  18  19
SUNKON  19   0
BALE-A  20  21
BALE-B  21   0
INDRAW  22   0
U-SANJ  23  24
L-SANJ  24  25
CHILIM  25  27
RASGAD  26  27
TRIS3A  27  28
TRIS2B  28  29
TRIS  29  30
DEVIGH  30   0
```

```
KULEK1  31  32
KULEK2  32  33
KULEK3  33   0
BUDHIG  34   0
UMARSY  35  36
MMARSY  36  39
KHUDI  37  39
LCHEPE  38  39
MARSYG  39   0
BIJAYP  40   0
MODI  41  42
LMODI  42  43
KGANDA  43   0
ANDHI  44   0
JHIMRK  45   0
CHAMEL  46   0
                        ********* HYDRO POWER PLANTS ********
46
  PUWA   1    2  0 116.00 0.01   0.85   0.05   0.00 320.00   2.50 480.00
   MAI   2    0  0 1 8.89 0.01   0.90   0.05   0.00 121.60  16.00 195.00
IKHUWA   3    0  0 110.00 0.01   0.90   0.05   0.00 605.00   4.00 900.00
PILUWA   4    0  0 1 5.50 0.01   0.91   0.05   0.00 107.00   3.50 650.00
UTAMOR   5    7  0 120.00 0.01   0.90   0.05   0.00 470.00 105.00 700.00
 MAIWA   6    7  0 110.81 0.01   0.91   0.05   0.00 190.09   8.07 609.62
MTAMOR   7    0  0 1 7.50 0.01   0.86   0.05   0.00  84.00 105.00 600.00
 PHAWA   8    9  0 114.00 0.01   0.90   0.05   0.00 292.00   2.10 600.00
KABE-A   9    0  0 1 5.40 0.01   0.85   0.05   0.00 111.40  37.73 445.00
HEWA  10    0  0 1 5.50 0.01   0.85   0.05   0.00 212.00   8.12 650.00
UTAMAK  11    0  0 122.00 0.01   0.91   0.05   0.00 800.00  66.001206.50
SIPRIN  12    0  0 110.00 0.01   0.85   0.05   0.00 150.00   7.50 900.00
KHANI  13    0  0 123.00 0.01   0.85   0.05   0.00 940.00   5.101136.00
KHIM-1  14    0  0 134.60 0.01   0.87   0.05   0.00 691.60  10.75 579.00
U-BHOT  15   19  0 1 7.20 0.01   0.80   0.05   0.00 143.20  36.80 700.00
CHAKU  16   19  0 1 7.50 0.01   0.86   0.05   0.00 124.50   2.70 650.00
BARAMC  17   19  0 125.00 0.01   0.86   0.05   0.00 545.00   0.90 525.30
SUNKOS  18   19  0 1 9.50 0.01   0.85   0.05   0.00 124.50   2.70 601.00
SUNKON  19    0  0 1 1.60 0.01   0.86   0.05   0.00  32.10  40.00 500.00
BALE-A  20   21  0 1 2.00 0.01   0.86   0.05   0.00  48.00  25.00 460.00
BALE-B  21    0  0 1 5.00 0.01   0.86   0.05   0.00  80.00  30.00 350.00
INDRAW  22    0  0 1 5.00 0.01   0.89   0.05   0.00  60.00  15.00 900.00
U-SANJ  23   24  0 1 5.30 0.01   0.85   0.05   0.00 156.00  11.102180.00
L-SANJ  24   25  0 1 9.20 0.01   0.85   0.05   0.00 432.80  11.601730.00
CHILIM  25   27  0 117.70 0.01   0.82   0.05   0.00 354.50   8.251136.00
RASGAD  26   27  0 1 9.42 0.01   0.91   0.05   0.00 158.48  80.001130.00
TRIS3A  27   28  0 112.50 0.01   0.85   0.05   0.00 132.00  51.00 720.00
TRIS2B  28   29  0 113.24 0.01   0.81   0.05   0.00  87.00  51.00 454.00
TRIS  29   30  0 1 2.80 0.01   0.85   0.05   0.00  56.75  45.30 147.05
DEVIGH  30    0  0 1 1.50 0.01   0.80   0.05   0.00  41.10  45.30 105.20
KULEK1  31   32  0 129.00 0.01   0.91   0.05   0.00 589.00  12.10 916.00
KULEK2  32   33  0 115.60 0.01   0.82   0.05   0.00 313.60  13.50 601.00
KULEK3  33    0  0 1 7.24 0.01   0.92   0.05   0.00 102.56  16.00 475.00
BUDHIG  34    0  0 112.00 0.01   0.84   0.05   0.00 185.00 430.00 312.00
UMARSY  35   36  0 1 4.80 0.01   0.85   0.05   0.00 118.40  48.74 650.00
MMARSY  36   39  0 1 4.50 0.01   0.79   0.05   0.00 120.00  80.00 525.30
KHUDI  37   39  0 110.00 0.01   0.86   0.05   0.00 105.40   4.55 550.00
LCHEPE  38   39  0 110.00 0.01   0.86   0.05   0.00 140.00   7.53 735.00
MARSYG  39    0  0 1 4.40 0.01   0.91   0.05   0.00  90.50  91.50 242.50
BIJAYP  40    0  0 1 2.60 0.01   0.86   0.05   0.00  65.40   8.30 890.00
MODI  41   42  0 1 3.04 0.01   0.86   0.05   0.00  66.96  27.50 800.00
LMODI  42   43  0 1 3.70 0.01   0.86   0.05   0.00  84.30  29.00 600.00
KGANDA  43    0  0 1 6.80 0.01   0.85   0.05   0.00 136.80 134.00 530.00
ANDHI  44    0  0 112.50 0.01   0.86   0.05   0.00 242.60   4.90 843.00
JHIMRK  45    0  0 1 9.50 0.01   0.86   0.05   0.00 189.50   8.00 550.00
CHAMEL  46    0  0 1 9.70 0.01   0.92   0.05   0.00  94.00  36.00 784.30
  PUWA  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5
  PUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
MAI  3.0  2.5  2.4  2.7  4.5 16.0 16.0 16.0 16.0 16.0  6.0  3.6
   MAI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
IKHUWA  2.0  1.7  1.5  2.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  2.6
IKHUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
PILUWA  2.8  2.1  1.9  2.8  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
PILUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
UTAMOR105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0
UTAMOR  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 MAIWA  2.2  1.8  1.9  2.6  5.2  8.1  8.1  8.1  8.1  8.1  4.5  2.9
```

```
 MAIWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MTAMOR105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0
MTAMOR  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 PHAWA  1.2  1.0  1.1  1.5  2.1  2.1  2.1  2.1  2.1  2.1  2.1  1.6
 PHAWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KABE-A 11.0  9.2  9.3 13.2 26.0 37.7 37.7 37.7 37.7 37.7 22.4 14.2
KABE-A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
  HEWA  3.8  3.0  2.6  4.0  8.1  8.1  8.1  8.1  8.1  8.1  8.1  5.6
  HEWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
UTAMAK 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0
UTAMAK  0.1  0.1  0.1  0.1  0.0  0.0  0.0  0.0  0.0  0.0  0.1  0.1
SIPRIN  1.8  1.6  1.5  1.8  3.2  7.5  7.5  7.5  7.5  7.5  4.0  2.6
SIPRIN  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 KHANI  0.7  0.6  0.6  0.7  1.2  4.0  5.1  5.1  5.1  5.1  2.0  1.0
 KHANI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KHIM-1  6.1  5.1  5.0  5.3  9.0 10.8 10.8 10.8 10.8 10.8 10.8  8.3
KHIM-1  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.1  0.1  0.1  0.1  0.1
U-BHOT 23.0 21.0 21.0 24.0 36.8 36.8 36.8 36.8 36.8 36.8 36.8 27.0
U-BHOT  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
 CHAKU  0.6  0.6  0.6  0.7  1.2  2.2  2.7  2.7  2.7  2.7  1.1  0.8
 CHAKU  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BARAMC  0.2  0.2  0.1  0.2  0.3  0.5  0.9  0.9  0.9  0.6  0.3  0.2
BARAMC  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
SUNKOS  1.8  1.6  1.7  1.9  2.7  2.7  2.7  2.7  2.7  2.7  2.7  2.2
SUNKOS  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
SUNKON 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0
SUNKON  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
BALE-A  2.3  2.0  2.0  2.2  3.2  9.0 25.0 25.0 25.0 10.0  5.0  3.0
BALE-A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BALE-B 12.7 11.1 10.7 12.1 18.0 30.0 30.0 30.0 30.0 30.0 24.0 17.0
BALE-B  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
INDRAW  7.0  6.0  6.0  6.6 10.0 15.0 15.0 15.0 15.0 15.0 13.1  9.1
INDRAW  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
U-SANJ 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1
U-SANJ  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
L-SANJ  2.3  2.0  2.0  2.6  5.1 11.6 11.6 11.6 11.6  9.0  4.2  3.0
L-SANJ  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
CHILIM  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3
CHILIM  0.0  0.0  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
RASGAD 37.0 33.0 33.0 42.0 80.0 80.0 80.0 80.0 80.0 80.0 69.0 47.0
RASGAD  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
TRIS3A 51.0 45.0 45.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0
TRIS3A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
TRIS2B 51.0 45.0 45.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0
TRIS2B  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  TRIS 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3
  TRIS  0.1  0.1  0.0  0.0  0.0  0.0  0.0  0.1  0.1  0.1  0.1  0.1
DEVIGH 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3
DEVIGH  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
KULEK1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1
KULEK1  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KULEK2 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5
KULEK2  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KULEK3 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4
KULEK3  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BUDHIG430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0
BUDHIG  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
UMARSY 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7
UMARSY  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MMARSY 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0
MMARSY  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 KHUDI  3.0  2.0  2.0  3.0  4.5  4.5  4.5  4.5  4.5  4.5  4.5  3.0
 KHUDI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
LCHEPE  5.0  4.0  4.0  4.0  6.0  7.5  7.5  7.5  7.5  7.5  7.5  6.0
LCHEPE  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MARSYG 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5
MARSYG  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BIJAYP  1.0  1.0  1.0  1.0  2.0  4.0  8.3  8.3  8.3  8.3  5.0  2.0
BIJAYP  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  MODI 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5
  MODI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 LMODI 10.0  8.0  8.0 11.0 18.0 29.0 29.0 29.0 29.0 29.0 18.0 13.0
 LMODI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KGANDA134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0
KGANDA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
```

```
 ANDHI  3.0  3.0  2.0  2.0  4.0  4.9  4.9  4.9  4.9  4.9  4.9  4.0
 ANDHI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
JHIMRK  4.0  4.0  3.0  3.0  3.0  8.0  8.0  8.0  8.0  8.0  8.0  5.0
JHIMRK  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
CHAMEL 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0
CHAMEL  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
   0     (MANDATORY TEC. MINIMUM - M3/S)
                         ********* PUMPED STORAGE PLANTS ********
 0
                         ********* DEFINITION OF CASCADES ********
18
N.RESERVOIRS  2  2  6  2  1  1  5  2  1  8  3  1  5  1  3  1  1  1
N.TURB.PLANT  2  2  6  2  1  1  5  2  1  8  3  1  5  1  3  1  1  1
 N.SPILLWAYS  2  2  6  2  1  1  5  2  1  8  3  1  5  1  3  1  1  1
N.PUMPED STO  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

3.2.2 INFLOW.dat

The data displays the monthly inflows to each reservoir for each year in $10^6 m^3$ (hectometer^3).

Glimpses of INFLOW.DAT

```
1980 2009
TRIBUTARY  INFLOWS  TO  PUWA KHOLA at PUWA (ILAM) ( HM3 )  1980 / 2009
   3.9   2.7   3.6   5.2  11.9  24.7  44.1  45.5  34.5  13.8   7.0   4.6
   3.3   2.3   2.3   4.1   8.1  19.2  44.7  61.4  32.4  12.0   6.2   4.0
   2.9   2.3   2.5   4.6   6.8  18.8  44.7  32.4  21.0   9.7   5.9   3.9
   4.7   3.4   3.0   2.6   5.9  14.4  75.1  36.8  37.2  16.5   7.8   5.2
   4.4   3.1   2.8   3.6   6.0  22.2  66.9  35.8  60.0  16.4   9.8   6.8
   5.0   4.4   3.7   3.7   7.1  13.9  38.5  36.4  36.7  29.4  12.0   7.4
   4.9   3.2   3.1   4.8   7.5  13.0  40.4  30.7  52.4  19.7   8.7   5.6
   3.9   2.9   3.6   4.0   5.9  11.6  55.2 117.7  47.1  26.8  11.2   6.9
   4.9   3.7   4.7   4.1   6.4  15.8  24.5  28.2  49.2  14.0   5.5   5.4
   5.0   3.9   4.2   3.1   8.0  25.3  35.2  28.6  38.9  18.1   7.9   6.0
   4.5   4.1   6.7  11.2  22.9  59.0  56.2  51.0  36.3  20.9   6.2   5.5
   6.8   4.9   5.3   5.5   6.9  25.2  58.2  51.0  44.7  10.8   6.5   4.5
   3.7   3.2   2.7   3.7   8.4   8.6  25.8  21.1  16.4  10.9   6.1   4.5
   4.3   3.0   2.8   5.7   6.6  12.8  25.4  34.6  20.7  13.9   8.5   6.0
  20.9  20.1  17.0  10.4   6.5   4.9  66.9  35.8  60.0  16.4   9.8   6.8
   4.8   3.6   3.3   4.1   6.4  13.9  38.5  42.3  47.1  13.2   9.2   5.2
   7.7   2.6   2.5   2.2   4.8   9.4  42.4  43.6  22.4  10.4   4.6   3.3
   2.3   1.9   1.7   2.9   3.9  22.9  22.7 177.3 137.1  64.4  22.6  11.3
   5.5   5.1  11.2  15.5  13.6  22.5 117.7  78.1  87.4  38.0   9.3   6.2
   5.4   4.1   3.4   2.7   7.0  49.3 102.8 101.1  85.0  41.6  14.6   9.7
   9.9   8.1   6.1   7.7  19.5  31.4  41.8  50.6  48.8  29.6  15.0   7.7
   4.8   4.2   3.9   3.6  11.6  20.8  32.7  46.1  57.7  62.0  15.8   8.2
   5.3   3.9   3.5   6.7   6.4  15.8  93.6  36.4  36.7  16.6   6.7   3.2
   1.9   1.7   2.3   2.6   2.3  31.2  90.3  52.9  36.6  26.4   6.5   2.1
   3.6   2.1   2.3   2.6   7.9  25.6  73.0  30.1  43.7  28.3  10.3   5.2
   3.2   2.2   1.6   2.3   3.3   8.8  59.0  70.4  30.7  38.0   9.3   6.2
   5.9   5.3   5.3   7.7   8.5  24.3  52.5  41.4  49.8  21.8   5.7   2.3
   1.9   1.7   2.3   2.6   2.3  31.2  90.3  52.9  36.6  26.4   6.5   2.1
   3.6   2.1   2.3   2.6   7.9  25.6  73.0  30.1  43.7  28.3  10.3   5.2
   3.2   2.2   1.6   2.3   3.3   8.8  59.0  70.4  30.7  38.0   9.3   6.2
```

Similar format for all other remaining 45 river stations

3.2.3 VALAGP

VALAGP.DAT

Identification data shows the following information:

year of study = 2030, starting year =1980, ending year=2009, 1= key for medium and short term solution, no of states of reservoir = 11, initial storage key1 (assigned as 0 meaning initial storage is 50% of max. available storage), initial storage key 2 (assigned as 0 meaning initial storage at next time is equal to final storage of previous time), first cascade ID = 1, last cascade ID = 18, key for hydrocascades=0.

Water value function data displays initial marginal value of reservoir for each state of reservoir. In this study, 7-13 Cts/Kwh is assigned as the initial marginal value. The final value will be optimized by the model.

Initial storage data shows the fractions of maximum available volume for the definition of initial storage of each reservoir. In this study, this data is taken as zero.

Glimpses of VALAGP.DAT

```
**************** IDENTIFICATION AND STUDY OPTIONS *********************
 2030 1980 2009    1 11  0  0  1 18   0
 ****************  WATER  VALUE  FUNCTION      *********************
 13.00 12.00  12.00  12.00  11.00  11.00  11.00  10.00   9.00   8.00   7.00
 ****************        INITIAL STORAGES         *********************
  0.00
  0.00
  0.00
  0.00
  0.00
```

3.2.4 MAINT

MAINT.DAT

Line 3 shows print out flags (1 or 0: yes or no) for following items:

Maintenance by thermal plant, maximum available capacity, Maintenance outage rate, hydro and thermal power allocation, expected generation costs.

Line 5 shows the number of hydroconditions to be considered individually and in average.

Line 6 onwards displays years for considering conditions of line 5.

Glimpses of MAINT.DAT

```
*****************  OPTIMIZATION AND PRINT OPTIONS   *******************
 2013    1    1                      IFASE1,IFASE2
    0    1    0    0    0
***************** HYDROLOGICAL CONDITIONS OPTIONS **********************
    0    0
 1985 1987
 2001 2002
```

3.2.5 RESEX

RESEX.DAT

Line 2 shows the ID for type of printed output (1 means annual result for average of hydro conditions), and dummy value (2014). Line 3 displays ID for printing of results of following components (0: no print, 1, 2: print): Electric node, secondary demand and exports, thermal power plants and imports, reservoirs, hydro turbine plants, pumping plants, transmission lines. Line 4 shows the ID for printing monthly results (1: print, 0: no print)

Glimpses of RESEX.DAT

```
   OUTPUT   FLAGS
 0001 2014
 0001 0001 0001 0001 0002 0002 0000
 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001 0001
```

3.2.6 RESIM

RESIM.DAT

Line 2 shows the ID of component (e.g. 05 means hydro plant), plant for which printed output is required (e.g. plant number 09 in hydro cascades). Line 3 shows the print out flags (1: print, 0: no print) for following variables for each load step: Water flow (10000 means print for first load step, no print for other load steps), head loss, net head, power output, volume discharged through turbine, energy generation, value of energy generation

Glimpses of RESIM.DAT

```
*++++++++      ITYPE, IPLANT+++++++
0509
```

```
10000100001000010000100001000010000111110001010
```

3.2.7 VWASP

VWASP.DAT

Line 1 shows number of periods considered. 12 periods (representing each month) in a year are considered. Line 2 represents ID name of periods. Line 3 and 4 shows number of load steps, and load step number to compute peak characteristics. Line 5 shows number of hydroconditions to be considered in WASP. Three hydroconditions (wet, dry and mean) are considered for WASP. Line 6 onwards shows number of years and corresponding years for each hydrocondition. The dry, wet and mean hydroconditon is assigned by comparing long term mean monthly flow with the mean monthly flow of a particular year.

Glimpses of VWASP.DAT

```
0012
JANUARY  FEBRUARY    MARCH    APRIL      MAY      JUNE
    JULY   AUAGUST SEPTEMBER   OCTOBER  NOVEMBER  DECEMBER
 0005 0001
 0003
     DRY 0005
 1980 1983 1988 1997 2009
     WET 0005
 1986 1995 1998 2000 2007
    MEAN 0020
 1981 1982 1984 1985 1987 1989 1990 1991 1992 1993
 1994 1996 1999 2001 2002 2003 2004 2005 2006 2008
```

3.3 OUTPUT OF VALORAGUA

3.3.1 VALAGP output

Optimization is done through VALAGP module, which performs iterations to produce the optimal solution for different states of reservoir for medium term management option. For reservoirs, the marginal cost varies from 0 to 57.6 Cents/kwh. When the reservoir is full of storage, the value of water is 0. When it is having lesser volume of water due to the downstream release during dry periods, the marginal cost is high. The minimum, maximum and incremental contents are similar in each month due to lesser number of storage type projects.

For short term option, total system operating cost and marginal cost of each load step for each month of a year is computed by the program. The marginal cost is in the range of 10cents/kwh during May-December, while it is in the range of 40-60Cents/Kwh during January-April period (dry period). During dry period, the thermal plants should be operated to fulfill deficit in power due to which the marginal cost goes up. During wet period, hydro plant can operate with installed capacity due to which the marginal cost becomes lesser.

Glimpses of VALORAGUA Output

VALAGP.PRN
(For reference, only the last iteration is shown here.)

```
SOLUTION OF THE MEDIUM TERM PROBLEM - ITERATION NR. :  2
         *******************************************************          MONTH   RMI     DR     RMA

                                                              12    26.41    15.75    183.96
 FVW   56.60  56.51  56.42  56.32  56.46  56.36  56.26  56.15  55.06  54.45  54.32
 S.D.   .32    .34    .37    .40    .32    .35    .38    .42   3.93   4.70   4.67
ACV.     0.   891.  1781.  2669.  3557.  4446.  5333.  6218.  7094.  7957.  8814.
                                                              11    26.41    15.75    183.96
 FVW   47.10  45.11  43.14  41.64  45.08  43.11  41.63  39.74  37.25  37.23  37.21
 S.D.  9.92   9.58   8.83   7.88   9.55   8.79   7.86   6.06   9.05   9.05   9.04
ACV.     0.   726.  1421.  2089.  2773.  3467.  4135.  4776.  5382.  5969.  6555.
                                                              10    26.41    15.75    183.96
 FVW   20.61  18.55  16.60  14.79  20.58  18.33  16.60  14.79  11.94  11.89  11.88
 S.D. 13.86  12.96  11.84  10.55  13.81  12.66  11.84  10.54   6.98   6.77   6.77
ACV.     0.   308.   585.   833.  1111.  1418.  1693.  1940.  2151.  2339.  2526.
                                                               9    26.41    15.75    183.96
 FVW    2.60   2.60   2.56   1.97   3.31   3.27   3.27   3.20   2.60   2.57   2.56
 S.D.  4.32   4.32   4.26   3.94   4.68   4.63   4.63   4.53   4.32   4.26   4.26
ACV.     0.    41.    82.   117.   159.   211.   262.   313.   359.   400.   440.
                                                               8    26.41    15.75    183.96
 FVW    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 S.D.   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
ACV.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
                                                               7    26.41    15.75    183.96
 FVW    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 S.D.   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
ACV.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
                                                               6    26.41    15.75    183.96
 FVW    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
 S.D.   .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00
ACV.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
                                                               5    26.41    15.75    183.96
 FVW    .63    .33    .33    .33   1.56    .93    .63    .63    .63    .33    .33
 S.D.  2.37   1.80   1.80   1.80   3.50   2.80   2.37   2.37   2.37   1.80   1.80
ACV.     0.     8.    13.    18.    33.    53.    65.    75.    85.    93.    98.
                                                               4    26.41    15.75    183.96
```

```
 FVW   19.77  18.76  18.76  15.76  19.77  18.76  18.62  15.76  15.75  14.75  14.74
 S.D.  14.53  14.12  14.11  12.34  14.53  14.11  13.92  12.33  12.32  11.49  11.48
ACV.     0.   304.   599.   871.  1151.  1454.  1749.  2020.  2268.  2508.  2740.
                                                              3    26.41    15.75    183.96
 FVW   53.82  53.19  51.56  50.02  52.42  51.03  49.46  47.89  45.87  44.82  43.10
 S.D.   5.34   5.80   6.81   7.40   6.19   7.03   7.48   7.60   7.33   6.94   7.68
ACV.     0.   843.  1668.  2468.  3275.  4090.  4882.  5649.  6387.  7102.  7794.
                                                              2    26.41    15.75    183.96
 FVW   56.21  56.03  55.87  55.65  55.86  55.67  55.46  55.28  54.85  54.41  53.84
 S.D.    .61    .72    .75    .91    .74    .81    .96   1.06   1.34   1.70   1.99
ACV.     0.   884.  1766.  2644.  3522.  4401.  5276.  6149.  7016.  7877.  8730.
                                                              1    26.41    15.75    183.96
 FVW   57.62  57.44  57.27  57.11  57.24  57.08  56.91  56.74  56.58  56.44  56.30
 S.D.    .47    .47    .46    .44    .43    .41    .40    .39    .36    .33    .29
ACV.     0.   906.  1810.  2711.  3612.  4512.  5410.  6306.  7198.  8089.  8977.

             RMI/RMA = MINIMUM/MAXIMUM EQUIVALENT RESERVOIR CONTENTS
             DR      = INCREMENTAL ENERGY CONTENTS
             FVW     = MARGINAL VALUE OF WATER AT EACH STATE OF THE EQUIVALENT RESERVOIR
             S.D.    = ASSOCIATED STANDARD DEVIATION
ACV.    = ACCUMULATED VALUE OF THE RESERVOIR'S ENERGY CONTENTS
```

(For short term: only last 3 years are shown here for reference)

```
SOLUTION OF THE SHORT TERM PROBLEM
               **********************************

                              MARGINAL COST BY LOAD STEP (CTS/KWH)

H.C. MONTH EL.NODE ITER.    COSTS     MAX.DEV.  STEP 1  STEP 2  STEP 3  STEP 4  STEP 5
               (MILL.US$)

 2007    1    1   101    .10779E+03    .0000   41.878  40.528  40.254  40.063  40.018
 2007    2    1    96   .17616E+03    .0000   57.132  56.451  55.794  54.611  53.866
 2007    3    1   104    .12320E+03    .0004   41.479  41.025  40.390  40.177  40.027
 2007    4    1   100    .79599E+02    .0005   40.368  40.135  39.424  39.105  38.284
 2007    5    1    95   .60587E+02    .0005   10.536  10.317  10.093  10.078  10.070
 2007    6    1    94   .52935E+01    .0001   10.067  10.042   9.491   8.968   8.915
 2007    7    1    93   .32286E+01    .0001   10.060  10.018    .001    .001    .001
 2007    8    1    93   .45968E+01    .0001   10.069  10.031    .001    .001    .001
 2007    9    1    94   .54842E+01    .0000   10.079  10.040   8.943    .001    .001
 2007   10    1    94    .43465E+01    .0001   10.077  10.025    .001    .001    .001
 2007   11    1    94    .13761E+02    .0002   11.137  10.084  10.032   9.904   9.753
```

```
2007  12   1   96   .51274E+02   .0000   10.556  10.298  10.087  10.066  10.049

2008   1   1  129   .88652E+02   .0004   41.313  40.258  40.058  39.597  39.499
2008   2   1   95  .17010E+03   .0000   56.832  56.123  55.406  54.299  53.904
2008   3   1  101   .13260E+03   .0003   41.601  41.143  40.477  40.200  40.103
2008   4   1  119   .92998E+02   .0004   41.358  40.485  40.141  39.993  39.546
2008   5   1   96  .52835E+02   .0000   10.458  10.249  10.082  10.066  10.057
2008   6   1   94  .52391E+01   .0000   10.067  10.042   8.973    .001    .001
2008   7   1   93  .32583E+01   .0001   10.060  10.018    .001    .001    .001
2008   8   1   93  .46134E+01   .0001   10.069  10.031    .001    .001    .001
2008   9   1   94  .54470E+01   .0000   10.079  10.040   8.940    .001    .001
2008  10   1   94   .43633E+01   .0000   10.077  10.025    .001    .001    .001
2008  11   1   95   .30590E+02   .0000   11.587  10.267  10.069  10.031  10.016
2008  12   1   95   .57870E+02   .0000   10.614  10.351  10.097  10.076  10.060

2009   1   1  115   .93614E+02   .0000   41.553  40.329  40.127  39.774  39.663
2009   2   1  100   .16843E+03   .0000   56.756  56.031  55.298  54.153  53.631
2009   3   1  105   .12180E+03   .0003   41.505  41.031  40.382  40.144  40.043
2009   4   1  111   .10658E+03   .0004   41.722  40.831  40.254  40.114  39.924
2009   5   1   96  .57192E+02   .0000   10.518  10.310  10.090  10.073  10.064
2009   6   1   95  .73060E+01   .0000   10.077  10.052  10.008   9.575   9.459
2009   7   1   93  .32613E+01   .0001   10.060  10.018    .001    .001    .001
2009   8   1   93  .46484E+01   .0001   10.070  10.031    .001    .001    .001
2009   9   1   93  .54561E+01   .0004   10.079  10.040   8.941    .001    .001
2009  10   1  192   .43897E+01   .0232   10.077  10.026   8.939   2.116   2.032
2009  11   1   96   .32982E+02   .0000   11.665  10.293  10.072  10.035  10.020
2009          12              1              97              .57384E+02              .0000          10.616          10.348          10.096          10.075          10.059
```

3.3.2 RESEX output

The main output of the VALORAGUA is depicted in the RESEX. In the output table, the annual values for the average of 30 years period are given. The salient features of output are summarized below.

Power balance

The fixed energy demand for 2030 was assigned as 1800GWh in CADIR data file. According to the result of VALORAGUA, 13444.99Gwh will be generated by hydroelectric power and 5257.53 GWh by thermal output. Total energy generated is 18702.5GWh. After satisfying fixed energy demand, 285.87 Gwh will be used for secondary demand and 418.741 Gwh will be excess. The peak power produced in load step 1 is 2953.55 MW, out of which 1937.6 MW is from hydropower. Marginal cost of generation in the hydro-thermal mixed system is 18.399 Cents/KWh.

Water balance

Water balance is computed by:

Final storage = initial storage + inflows -outflows – losses

Evaporation loss and mandatory release are not considered in the study. Outflows represent downstream turbine volume and spilled volume. In ROR type project, as inflow is equal to outflow, the initial storage becomes equal to final storage. In storage type projects, inflow is not equal to outflow. Therefore, there is some variation in initial and final storage. For the whole system, the initial storage is 144.41 Mm^3 and final storage is 145.80 Mm^3. The turbine volume of water is 33817.2 Mm^3.The marginal value of water for the whole system is 0.5222 Cents/m^3.

Hydroelectric power plants

The utilization factor is 73.04%. Energy generated is only 73.04% of maximum operationally feasible energy generation. Average energetic coefficient (ratio of energy generated to water flow) is 0.398 Kwh/m^3. The marginal value of water for hydroelectric plant is 2.709 cents/m^3.

3.3.3 VWASP output

VWASP output shows the base capacity (MWB), available capacity (MWC), inflow energy (EA) and minimum requirements for base load generation (EMIN). EA, EMIN and MWC are used in WASP model.

RESEX.PRN

```
1                                                          PAGE   1
            DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :    BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                     YEAR
       MEAN OF HYDRO CONDITIONS: 1980 - 2009                    2030


                                    ELECTRIC NODE

                         POWER BALANCE EQUATION - MARGINAL COSTS


                                  HYDRO          NET
                  FIXED   SECONDARY  THERMAL  ELECTRIC   PUMPING    TRANS          MARGINAL
  ELECTRIC   LOAD       POWER     POWERPOWERPOWERPOWER   PORTED     POWER    COST OF    VALUE OF
   NODE     STEP       DEMAND    DEMAND    OUTPUT    OUTPUT   CONSUMPT.   POWER    EXCESS   GENERATION
GENERATION
                  MW       MWMWMWMWMWMW      CTS/KWH    MILL.US$


  SYSTEM      1       2953.55     0.00  -1015.95  -1937.60      0.00      0.00    -0.008     22.110    228.818
              2       2625.44     0.00   -839.47  -1785.97      0.00      0.00    -0.008     21.940    555.064
              3       2234.75    31.36   -645.22  -1624.35      0.00      0.00    -3.470     19.728    705.998
              4       1949.21    39.74   -552.17  -1485.04      0.00      0.00   -48.254     17.348    928.748
              5       1785.40    40.72   -501.10  -1413.41      0.00      0.00   -88.377     16.478   1022.508

        TOTAL (GWH)  17997.91   285.87  -5257.53 -13444.99      0.00      0.00  -418.741     18.399   3441.136
1                                                          PAGE   2
            DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :    BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                     YEAR
       MEAN OF HYDRO CONDITIONS: 1980 - 2009                    2030


                                 SECONDARY DEMAND SYSTEM

                                    SUMMARY REPORT



                                                   UNITARY
        SECONDARY   SUPPLIED  UTILIZATION  TOTAL     TOTAL     NET      NET
         DEMAND     DEMAND      FACTOR    BENEFIT    COST    BENEFIT  BENEFIT
                  GWH        %       M US$     M US$     M US$    US$/KW

        S.DEM1      285.87       31.08    25.602     2.208    23.394   222.80

        TOTAL       285.87       31.08    25.602     2.208    23.394   222.80
1                                                          PAGE   3
            DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :    BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                     YEAR
       MEAN OF HYDRO CONDITIONS: 1980 - 2009                    2030
```

```
                         SECONDARY DEMAND

                      POWER SUPPLIED BY LOAD STEP

    ===================================================================
    LOAD STEP              1       2       3       4       5
DURATION   (HOURS)       350.    964.   1577.   2628.   3241.
TOTAL TIME (HOURS)       350.   1314.   2891.   5519.   8760.
    ===================================================================


        SUPPLIED
    SECONDARY   ENERGY              POWER SUPPLIED
     DEMAND     GWH                 MW

     S.DEM1    285.873     0.000    0.000   31.355   39.741   40.723

     SYSTEM    285.873     0.000    0.000   31.355   39.741   40.723
1                                                          PAGE   4
           DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :    BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                       YEAR
      MEAN OF HYDRO CONDITIONS: 1980 - 2009                         2030


                             THERMAL POWER SYSTEM

                              SUMMARY REPORT

     THERMAL   VARIABLE                  TOTAL
      POWER    UNITARY    TOTAL     VALUE OF   VARIABLE    NET    UNITARY  UTILIZATION
      PLANT     COST    GENERATION GENERATION    COSTS    BENEFIT  BENEFIT    FACTOR
              CTS/KWH     GWH      MILL.US$   MILL.US$  MILL.US$  US$/KW       %

    DUHABI     40.0000     46.79      21.37     18.77      2.59   100.82      20.77
    HETAUD     40.0000     12.18       5.50      4.89      0.61    92.25      21.04
    ADD        40.0000    532.20     246.84    213.80     33.03   110.11      20.25
    IMP        10.0000   4593.20    1453.87    461.40    992.47   992.47      52.43
    REST       55.0000     73.16      41.38     40.81      0.57     0.19       0.28

    SYSTEM     14.0688   5257.53    1768.95    739.67   1029.28              44.42*

    ---------------------------------------------------------------------------------
     * DOES NOT INCLUDE THE UNSERVED ENERGY   REST
1                                                          PAGE   5
           DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :    BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                       YEAR
      MEAN OF HYDRO CONDITIONS: 1980 - 2009                         2030



                        THERMAL POWER PLANTS

                      POWER OUTPUT BY LOAD STEP


    ===================================================================
```

```
      LOAD STEP           1      2      3      4      5
DURATION  (HOURS)       350.   964.   1577.  2628.  3241.
TOTAL TIME (HOURS)      350.   1314.  2891.  5519.  8760.
      ================================================================

       THERMAL   ENERGY
POWER  GENERATION            POWER OUTPUT
        PLANT    GWH                MW

       DUHABI    46.794     7.794   7.657   6.905   5.141   3.791
       HETAUD    12.178     2.107   2.065   1.837   1.328   0.945
       ADD      532.204    99.587  96.260  80.469  54.990  41.082
       IMP     4593.197   878.873 712.812 542.047 485.021 453.240
       RESTTH    73.159    27.587  20.677  13.965   5.686   2.038

       SYSTEM   5257.532  1015.948 839.472 645.223 552.165 501.096
1                                                        PAGE  6
            DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :   BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                     YEAR
      MEAN OF HYDRO CONDITIONS: 1980 - 2009                       2030


                              HYDRAULIC NODES (RESERVOIRS)

                         WATER BALANCE EQUATION - WATER VALUES IN MILLION M3

              UP     DOWN     UP          DOWN      UP     DOWN                    MARGINAL
       INITIAL   STREAM   STREAMSTREAM  TRIBU-   STREAM   STREAMSTREAM  EVAPOR.   MANDATORY  FINAL  VALUE
OF VALUE OF
 RESERVOIR   STORAGE  TURBINED  PUMPED  SPILLED    TARY   TURBINED  PUMPED  SPILLED    VOLUME    RELEASES
STORAGE  WATER    INFLOW
            VOLUME   VOLUMEVOLUME  INFLOW   VOLUME   VOLUMEVOLUME                    CTS/M3  MILL.US$

 PUWA       1.00    0.00    0.00    0.00   240.60  -57.97    0.00 -182.88   0.000     0.00    1.00    1.703    4.097
 MAI       1.00   57.97    0.00  182.88   465.89 -256.68    0.00  -450.10   0.000     0.00    1.00    0.039    0.273

 IKHUWA      1.00    0.00    0.00    0.00   231.56   -91.65    0.00 -140.12    0.000     0.00    1.00    2.082    4.822
 PILUWA     1.00    0.00    0.00    0.00   288.63  -88.01    0.00 -200.85   0.000     0.00    1.00    0.430    1.241

 UTAMOR      1.00    0.00    0.00    0.00  3410.51 -1872.51    0.00 -1537.04   0.000     0.00    1.00    4.828  164.657
 MAIWA      1.00    0.00    0.00    0.00   318.87 -126.32    0.00 -192.59   0.000     0.00    1.00    0.359    1.143
 MTAMOR      1.00  1998.83    0.00  1729.63  3816.05 -2521.68    0.00 -5023.66   0.000     0.00    1.00    0.596   44.935
 PHAWA      1.00    0.00    0.00    0.00   180.65  -51.62    0.00  -129.25   0.000     0.00    1.00    0.630    1.138
 KABE-A     1.00   51.62    0.00  129.25  1592.80 -645.76    0.00 -1127.76   0.000     0.00    1.00    0.207    3.679
 HEWA      1.00    0.00    0.00    0.00   394.50 -168.15    0.00 -225.61   0.000     0.00    1.00    0.964    3.802

 UTAMAK      1.00    0.00    0.00    0.00  2683.42 -1189.81    0.00 -1493.33   0.000     0.00    1.00    6.727  180.512
 SIPRIN    1.00    0.00    0.00    0.00   307.55 -131.09    0.00  -176.71   0.000     0.00    1.00    0.297    0.912

 KHANI      1.00    0.00    0.00    0.00   116.84   -70.43    0.00   -46.57   0.000     0.00    1.00    2.464    2.879

 KHIM-1     1.00    0.00    0.00    0.00  1002.90 -231.20    0.00  -771.84   0.000     0.00    1.00    1.725   17.301

 U-BHOT     1.00    0.00    0.00    0.00  2439.58 -823.05    0.00 -1617.60   0.000     0.00    1.00    0.508   12.395
 CHAKU      1.00    0.00    0.00    0.00    68.49  -42.42    0.00   -26.28   0.000     0.00    1.00    0.529    0.362
 BARAMC      1.00    0.00    0.00    0.00    17.13  -12.44    0.00    -4.98   0.000     0.00    1.00    1.480    0.254
 SUNKOS      1.00    0.00    0.00    0.00   193.96  -64.40    0.00  -129.76   0.000     0.00    1.00    0.431    0.837
 SUNKON      1.00   942.30    0.00  1778.61   485.00 -727.49    0.00 -2250.13   0.000     0.00    1.00    0.255    8.161

 BALE-A     1.00    0.00    0.00    0.00   290.03 -248.83    0.00   -39.86   0.000     0.00    1.00    0.235    0.681
 BALE-B     1.00  248.83    0.00   39.86  1600.98 -616.31    0.00 -1274.72   0.000     0.00    1.00    0.083    1.560

 INDRAW      1.00    0.00    0.00    0.00   870.08 -283.12    0.00  -586.95   0.000     0.00    1.00    0.270    2.352

 U-SANJ     1.00    0.00    0.00    0.00   289.55 -176.92    0.00  -112.58   0.000     0.00    1.00    1.545    4.472
 L-SANJ     1.00  176.92    0.00  112.58   325.14 -191.76    0.00  -423.11   0.000     0.00    1.00    0.000    0.000
 CHILIM     1.00  191.76    0.00  423.11   224.81 -215.16    0.00  -624.53   0.000     0.00    1.00    1.336   11.219
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RASGAD      1.00    0.00    0.00    0.00  5234.26 -1787.50    0.00 -3447.46    0.000     0.00    1.00   0.657   34.371
TRIS3A      1.00  2002.66    0.00  4071.99  7204.24 -1495.93    0.00 -11782.1    0.000     0.00    1.00   0.000   0.000
TRIS2B      1.00  1495.93    0.00 11782.07  7259.74 -1497.96    0.00 -19039.7    0.000     0.00    1.00   0.000   0.000
TRIS      1.00  1497.96    0.00 19039.73  1977.06 -1275.43    0.00 -21239.3    0.000     0.00    1.00   0.000   0.000
DEVIGH      1.00  1275.43    0.00 21239.31  6582.46  -931.68    0.00 -27875.0    0.000     0.00    1.00   0.000   0.000

KULEK1     83.94    0.00    0.00    0.00   288.16  -240.07    0.00   -46.59    0.000     0.00   85.11   8.466   24.395
KULEK2      1.00   240.07    0.00   46.59   288.16  -328.14    0.00  -246.85    0.000     0.00    1.00   3.592   20.645
KULEK3      1.00   328.14    0.00  246.85   327.04  -417.76    0.00  -484.36    0.000     0.00    1.00   1.193   10.766

BUDHIG      3.26    0.00    0.00    0.00  7763.11 -4937.32    0.00 -2836.03    0.000     0.00    3.31   1.403  108.954

UMARSY      1.00    0.00    0.00    0.00   706.31  -533.11    0.00  -176.32    0.000     0.00    1.00   1.275    9.006
MMARSY      1.00   533.11    0.00  176.32  5516.77 -1850.48    0.00 -4372.43    0.000     0.00    1.00   0.643   40.031
KHUDI     1.00    0.00    0.00    0.00   262.65   -90.40    0.00  -172.67    0.000     0.00    1.00   0.454    1.191
LCHEPE      1.00    0.00    0.00    0.00   543.87  -157.20    0.00  -386.79    0.000     0.00    1.00   0.757    4.116
MARSYG      1.00  2098.07    0.00  4931.89  5534.67 -2132.12    0.00 -10452.7    0.000     0.00    1.00   0.051    6.424

BIJAYP      1.00    0.00    0.00    0.00   142.24  -105.85    0.00   -37.66    0.000     0.00    1.00   0.271    0.385

MODI      1.00    0.00    0.00    0.00  1307.25  -545.49    0.00  -762.02    0.000     0.00    1.00   0.588    7.691
LMODI      1.00   545.49    0.00  762.02  1423.68  -245.89    0.00 -2379.10    0.000     0.00    1.00   0.000   0.000
KGANDA      7.64   245.89    0.00  2379.10  9168.75 -3472.72    0.00 -8426.77    0.000     0.00    7.69   1.007  118.787

ANDHI      1.00    0.00    0.00    0.00   526.29  -102.15    0.00  -424.37    0.000     0.00    1.00   0.430    2.262

JHIMRK      1.00    0.00    0.00    0.00   610.93  -149.51    0.00  -461.90    0.000     0.00    1.00   0.554    3.382

CHAMEL      7.64    0.00    0.00    0.00  1250.95  -615.75    0.00  -635.89    0.000     0.00    7.69   1.164   14.566


SYSTEM    144.41 13931.00    0.00 69071.79 85774.09 -33817.2    0.00 -134475.   0.000     0.00  145.80   0.522  880.657
1                                                                      PAGE   7
          DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :   BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                     YEAR
     MEAN OF HYDRO CONDITIONS: 1980 - 2009                  2030


                         HYDROELECTRIC POWER PLANTS

                           SUMMARY REPORT


 HYDRO   AVERAGE   AVERAGEMARGINAL  VALUEVALUE
 POWER     NET   ENERGETIC TURBINED    ENERGY   UTILIZATION VALUE OF    OFOF      NET    UNITARY
PLANT     HEAD     COEF.    VOLUME   GENERATION    FACTOR      WATER    WATER    GENERATION BENEFIT
BENEFIT
        M     KWH/M3   MILL.M3     GWH        %       CTS/M3  MILL.US$   MILL.US$  MILL.US$ US$/KW

 PUWA     320.00    0.733   57.97     42.49      86.58   7.119     4.13      6.88     6.88   1228.41
 MAI     121.60    0.295  256.68     75.71     100.00   0.106     0.27      6.24     6.24    744.16

 IKHUWA    605.00    1.467   91.65    134.50      98.06   5.317     4.87     17.05    17.05   1088.75
 PILUWA    107.00    0.262   88.01     23.09      97.53   1.376     1.21      3.36     3.36   1243.12

 UTAMOR    470.00    1.140  1872.51   2134.63      61.90   8.790   164.59    204.34   204.34    519.10
 MAIWA    115.71    0.284  126.32     35.85      99.69   0.902     1.14      3.94     3.94    960.44
 MTAMOR     84.00    0.195  2521.68    490.94      87.19   1.783    44.95     66.32    66.32   1031.73
 PHAWA    292.00    0.708   51.62     36.56     100.00   2.241     1.16      5.06     5.06   1228.02
 KABE-A    111.40    0.255  645.76    164.79     100.00   0.569     3.67     18.12    18.12    966.30
 HEWA    212.00    0.486  168.15     81.66      90.43   2.269     3.82     10.18    10.18    987.87

 UTAMAK    800.00    1.962  1189.81   2334.35      64.78  15.182   180.64    228.24   228.24    554.82
 SIPRIN    150.00    0.344  131.09     45.04     100.00   0.703     0.92      4.19     4.19    826.15
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 KHANI    940.00    2.153   70.43    151.65     91.49   4.134    2.91     11.24   11.24   594.27

 KHIM-1   691.60    1.622  231.20    374.91     97.18   7.443   17.21     50.11   50.11  1137.78

 U-BHOT   143.20    0.309  823.05    254.11     98.86   1.506   12.40     38.48   38.48  1311.45
 CHAKU    124.50    0.289   42.42     12.24     94.54   0.809    0.34      1.19    1.19   807.41
 BARAMC   538.20    1.247   12.44     15.51     96.38   2.064    0.26      1.44    1.44   784.91
 SUNKOS   124.50    0.285   64.40     18.37     97.20   1.286    0.83      2.84    2.84  1314.60
 SUNKON    32.10    0.074  727.49     54.12     68.45   1.121    8.15     12.81   12.81  1418.84

 BALE-A    48.00    0.111  248.83     27.68     89.49   0.273    0.68      1.86    1.86   526.49
 BALE-B    80.00    0.185  616.31    114.27    100.00   0.253    1.56     13.59   13.59  1045.98

 INDRAW    60.00    0.144  283.12     40.75     99.14   0.830    2.35      5.45    5.45  1160.90

 U-SANJ   156.00    0.357  176.92     63.22     54.88   2.522    4.46      5.63    5.63   428.41
 L-SANJ   432.80    0.991  191.76    190.12    100.00   0.000    0.00     16.98   16.98   792.33
 CHILIM   354.50    0.783  215.16    168.56     97.38   5.200   11.19     25.69   25.69  1299.84
 RASGAD   158.48    0.389 1787.50    694.74    100.00   1.923   34.37     88.62   88.62  1123.95
 TRIS3A   132.00    0.302 1495.93    452.34    100.00   0.000    0.00     81.05   81.05  1707.72
 TRIS2B    87.00    0.190 1497.96    284.49    100.00   0.000    0.00     50.88   50.88  1805.97
 TRIS      56.75    0.130 1275.43    165.81    100.00   0.000    0.00     30.67   30.67  1683.86
 DEVIGH    39.00    0.084  931.68     78.34     78.58   0.000    0.00     20.27   20.27  1780.92

 KULEK1   658.05    1.614  240.07    387.44     71.78  24.518   58.86     69.06   69.06  1120.90
 KULEK2   313.60    0.693  328.14    227.41     90.54   6.265   20.56     37.43   37.43  1305.50
 KULEK3   102.56    0.254  417.76    106.23     93.08   2.575   10.76     17.99   17.99  1381.03

 BUDHIG   128.85    0.292 4937.32   1440.14     50.02   2.213  109.26    135.01  135.01   410.74

 UMARSY   118.40    0.271  533.11    144.59     37.92   1.688    9.00     12.43   12.43   285.58
 MMARSY    98.00    0.209 1850.48    386.10     88.43   2.163   40.03     57.59   57.59  1155.35
 KHUDI    105.40    0.244   90.40     22.08     87.12   1.243    1.12      3.07    3.07  1061.28
 LCHEPE   135.00    0.313  157.20     49.19     90.26   2.627    4.13      6.05    6.05   973.32
 MARSYG    87.10    0.214 2132.12    455.44     82.92   0.301    6.42     89.68   89.68  1430.31

 BIJAYP    65.40    0.152  105.85     16.04     86.26   0.367    0.39      1.20    1.20   565.09

 MODI      66.96    0.155  545.49     84.66     69.04   1.410    7.69      9.51    9.51   679.17
 LMODI     17.50    0.041  245.89      9.97     71.46   0.000    0.00      2.23    2.23  1397.71
 KGANDA   136.80    0.313 3472.72   1088.26     90.57   3.432  119.18    162.81  162.81  1186.92

 ANDHI    242.60    0.562  102.15     57.44     98.09   2.189    2.24      8.32    8.32  1245.30

 JHIMRK   189.50    0.439  149.51     65.67     96.90   2.273    3.40      8.83    8.83  1140.87

 CHAMEL    94.00    0.233  615.75    143.51     67.43   2.419   14.89     18.26   18.26   751.65


 SYSTEM   351.19    0.398 33817.24 13444.99    73.04   2.709  915.99   1672.19 1672.19   795.81
1                                                                PAGE   8
          DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :   BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                          YEAR
     MEAN OF HYDRO CONDITIONS: 1980 - 2009                             2030



                  HYDROELECTRIC POWER PLANTS

                  POWER OUTPUT BY LOAD STEP

     ================================================================
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       LOAD STEP            1      2      3      4      5
DURATION  (HOURS)        350.   964.  1577.  2628.  3241.
TOTAL TIME (HOURS)       350.  1314.  2891.  5519.  8760.
       ===============================================================

             ENERGY
       TURBINING GENERATION              POWER OUTPUT
        PLANT     GWH                   MW

        PUWA     42.494    5.385   5.184   4.989   4.773   4.690
        MAIIK    75.706    8.776   8.768   8.744   8.604   8.572
        IKHUWA   134.497    15.844  15.827  15.551  15.343  15.072
        PILUWA    23.095     2.787   2.732   2.666   2.621   2.590
        UTAMOR  2134.633   339.287  298.426  261.002  233.970  216.513
        MAIWAM    35.847    4.249   4.235   4.153   4.077   4.015
        MTAMOR   490.938    60.230  58.259  56.599  55.634  54.993
        PHAWAK    36.559    4.265   4.248   4.203   4.167   4.132
        KABE-A   164.793   19.234  19.225  19.085  18.843  18.485
        HEWAUT    81.660   10.466  10.386  10.126   9.006   8.747
        UTAMAK  2334.350   390.445 345.222 292.060 253.143 228.034
        SIPRIN   45.044    5.275   5.259   5.201   5.136   5.069
        KHANIK   151.648   19.125  19.040  18.774  17.216  15.967
        KHIM-1   374.906   45.262  44.639  43.373  42.556  41.900
        U-BHOT   254.108   30.195  29.906  29.376  28.856  28.556
        CHAKUB    12.240    1.525   1.520   1.466   1.375   1.331
        BARAMC    15.513    1.882   1.878   1.841   1.759   1.703
        SUNKOS    18.367    2.267   2.244   2.188   2.044   2.033
        SUNKON    54.124    9.008   8.760   6.843   5.462   5.363
        BALE-A    27.682    3.625   3.620   3.549   3.089   2.841
        BALE-B   114.274   13.538  13.459  13.177  13.001  12.840
        INDRAW    40.745    4.886   4.827   4.711   4.619   4.570
        U-SANJ    63.224   11.458   9.860   8.243   6.692   5.900
        L-SANJ   190.119   21.725  21.725  21.723  21.712  21.677
        CHILIM   168.561   20.123  19.761  19.450  19.128  18.984
        RASGAD   694.737   81.795  81.419  80.089  78.978  78.299
        TRIS3A   452.338   51.706  51.700  51.665  51.622  51.609
        TRIS2B   284.487   32.488  32.482  32.477  32.474  32.473
        TRISDE   165.806   18.955  18.949  18.932  18.925  18.919
        DEVIGH    78.340   11.730  11.730   9.682   8.120   8.120
        KULEK1   387.438   58.380  54.008  48.815  41.538  39.740
        KULEK2   227.409   28.793  27.769  26.600  25.566  25.123
        KULEK3   106.230   13.016  12.604  12.274  12.027  11.898
        BUDHIG  1440.135   247.776 212.076 182.432 154.796 140.224
        UMARSY   144.593   35.094  29.293  20.764  12.623  11.771
        MMARSY   386.096   49.050  46.955  44.902  43.584  42.676
        KHUDIL    22.082    2.965   2.838   2.731   2.406   2.370
        LCHEPE    49.186    6.344   6.027   5.731   5.538   5.419
        MARSYG   455.440   63.512  61.455  57.707  48.624  47.881
        BIJAYP    16.045    2.169   2.150   2.029   1.782   1.645
        MODI L    84.657   12.346  11.149  10.108   9.420   8.915
        LMODIK     9.973    1.649   1.646   1.270   0.991   0.988
        KGANDA  1088.263   134.549 130.056 125.805 123.173 121.475
        ANDHIJ    57.438    6.876   6.798   6.642   6.525   6.435
        JHIMRK    65.665    7.936   7.880   7.713   7.455   7.262
        CHAMEL   143.509   19.613  17.979  16.895  16.042  15.585

        SYSTEM   13444.99   1937.604 1785.973 1624.352 1485.038 1413.406
1                                                           PAGE   9
           DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :   BASIC CASE OPTM
  PROGRAM   RESEX



ANNUAL  VALUES                                      YEAR
       MEAN OF HYDRO CONDITIONS: 1980 - 2009                    2030
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                    HYDROELECTRIC POWER PLANTS

                     WATER FLOW BY LOAD STEP

      ===========================================================
      LOAD STEP              1        2        3        4        5
DURATION   (HOURS)       350.     964.    1577.    2628.    3241.
TOTAL TIME (HOURS)       350.    1314.    2891.    5519.    8760.
      ===========================================================

       HYDRO    TURBINED
       POWER     VOLUME                 WATER FLOW
       PLANT    MILL.M3                 M3/S

      PUWA      57.970    2.041   1.964   1.890   1.809   1.777
      MAIIK    256.683    8.265   8.258   8.235   8.103   8.073
      IKHUWA    91.655    2.999   2.996   2.944   2.904   2.853
      PILUWA    88.009    2.950   2.892   2.822   2.775   2.741
      UTAMOR  1872.510   82.673  72.717  63.598  57.011  52.757
      MAIWAM   126.322    4.160   4.146   4.065   3.991   3.930
      MTAMOR  2521.679   85.936  83.123  80.755  79.379  78.463
      PHAWAK    51.619    1.673   1.666   1.648   1.634   1.621
      KABE-A   645.765   20.936  20.927  20.774  20.511  20.122
      HEWAUT   168.149    5.986   5.941   5.792   5.151   5.003
      UTAMAK  1189.806   55.280  48.877  41.350  35.840  32.285
      SIPRIN   131.090    4.264   4.252   4.204   4.152   4.098
      KHANIK    70.426    2.467   2.456   2.422   2.221   2.060
      KHIM-1   231.201    7.754   7.647   7.430   7.290   7.178
      U-BHOT   823.049   27.167  26.907  26.430  25.962  25.693
      CHAKUB    42.417    1.468   1.463   1.411   1.324   1.282
      BARAMC    12.436    0.419   0.418   0.410   0.392   0.379
      SUNKOS    64.401    2.208   2.185   2.131   1.990   1.980
      SUNKON   727.490   33.632  32.708  25.548  20.392  20.025
      BALE-A   248.830    9.051   9.039   8.862   7.714   7.094
      BALE-B   616.310   20.281  20.163  19.741  19.477  19.236
      INDRAW   283.124    9.431   9.316   9.094   8.916   8.822
      U-SANJ   176.922    8.906   7.664   6.407   5.202   4.587
      L-SANJ   191.761    6.087   6.087   6.086   6.083   6.073
      CHILIM   215.163    7.135   7.007   6.897   6.782   6.731
      RASGAD  1787.500   58.459  58.190  57.239  56.445  55.960
      TRIS3A  1495.932   47.499  47.493  47.461  47.422  47.410
      TRIS2B  1497.955   47.518  47.510  47.502  47.498  47.495
      TRISDE  1275.431   40.502  40.490  40.452  40.437  40.425
      DEVIGH   931.684   38.751  38.751  31.984  26.826  26.826
      KULEK1   240.072   10.106   9.362   8.472   7.110   6.812
      KULEK2   328.139   11.541  11.130  10.662  10.248  10.070
      KULEK3   417.757   14.218  13.768  13.408  13.138  12.997
      BUDHIG  4937.316  236.731 201.571 173.560 147.331 133.728
      UMARSY   533.110   35.942  30.001  21.266  12.928  12.056
      MMARSY  1850.475   65.302  62.512  59.779  58.025  56.816
      KHUDIL    90.395    3.372   3.227   3.105   2.736   2.695
      LCHEPE   157.198    5.632   5.351   5.088   4.917   4.811
      MARSYG  2132.125   82.591  79.917  75.042  63.231  62.264
      BIJAYP   105.851    3.975   3.939   3.719   3.265   3.014
      MODI L   545.494   22.099  19.955  18.092  16.860  15.956
      LMODIK   245.893   11.295  11.271   8.697   6.788   6.767
      KGANDA  3472.722  119.265 115.283 111.515 109.182 107.677
      ANDHIJ   102.153    3.397   3.359   3.281   3.224   3.179
      JHIMRK   149.509    5.019   4.984   4.878   4.715   4.593
      CHAMEL   615.749   23.376  21.428  20.136  19.120  18.575

      SYSTEM  33817.24  1299.761 1220.313 1126.286 1038.452 1004.991
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Sample of VWASP.PRN

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1                                                       PAGE   1
           DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :    BASIC CASE OPTM
  PROGRAM   VWASP



                                    STUDY YEAR     :     2030
                                    HYDRO CONDITION:       DRY
                                    PERIOD         :   JANUARY
                                    - 1980- 1983- 1988- 1997- 2009
              HYDROELECTRIC POWER PLANTS -- TURBINE UNITS

                   DATA PREPARATION FOR WASP

         HYDRO
         POWER        MWB      MWC      EA     EMIN
         PLANT        (MW)     (MW)    (GWH)   (GWH)

         PUWA         3.58     5.16     2.82     2.62
         MAI        3.03     3.03     2.25     2.21

         IKHUWA        9.28    10.04     7.12     6.77
         PILUWA       2.08     2.51     1.61     1.52

         UTAMOR       63.26   271.89    74.03    46.18
         MAIWA        1.88     2.14     1.47     1.37
         MTAMOR       36.20    47.33    27.97    26.43
         PHAWA        2.75     2.91     2.07     2.01
         KABE-A       8.73     9.60     6.82     6.37
         HEWA        5.22     6.31     4.23     3.81

         UTAMAK       68.80   361.61    90.45    50.23
         SIPRIN       2.12     2.12     1.57     1.54

         KHANI        5.16     5.16     3.84     3.76

         KHIM-1       29.06    33.83    22.54    21.22

         U-BHOT       23.28    24.29    17.58    16.99
         CHAKU        0.58     0.59     0.44     0.42
         BARAMC        0.76     0.85     0.60     0.56
         SUNKOS        1.74     1.76     1.30     1.27
         SUNKON        8.11     9.92     6.20     5.92

         BALE-A       0.74     0.88     0.61     0.54
         BALE-B       7.53     8.05     5.78     5.50

         INDRAW        3.18     3.45     2.42     2.32

         U-SANJ       0.85     9.84     1.99     0.62
         L-SANJ       7.71     7.80     5.78     5.62
         CHILIM       16.19    20.07    12.39    11.82
         RASGAD       46.01    49.18    34.94    33.59
         TRIS3A       52.74    52.74    39.24    38.50
         TRIS2B       33.13    33.13    24.65    24.18
         TRIS       18.13    18.13    13.49    13.23
         DEVIGH       12.69    12.69     9.44     9.26

         KULEK1       23.01    42.98    20.15    16.80
         KULEK2       14.24    19.20    11.39    10.40
         KULEK3        7.19     9.89     5.60     5.25

         BUDHIG       26.01   195.48    44.30    18.99

         UMARSY        4.01    30.01     5.67     2.93
         MMARSY       32.46    46.53    25.61    23.69
```

```
          KHUDI        1.85     2.34     1.44     1.35
          LCHEPE        3.65     5.12     2.85     2.67
          MARSYG        50.14    61.91    38.47    36.60

          BIJAYP       0.48     0.52     0.37     0.35

          MODI         3.92     9.90     3.58     2.86
          LMODI        1.35     1.39     1.01     0.99
          KGANDA        82.21   117.54    64.52    60.01

          ANDHI        5.31     5.77     4.07     3.87

          JHIMRK        5.97     6.01     4.46     4.36

          CHAMEL        6.79    14.04     5.86     4.96

          SYSTEM      743.10  1585.61   664.98   542.46
1                                                                 PAGE   2
             DEPT. OF ELECTRICITY DEVELOPMENT
STUDY :    BASIC CASE OPTM
  PROGRAM   VWASP



                                              STUDY YEAR    :     2030
                                              HYDRO CONDITION:      DRY
                                              PERIOD        :  FEBRUARY
                                              - 1980- 1983- 1988- 1997- 2009
               HYDROELECTRIC POWER PLANTS -- TURBINE UNITS

                   DATA PREPARATION FOR WASP

          HYDRO
          POWER         MWB      MWC       EA     EMIN
          PLANT        (MW)     (MW)    (GWH)    (GWH)

          PUWA         2.41     4.45     2.05     1.76
          MAI        2.52     2.52     1.69     1.84

          IKHUWA        7.55     8.53     5.49     5.52
          PILUWA        1.37     1.88     1.07     1.00

          UTAMOR        0.95   245.52    54.60     0.69
          MAIWA         1.50     1.75     1.11     1.10
          MTAMOR        26.45    40.57    20.67    19.31
          PHAWA         2.22     2.42     1.56     1.62
          KABE-A        7.17     8.03     5.18     5.23
          HEWA         2.87     4.98     2.69     2.10

          UTAMAK        0.00   326.99    70.65     0.00
          SIPRIN       1.88     1.88     1.26     1.37

          KHANI        4.42     4.42     2.97     3.23

          KHIM-1       23.78    28.28    17.45    17.36

          U-BHOT       21.55    22.17    14.72    15.73
          CHAKU        0.59     0.59     0.40     0.43
          BARAMC        0.85     0.85     0.57     0.62
          SUNKOS        1.56     1.56     1.05     1.14
          SUNKON        6.95     9.08     5.09     5.07

          BALE-A       0.71     0.76     0.50     0.52
          BALE-B       6.92     7.04     4.70     5.05

          INDRAW        2.78     2.95     1.93     2.03
```

U-SANJ	0.00	8.72	1.59	0.00
L-SANJ	6.78	6.78	4.56	4.95
CHILIM	13.80	18.45	10.24	10.07
RASGAD	39.60	43.86	28.17	28.91
TRIS3A	46.54	46.54	31.27	33.97
TRIS2B	29.23	29.23	19.64	21.34
TRIS	18.13	18.13	12.18	13.23
DEVIGH	12.69	12.69	8.53	9.26
KULEK1	34.87	42.03	25.99	25.46
KULEK2	18.57	19.20	12.74	13.55
KULEK3	7.95	10.41	5.83	5.81
BUDHIG	0.00	175.40	34.11	0.00
UMARSY	2.44	23.43	4.33	1.78
MMARSY	24.72	42.29	20.51	18.05
KHUDI	1.42	1.67	1.02	1.04
LCHEPE	2.59	4.24	2.12	1.89
MARSYG	49.59	59.86	35.57	36.20
BIJAYP	0.41	0.52	0.32	0.30
MODI	1.54	9.05	2.80	1.12
LMODI	1.08	1.11	0.74	0.79
KGANDA	66.01	107.25	52.85	48.18
ANDHI	4.59	5.77	3.39	3.35
JHIMRK	5.28	6.01	3.78	3.85
CHAMEL	4.77	13.20	5.14	3.49
SYSTEM	519.60	1433.06	544.84	379.31

Appendix -4

Application of WASP

Table of Contents

List of Tables:

4. APPLICATION OF WASP

In order to link the outputs, same number of hydro plants as used in VALORAGUA is considered in WASP model. In 46 plants, 23 are existing plants (fixed system) and remaining 23 are considered as candidate plants for expansion. The list of plants in both categories is given below.

Table 4-1: List of fixed and candidate plants

S.N.	Code	Name of plant
1	PUWA	PUWA
2	MAI	MAI
3	PILU	PILUWA
4	SIPR	SIPRIN
5	KH-1	KHIMTI-1
6	U-BH	UPPER BHOTEKOSHI
7	CHAK	CHAKU
8	SUNK	SUNKOSHI SMALL
9	SUNN	SUNKOSHI
10	INDR	INDRAWATI
11	CHIL	CHILIME
12	TRIS	TRISHULI
13	DEVI	DEVIGHAT
14	KUL1	KULEKHANI-1
15	KUL2	KULEKHANI-2
16	MMRY	MIDDLE MARSYANGDI
17	KHUD	KHUDI
18	MARS	MARSYANGDI
19	BIJA	BIJAYPUR
20	MODI	MODI
21	KGAN	KALI GANDAKI
22	ANDH	ANDHI
23	JMRK	JHIMRUK

Table 4-2: Expansion plants

S.N.	Code	Name of plant
1	KHAN	KHANI
2	BARA	BARAMCHI
3	KUL3	KULEKHANI-3
4	LMOD	LOWER MODI
5	CHAM	CHAMELIYA
6	HEWA	HEWA
7	PHAW	PHAWA
8	BALA	BALEPHI-A
9	USAN	UPPER SANJEN
10	IKHU	IKHUWA

11	KABA	KABELI-A
12	LCHE	LOWER CHEPE
13	MAIW	MAIWA
14	LSAN	LOWER SANJEN
15	BALB	BALEPHI-B
16	TRIB	TRISHULI3B
17	UMSY	UPPER MARSYANGDI
18	UTAK	UPPER TAMAKOSHI
19	RASG	RASUWAGADHI
20	UTAM	UPPER TAMOR
21	MTMR	MIDDLE TAMOR
22	TRIA	TRISHULI2A
23	BUDG	BUDHI GANDAKI

4.1 DATA AND PARAMETERS FOR DIFFERENT MODULES OF WASP FOR BASE CASE

4.1.1 Loadsys

Simulation period considered is the 2011-2030 (20 years' time horizon), twelve periods per year and 50 cosine terms in Fourier approximation are considered. Type 1 data shows annual peak load of each year, which is taken from NEA forecasts. Type 2 data shows the ratio of the peak load in each period expressed as a fraction of the annual peak. Type 3 data shows the coefficients of fifth order polynomial representation of LDC, which is obtained by auxiliary tool available in WASP.

```
LOADSY.DAT
              Demonstration Case (Variable Expansion)
12  50   0
1017.10  2011
  2
  0.951   0.915   0.894   0.906   0.910   0.926   0.928   0.910   0.907   0.934
  0.916   1.000
  3
    1.0000    -2.8852     9.5950   -15.3243   10.83504    -2.7618
    1.0000    -1.2649     2.0056    -3.3404     4.1922    -2.0569
    1.0000    -1.3636     2.5381    -4.5041     5.3152    -2.4539
    1.0000    -1.7891     5.2904    -9.8477     9.4224    -3.5068
    1.0000    -1.8388     5.5570   -10.4326     9.9904    -3.7090
    1.0000    -3.1548    11.5001   -20.2684    16.8152    -5.3767
    1.0000    -2.8302     8.2488   -10.5065     5.3813    -0.7455
    1.0000    -3.4718    13.7085   -26.9957    25.1686    -8.8759
    1.0000    -3.2952    11.9500   -22.0191    19.6319    -6.7215
    1.0000    -3.5642    13.5949   -25.7003    23.1841     -7.971
    1.0000    -3.5642    13.5949   -25.7003    23.1841    -7.9710
    1.0000    -2.2994     5.4637    -6.1302     3.1947     -.7489
  1
1106.90  2012
  1
1213.20  2013
  1
1321.70  2014
  1
1437.20  2015
  1
1560.00  2016
  1
1690.80  2017
  1
```

```
1820.20  2018
  1
1956.90  2019
  1
2102.00  2020
  1
2256.00  2021
  1
2413.00  2022
  1
2595.40  2023
  1
2791.10  2024
  1
3001.10  2025
  1
3226.70  2026
  1
3468.90  2027
  1
3729.10  2028
  1
3963.00  2029
  1
4205.62  2030
  1
```

4.1.2 Fixsys

Four thermal plants are considered:
HETU: HETAUDA (as specified in VALORAGUA)
MULT: DUHABI (as specified in VALORAGUA)
PRC1: IMPORT1 (300MW)
PRC2: IMPORT2 (200MW)
Two composite hydro plants are considered:
HYD1: Plant with capacity less than or equal to 45MW (18 plants)
HYD2: Plant with capacity greater than 45MW (5 plants)
Number of periods per year = 12, Number of thermal plants= 4, Number of hydro-conditions = 3 Fixed operating and maintenance costs of hydroelectric= 2.1 USD/KW month, Probability of hydro-conditions = 20% (dry), 20% (wet), 60% (mean)
The third and fourth column of thermal plant data shows the minimum operating level of each unit (MW), Maximum unit generating capacity (MW). Last two columns show fixed and variable operation and maintenance cost respectively.
The third and fourth column of the first line of hydro plant data shows the installed capacity (MW), and energy storage capacity (GWh). For each period and each hydro condition, the data part displays the following: Period inflow energy (GWh) of the hydro project, Minimum generation in base in the period (GWh), Available capacity in period (MW) of the project. This data is taken from the output of VWASP of VALORAGUA.

FIXSYS.dat

```
        Demonstration Case (Variable Expansion)            4
   0 HETU HET THERMAL PLANTS
   1 MULT MULTIFUEL PLANTS
   2 PRC1 PURCHASE1
   3 PRC2 PURCHASE2
     HYD1 HYDRO PLANTS GROUP 1
     HYD2 HYDRO PLANTS GROUP 2
2011  12   4   3  HYD1   2.1  HYD2   2.10.20000.20000.6000
HETU  1   3.  10.  2180.  2010. 240.2160.  0 0  20. 55  10.        5.3  2.6
```

```
      0.       0.       0.
MULT  6   1.  6.5  2180.  2010. 240.2160.  1 0  20. 55  25.       5.3  2.6
      0.       0.       0.
PRC1  1   1. 300. 10000. 10000.   0. 638.  3 0  10. 10  20.        0.   0.
      0.       0.       0.
PRC2  1   1. 200. 10000. 10000.   0. 638.  3 0  10. 10  30.        0.   0.
      0.       0.       0.
 0 0      0.0      1.0 SO2 NOx 1
  0
  0
  2
PUWA  HYD1    6    0
2.8  2.6  5.2  3.4  3.3  5.6  3.3  3.1  5.5
2.0  1.8  4.5  2.8  2.7  5.2  2.5  2.3  4.9
2.2  1.9  4.3  3.1  2.9  5.0  2.6  2.2  4.6
2.6  2.4  4.9  3.5  3.4  5.6  3.0  2.9  5.2
3.8  3.6  5.7  4.1  4.0  5.8  4.3  4.2  6.0
4.5  4.5  6.3  4.5  4.5  6.3  4.5  4.4  6.3
4.7  4.6  6.3  4.7  4.6  6.3  4.7  4.6  6.3
4.7  4.6  6.3  4.7  4.6  6.3  4.7  4.6  6.3
2.7  2.7  3.8  2.7  2.7  3.8  1.9  1.5  3.8
2.8  2.8  3.8  2.8  2.8  3.8  2.8  2.8  3.8
4.4  4.4  6.3  4.5  4.5  6.3  4.4  4.4  6.3
4.1  3.9  6.2  3.7  3.5  5.8  3.7  3.5  5.8
  2
MAI  HYD1   19    0
2.3  2.2  3.0  2.3  2.2  3.0  2.3  2.2  3.0
1.7  1.6  2.5  1.7  1.6  2.5  1.7  1.6  2.5
1.8  1.8  2.4  1.8  1.8  2.4  1.8  1.8  2.4
2.0  1.9  2.7  2.0  1.9  2.7  2.0  1.9  2.7
3.3  3.3  4.5  3.3  3.1  4.5  3.3  3.2  4.5
9.7  9.1 15.3 10.9 10.7 16.1 10.6 10.4 15.5
 12.0 11.8 16.1 12.0 11.8 16.1 12.0 11.8 16.1
 12.0 11.8 16.1 12.0 11.8 16.1 12.0 11.8 16.1
 11.6 11.6 16.1 11.6 11.6 16.1 11.6 11.6 16.1
 11.1 10.3 16.1 12.0 11.8 16.1 11.5 11.1 15.9
4.4  4.3  6.0  4.4  4.3  6.0  4.4  4.3  6.0
2.7  2.6  3.6  2.7  2.6  3.6  2.7  2.6  3.6
  2
PILU  HYD1    3    0
1.6  1.5  2.5  1.6  1.5  2.5  1.7  1.6  2.5
1.1  1.0  1.9  1.1  1.1  1.9  1.2  1.1  1.9
1.0  0.8  1.7  1.1  1.0  1.7  1.1  0.9  1.7
1.2  1.1  2.3  1.6  1.6  2.5  1.5  1.4  2.4
2.0  2.0  3.0  2.3  2.2  3.1  2.2  2.1  3.1
2.3  2.2  3.1  2.3  2.2  3.1  2.3  2.2  3.1
2.3  2.3  3.1  2.3  2.3  3.1  2.3  2.3  3.1
2.3  2.3  3.1  2.3  2.3  3.1  2.3  2.3  3.1
2.3  2.2  3.1  2.3  2.2  3.1  2.3  2.2  3.1
2.3  2.3  3.1  2.2  2.1  3.1  2.3  2.3  3.1
2.2  2.2  3.1  2.2  2.1  3.1  2.2  2.1  3.1
2.0  1.9  3.1  2.2  2.1  3.1  1.8  1.7  2.9
  2
SIPR  HYD1   10    0
1.6  1.5  2.1  1.4  1.3  2.1  1.5  1.5  2.1
1.3  1.2  1.9  1.2  1.1  1.9  1.2  1.2  1.9
1.3  1.3  1.8  1.2  1.1  1.8  1.3  1.2  1.8
1.5  1.5  2.1  1.4  1.2  2.1  1.4  1.3  2.1
2.5  2.4  3.8  2.4  2.3  3.8  2.4  2.2  3.8
6.2  6.2  8.8  5.8  5.7  8.6  6.0  6.0  8.6
6.6  6.4  8.8  6.6  6.4  8.8  6.6  6.4  8.8
6.6  6.4  8.8  6.6  6.4  8.8  6.6  6.4  8.8
6.3  6.3  8.8  6.3  6.3  8.8  6.3  6.3  8.8
6.5  6.3  8.8  6.6  6.4  8.8  6.1  5.9  8.6
3.2  3.2  4.7  3.3  3.3  4.7  3.2  3.2  4.7
2.3  2.2  3.1  2.1  2.0  3.1  2.2  2.1  3.1
  2
```

```
 KH-1  HYD2    60     0
22.5 21.2 33.8 21.8 20.4 33.8 22.7 21.4 33.8
17.4 17.4 28.3 16.6 15.5 28.3 17.2 17.2 28.3
18.7 17.3 27.7 18.3 16.6 27.7 17.7 15.5 27.7
20.2 19.9 29.4 20.8 20.6 29.4 18.4 17.1 29.4
30.6 29.2 47.6 30.0 28.6 47.1 31.4 30.2 47.5
42.9 42.9 59.6 42.9 42.9 59.6 42.9 42.9 59.6
44.4 43.5 59.6 44.4 43.5 59.6 44.4 43.5 59.6
39.9 39.2 53.7 39.9 39.2 53.7 39.9 39.2 53.7
38.6 38.6 53.7 38.6 38.6 53.7 38.6 38.6 53.7
39.9 39.2 53.7 39.9 39.2 53.7 39.9 39.1 53.7
37.0 37.0 53.7 35.4 34.8 53.7 35.7 35.7 53.7
25.4 23.6 41.4 25.7 24.2 41.4 25.5 23.9 41.4
  2
 U-BH  HYD1    45     0
17.6 17.0 24.3 17.3 16.8 24.3 16.6 15.9 24.3
14.7 14.7 22.2 14.6 14.5 22.2 13.3 13.2 22.2
15.8 15.2 22.2 16.2 15.7 22.2 14.5 13.3 22.1
18.0 18.0 25.3 16.6 15.7 25.3 16.3 15.7 25.2
26.4 25.6 38.2 28.9 28.4 38.9 25.7 24.9 36.8
28.0 27.9 38.9 28.0 27.9 38.9 28.0 27.9 38.9
28.9 28.4 38.9 28.9 28.4 38.9 28.4 27.7 38.9
28.9 28.4 38.9 28.9 28.4 38.9 28.9 28.4 38.9
16.8 16.7 23.3 16.8 16.7 23.3 16.5 16.5 23.3
17.4 17.0 23.3 17.4 17.0 23.3 17.1 16.6 23.3
26.6 26.5 38.9 27.1 27.0 38.9 26.8 26.7 38.9
18.1 17.1 28.2 18.1 17.2 28.4 20.1 19.4 28.5
  2
CHAK  HYD1     3     0
0.4  0.4  0.6  0.4  0.4  0.6  0.4  0.4  0.6
0.4  0.4  0.6  0.4  0.4  0.6  0.4  0.4  0.6
0.4  0.4  0.6  0.4  0.4  0.6  0.4  0.3  0.6
0.5  0.5  0.7  0.5  0.5  0.7  0.4  0.4  0.7
0.7  0.7  1.2  0.9  0.9  1.2  0.7  0.7  1.2
1.3  1.1  2.1  1.5  1.5  2.2  1.4  1.4  2.1
2.0  2.0  2.7  1.6  1.5  2.7  1.9  1.9  2.7
1.6  1.4  2.7  2.0  2.0  2.7  1.8  1.8  2.7
1.9  1.9  2.7  1.9  1.9  2.7  1.9  1.9  2.7
1.5  1.0  2.7  1.8  1.6  2.7  1.6  1.5  2.6
0.7  0.7  1.1  0.7  0.7  1.1  0.7  0.7  1.1
0.5  0.4  0.8  0.5  0.4  0.8  0.5  0.4  0.8
  2
SUNK  HYD1     3     0
1.3  1.3  1.8  1.3  1.2  1.8  1.2  1.2  1.8
1.1  1.0  1.6  1.0  1.0  1.6  1.0  1.0  1.6
1.2  1.1  1.7  1.2  1.2  1.7  1.1  1.0  1.6
1.3  1.3  1.9  1.3  1.3  1.9  1.2  1.2  1.8
1.9  1.8  2.6  2.0  1.9  2.6  1.8  1.7  2.5
1.9  1.9  2.6  1.9  1.9  2.6  1.9  1.9  2.6
2.0  1.9  2.6  2.0  1.9  2.6  1.9  1.8  2.6
1.4  1.1  2.6  2.0  1.9  2.6  1.7  1.7  2.6
1.3  1.1  2.6  1.1  0.8  2.6  1.3  1.0  2.6
2.0  1.9  2.6  2.0  1.9  2.6  1.9  1.9  2.6
1.8  1.8  2.6  1.9  1.9  2.6  1.9  1.9  2.6
1.3  1.2  2.0  1.3  1.3  2.1  1.5  1.4  2.1
  2
SUNN  HYD1    10     0
6.2  5.9  9.9  6.4  6.1  9.7  5.8  5.5  9.3
5.1  5.1  9.1  5.3  5.3  9.1  4.7  4.7  8.6
5.4  5.1  8.7  6.2  5.9  9.4  5.1  4.7  8.4
6.1  6.0  9.7  6.4  6.2  9.7  5.5  5.3  9.1
7.4  7.2 10.2  7.3  7.2 10.2  7.2  7.0  9.9
5.4  4.5 10.2  3.4  1.5 10.2  3.9  2.2 10.2
1.1  0.0 10.2  1.1  0.0 10.2  1.1  0.0 10.2
0.8  0.0  7.1  0.8  0.0  7.1  0.8  0.0  7.1
1.7  0.0  7.1  1.7  0.0  7.1  1.7  0.0  7.1
3.7  3.1  7.1  2.6  2.1  7.1  3.4  2.9  7.1
```

```
7.3  7.2 10.2  7.1  7.1 10.2  7.3  7.2 10.2
6.4  6.1  9.9  6.8  6.5  9.9  6.8  6.5 10.0
   2
INDR  HYD1     8     0
2.4  2.3  3.5  2.3  2.2  3.5  2.4  2.3  3.5
1.9  1.9  3.0  1.8  1.7  3.0  1.8  1.8  3.0
2.1  2.0  3.0  1.9  1.8  3.0  2.0  1.8  3.0
2.3  2.2  3.3  2.2  2.1  3.3  2.1  2.0  3.3
2.8  2.7  4.8  3.5  3.4  4.9  3.2  3.1  4.7
5.0  5.0  7.3  5.3  5.3  7.4  5.1  5.1  7.4
5.5  5.4  7.4  4.6  4.3  7.4  5.4  5.3  7.4
3.9  3.8  5.2  3.9  3.8  5.2  3.9  3.8  5.2
3.7  3.7  5.2  3.7  3.7  5.2  3.7  3.7  5.2
3.9  3.8  5.2  3.9  3.8  5.2  3.9  3.8  5.2
4.1  4.1  6.5  4.5  4.4  6.5  4.3  4.2  6.5
3.0  2.9  4.5  3.1  3.0  4.5  3.2  3.1  4.5
   2
CHIL  HYD1    22     0
 12.4 11.8 20.1 12.2 11.6 19.8 12.2 11.6 20.1
 10.2 10.1 18.4 10.2 10.2 18.3  9.7  9.4 18.0
9.7  9.3 13.3  9.6  9.2 13.3  9.6  9.2 13.3
9.6  9.5 13.3  9.5  9.5 13.3  9.4  9.4 13.3
 16.4 16.1 22.1 16.4 16.1 22.1 16.4 16.0 22.1
 15.9 15.9 22.1 15.9 15.9 22.1 15.9 15.9 22.1
 16.4 16.1 22.1 16.4 16.1 22.1 15.6 15.0 22.1
 16.4 16.1 22.1 16.4 16.1 22.1 16.4 16.1 22.1
 15.9 15.9 22.1 15.9 15.9 22.1 15.9 15.9 22.1
 16.4 16.1 22.1 16.4 16.1 22.1 16.4 16.1 22.1
 15.8 15.7 22.1 15.9 15.9 22.1 15.9 15.9 22.1
 14.6 14.0 21.9 14.6 14.0 22.0 14.4 13.8 21.8
   2
TRIS  HYD1    24     0
 13.5 13.2 18.1 13.5 13.2 18.1 13.5 13.2 18.1
 12.2 12.1 18.1 12.2 12.1 18.1 12.2 12.1 18.1
 15.0 14.7 20.1 15.0 14.7 20.1 15.0 14.7 20.1
 14.5 14.4 20.1 14.4 14.3 20.1 14.4 14.4 20.1
 15.0 14.7 20.1 14.3 14.0 19.9 14.7 14.4 19.9
 14.5 14.4 20.1 14.5 14.4 20.1 14.5 14.4 20.1
 15.0 14.7 20.1 15.0 14.7 20.1 15.0 14.7 20.1
 13.5 13.2 18.1 13.5 13.2 18.1 13.5 13.2 18.1
 13.1 13.0 18.1 13.1 13.0 18.1 13.1 13.0 18.1
 13.5 13.2 18.1 13.5 13.2 18.1 13.5 13.2 18.1
 13.1 13.0 18.1 13.1 13.0 18.1 13.1 13.0 18.1
 13.5 13.2 18.1 13.5 13.2 18.1 13.5 13.2 18.1
   2
DEVI  HYD1    15     0
9.4  9.3 12.7  9.4  9.3 12.7  9.4  9.3 12.7
8.5  8.5 12.7  8.5  8.5 12.7  8.5  8.5 12.7
9.4  9.3 12.7  9.4  9.3 12.7  9.4  9.3 12.7
9.1  9.1 12.7  9.1  9.1 12.7  9.1  9.1 12.7
9.4  9.3 12.7  9.4  9.3 12.7  9.4  9.3 12.7
6.7  5.6 12.7  4.2  1.9 12.7  4.8  2.8 12.7
1.4  0.0 12.7  1.6  0.0 12.7  1.4  0.0 12.7
1.0  0.0  8.9  1.0  0.0  8.9  1.0  0.0  8.9
2.1  0.0  8.9  2.1  0.0  8.9  2.1  0.0  8.9
4.6  3.9  8.9  3.2  2.6  8.9  4.3  3.6  8.9
9.1  9.1 12.7  9.1  9.1 12.7  9.1  9.1 12.7
9.4  9.3 12.7  9.4  9.3 12.7  9.4  9.3 12.7
   2
KUL1  HYD2    60    90
 20.1 16.8 43.0 22.1 19.0 44.0 22.3 19.3 44.1
 26.0 25.5 42.0 24.6 22.8 43.2 26.4 25.9 43.5
 39.2 36.7 61.1 41.8 39.3 64.7 40.3 37.3 64.0
 32.6 31.2 55.6 35.9 33.9 59.1 41.0 40.0 63.2
 13.3 10.5 36.2 31.0 28.6 50.7 32.2 30.6 51.4
 23.4 17.1 48.1 22.1 13.5 55.3 25.8 20.4 51.8
 26.7 21.1 53.5 23.5 16.8 56.6 31.5 26.6 55.9
```

```
 45.2 43.3 64.1 48.9 48.0 65.8 45.0 43.4 63.2
 44.3 41.9 69.9 45.5 43.9 69.4 48.3 48.0 69.8
 39.4 32.4 71.0 41.3 32.3 71.8 45.2 39.7 70.0
 24.5 21.1 71.5 20.5 15.3 71.6 24.2 20.7 71.7
 18.6 13.6 56.2 14.9  8.4 54.5 17.5 11.8 56.3
   2
KUL2  HYD1    32     0
 11.4 10.4 19.2 13.4 12.9 19.2 13.6 13.1 19.2
 12.7 12.7 19.2 12.8 12.7 19.2 12.8 12.7 19.2
 19.0 17.9 29.4 21.2 20.2 31.1 21.1 20.0 31.3
 17.4 16.4 29.3 18.9 18.1 30.1 20.9 20.5 31.4
10.1  8.8 22.2 18.1 16.4 28.7 18.5 17.6 28.4
 17.6 14.2 31.5 21.1 20.5 32.0 19.3 18.0 30.3
 23.8 23.4 32.0 21.0 19.3 32.0 23.5 22.9 32.0
 23.8 23.4 32.0 23.8 23.4 32.0 23.8 23.4 32.0
 23.0 23.0 32.0 23.0 23.0 32.0 23.0 23.0 32.0
 22.0 20.0 32.0 22.8 21.6 32.0 23.5 22.9 32.0
 17.8 17.4 32.0 16.4 15.7 32.0 18.1 17.7 32.0
 14.5 13.3 27.3 11.6 10.2 24.9 13.6 12.2 26.8
   2
MMRY  HYD2    70     0
 25.6 23.7 46.5 25.5 23.6 47.2 25.6 23.8 47.0
 20.5 18.1 42.3 20.9 18.7 43.2 19.5 17.0 41.7
 23.0 20.2 41.9 22.6 19.9 41.9 21.1 17.2 41.2
 25.3 23.8 45.0 27.5 26.0 47.3 25.5 23.7 46.0
 34.9 33.7 51.3 36.3 35.4 51.2 36.3 35.3 50.6
 37.1 37.0 51.6 37.1 37.0 51.6 37.1 37.0 51.6
 38.4 37.7 51.6 38.4 37.7 51.6 38.4 37.7 51.6
 38.4 37.7 51.6 38.4 37.7 51.6 38.4 37.7 51.6
 37.1 37.0 51.6 37.1 37.0 51.6 37.1 37.0 51.6
 38.4 37.7 51.6 38.3 37.4 51.6 38.4 37.6 51.6
 35.1 35.1 51.6 37.1 37.0 51.6 35.8 35.8 51.6
 32.0 30.4 51.4 34.3 32.9 51.5 31.2 29.3 51.1
   2
KHUD  HYD1     4     0
1.4  1.4  2.3  1.3  1.2  2.2  1.4  1.3  2.3
1.0  1.0  1.7  1.0  0.9  1.7  1.0  1.0  1.7
1.1  1.0  1.7  1.0  0.9  1.7  1.0  0.9  1.7
1.4  1.3  2.3  1.4  1.3  2.3  1.4  1.3  2.3
1.6  1.6  2.6  2.3  2.2  3.2  2.0  2.0  3.0
2.6  2.5  3.7  2.7  2.7  3.8  2.7  2.7  3.8
2.8  2.7  3.8  2.8  2.7  3.8  2.8  2.7  3.8
2.8  2.7  3.8  2.8  2.7  3.8  2.8  2.7  3.8
1.4  0.7  3.8  1.3  0.6  3.8  1.4  0.8  3.8
2.4  2.2  3.8  2.3  2.0  3.8  2.5  2.3  3.8
2.4  2.4  3.7  2.1  2.1  3.7  2.0  2.0  3.7
1.1  1.0  2.2  1.0  0.9  2.2  1.1  1.0  2.2
   2
MARS  HYD2    69     0
 38.5 36.6 61.9 42.9 41.2 65.5 42.4 40.7 64.5
 35.6 35.5 59.9 40.1 40.0 64.1 38.7 38.5 63.0
 36.2 33.7 57.8 40.8 38.5 62.3 37.2 34.3 58.8
 38.1 37.1 61.4 41.0 39.5 63.8 42.2 41.3 64.1
 42.0 40.4 63.0 43.3 42.0 63.3 43.1 41.6 62.9
 47.1 47.0 65.6 28.2 19.1 65.6 43.2 41.7 65.6
 34.7 28.7 65.6 28.9 21.6 65.6 34.5 28.2 65.6
 32.1 26.3 65.6 45.1 43.1 65.6 40.3 37.3 65.6
 25.7 15.3 65.6 23.8 12.4 65.6 25.7 15.3 65.6
 42.0 37.8 65.6 39.7 34.2 65.6 42.9 38.7 65.6
 43.0 42.9 65.6 42.3 42.2 65.6 41.0 40.6 65.6
 30.0 27.5 56.6 28.0 25.3 54.8 29.8 27.2 56.3
   2
BIJA  HYD1     5     0
0.4  0.3  0.5  0.3  0.3  0.5  0.4  0.3  0.5
0.3  0.3  0.5  0.3  0.3  0.5  0.3  0.3  0.5
0.4  0.3  0.5  0.3  0.3  0.5  0.3  0.3  0.5
0.4  0.4  0.5  0.4  0.4  0.5  0.4  0.3  0.5
```

```
0.6  0.6  1.0  0.7  0.7  1.0  0.7  0.6  1.0
1.3  0.9  2.1  1.4  1.4  2.1  1.4  1.3  2.1
3.2  3.1  4.3  3.2  3.1  4.3  3.2  3.1  4.3
3.2  3.1  4.3  3.2  3.1  4.3  3.2  3.1  4.3
2.9  2.8  4.3  3.0  3.0  4.3  2.8  2.8  4.3
1.8  0.8  4.3  1.6  0.7  4.3  1.8  1.1  4.1
0.9  0.7  2.6  1.0  0.7  2.6  0.9  0.7  2.6
0.7  0.6  1.0  0.6  0.4  1.0  0.6  0.5  1.0
  2
MODI  HYD1    15     0
3.6  2.9  9.9  3.5  2.8  9.8  3.8  3.1  9.9
2.8  1.1  9.1  2.6  0.8  8.9  2.9  1.3  9.1
3.0  1.8  8.7  2.7  1.4  8.4  3.1  1.9  8.7
4.4  3.7 10.1  4.0  2.8  9.8  3.8  2.9  9.6
6.6  6.2 11.9  7.6  7.0 12.5  6.5  6.1 11.4
 10.3 10.2 14.6 10.5 10.5 14.6 10.4 10.4 14.5
 10.9 10.7 14.6 10.9 10.7 14.6 10.9 10.7 14.6
 10.9 10.7 14.6 10.9 10.7 14.6 10.9 10.7 14.6
10.0  9.8 14.6 10.5 10.5 14.6 10.5 10.5 14.6
10.3  9.6 14.6  9.4  8.5 14.6 10.8 10.5 14.6
6.3  5.9 14.6  7.5  7.1 14.6  6.4  6.0 14.6
5.3  4.6 11.6  5.2  4.5 11.6  4.6  3.9 11.3
  2
KGAN  HYD2   144     1
 64.5 60.0117.5 72.6 68.4124.7 74.2 70.1126.5
 52.9 48.2107.3 57.0 53.4111.0 57.5 54.6111.2
 55.4 49.0102.1 59.5 53.4105.3 61.1 53.7108.1
 71.8 68.8124.2 76.6 72.3128.8 71.7 68.3122.9
98.5 95.6141.7101.2 98.5142.4101.0 98.2142.2
103.3103.0143.6103.4103.0143.6103.2103.0143.6
106.8104.8143.6106.8104.8143.6106.8104.8143.6
106.8104.8143.6106.8104.8143.6106.8104.8143.6
103.4103.0143.6103.4103.0143.6103.4103.0143.6
106.8104.8143.6106.8104.8143.6106.8104.8143.6
103.4103.0143.6103.4103.0143.6103.4103.0143.6
 98.7 95.3143.0 98.9 95.4143.6 94.1 89.8142.9
  2
ANDH  HYD1     9     0
4.1  3.9  5.8  4.0  3.8  5.8  4.1  4.0  5.8
3.4  3.4  5.8  3.5  3.5  5.8  3.5  3.5  5.8
2.8  2.6  3.9  2.7  2.5  3.9  2.7  2.5  3.9
2.5  2.4  3.9  2.8  2.8  3.9  2.4  2.3  3.9
5.3  5.2  7.7  5.7  5.6  7.7  5.1  4.9  7.5
6.8  6.7  9.4  6.8  6.7  9.4  6.8  6.7  9.4
7.0  6.9  9.4  7.0  6.9  9.4  7.0  6.9  9.4
4.9  4.8  6.6  4.9  4.8  6.6  4.9  4.8  6.6
4.8  4.7  6.6  4.8  4.7  6.6  4.8  4.7  6.6
4.9  4.8  6.6  4.9  4.8  6.6  4.8  4.7  6.6
6.5  6.5  9.4  6.5  6.4  9.4  6.3  6.2  9.4
4.7  4.4  7.7  4.8  4.5  7.7  4.8  4.5  7.6
  2
JMRK  HYD1    12     0
4.5  4.4  6.0  4.1  3.9  6.0  4.3  4.1  6.0
3.8  3.7  6.0  3.6  3.4  6.0  3.6  3.6  6.0
3.2  3.0  4.5  3.1  2.9  4.5  3.1  2.8  4.5
2.8  2.5  4.5  2.8  2.4  4.5  2.6  2.1  4.5
2.7  2.4  4.5  2.8  2.6  4.5  2.8  2.5  4.5
6.6  5.7 11.3  8.7  8.6 12.0  7.6  7.2 11.7
8.9  8.8 12.0  8.9  8.8 12.0  8.9  8.8 12.0
8.9  8.8 12.0  8.9  8.8 12.0  8.9  8.8 12.0
5.2  5.1  7.2  5.2  5.1  7.2  5.2  5.1  7.2
5.4  5.3  7.2  5.4  5.3  7.2  5.4  5.3  7.2
8.3  8.3 12.0  8.4  8.3 12.0  7.8  7.7 12.0
5.4  5.2  7.5  5.3  5.1  7.5  5.1  4.9  7.5
  1              (end of year  2011)
  1              (end of year  2012)
  1              (end of year  2013)
```

```
  1              (end of year  2014)
  1              (end of year  2015)
  1              (end of year  2016)
  1              (end of year  2017)
  1              (end of year  2018)
  1              (end of year  2019)
  1              (end of year  2020)
  1              (end of year  2021)
  1              (end of year  2022)
  1              (end of year  2023)
  1              (end of year  2024)
  1              (end of year  2025)
  1              (end of year  2026)
  1              (end of year  2027)
  1              (end of year  2028)
  1              (end of year  2029)
  1              (end of year  2030)
```

4.1.3 Varsys

Three thermal plants are considered for expansion, in addition to fixed system specified in VALORAGUA and Fixsys:
THERM: THERMAL (200MW)
MULT: MULTIFUEL (100MW)
PRCH: IMPORT (500MW for expansion)
(The import including Fixsys and Varsys is 1000MW as specified in VALORAGUA)
Two composite hydro plants are considered:
HYD1: Plant with capacity less than or equal to 45MW (16 plants)
HYD2: Plant with capacity greater than 45MW (7 plants)
Number of periods per year= 12, Number of thermal plants= 3, Number of hydro-conditions = 3
Fixed operating and maintenance costs of hydroelectric= 2.1 USD/KW month, Probability of hydro-conditions= 20% (dry), 20% (wet), 60% (mean)
The second and third column of thermal plant data shows the minimum operating level of each unit (MW), Maximum unit generating capacity (MW). Last two columns show fixed and variable operation and maintenance cost respectively.
The third and fourth column of the first line of hydro plant data shows the installed capacity (MW), and energy storage capacity (GWh). For each period and each hydro condition, the data part displays the following: Period inflow energy (GWh) of the hydro project, Minimum generation in base in the period (GWh), Available capacity in period (MW) of the project. This data is taken from the output of VWASP of VALORAGUA.

VARSYS.dat

```
        Demonstration Case (Variable Expansion)
    12   3   3  HYD1   2.1  HYD2   2.10.20000.20000.6000           16  7  0
THRM     10. 200.  3590.  2650. 500.2500.  1 0  20. 37 12.5       2.8  2.6
      0.0      0.0      0.0
MULT     10. 100.  2180.  2010. 240.2160.  3 0  20. 55  20.       5.3  2.6
      0.0      0.0      0.0
PRCH     1. 500. 10000. 10000.   0. 638.  415  10.  0  25.       0.0  0.0
      0.0      0.0      0.0
 0                  SO2 NOx 1
  0
  0
KHAN  HYD1    30    0  2015
3.8  3.8  5.2  3.4  2.7  5.2  3.8  3.5  5.2
3.0  2.9  4.4  3.0  2.9  4.4  3.0  2.9  4.4
3.3  3.2  4.4  3.0  2.6  4.4  3.2  3.0  4.4
3.7  3.7  5.2  3.3  2.6  5.2  3.5  3.3  5.2
```

```
6.0  5.3  8.8  5.6  4.9  8.8  5.6  4.6  8.8
 18.4 15.1 29.5 18.7 17.2 29.5 18.0 16.7 28.9
 27.9 27.4 37.6 27.9 27.4 37.6 27.9 27.4 37.6
 27.9 27.4 37.6 27.9 27.4 37.6 27.9 27.4 37.6
 27.0 27.0 37.6 27.0 27.0 37.6 27.0 27.0 37.6
 19.8 11.3 37.6 19.5 12.8 37.6 17.2 10.6 36.0
8.4  7.2 14.7  8.5  7.3 14.7  8.1  6.8 14.7
5.4  5.3  7.4  5.1  4.3  7.4  5.3  5.0  7.4
BARA  HYD1    4    0  2015
0.6  0.6  0.8  0.6  0.5  0.8  0.5  0.4  0.8
0.6  0.6  0.8  0.6  0.6  0.8  0.5  0.5  0.8
0.3  0.3  0.4  0.3  0.3  0.4  0.3  0.3  0.4
0.6  0.6  0.8  0.6  0.6  0.8  0.6  0.6  0.8
0.9  0.8  1.3  0.9  0.9  1.3  0.8  0.8  1.3
1.3  1.1  2.1  1.4  1.4  2.1  1.5  1.5  2.1
2.8  2.8  3.8  2.1  2.0  3.8  2.7  2.6  3.8
2.8  2.8  3.8  2.8  2.8  3.8  2.8  2.8  3.8
2.6  2.5  3.8  2.7  2.6  3.8  2.6  2.6  3.8
1.5  1.0  2.6  1.8  1.7  2.6  1.7  1.6  2.5
0.8  0.8  1.3  0.9  0.8  1.3  0.9  0.9  1.3
0.6  0.5  0.8  0.6  0.5  0.8  0.6  0.5  0.8
KUL3  HYD1   14    0  2015
5.6  5.3  9.9  7.0  6.7 11.4  7.7  7.4 11.9
5.8  5.8 10.4  6.5  6.5 11.3  7.2  7.2 12.0
7.8  7.4 11.9  9.2  8.9 13.3  9.2  8.8 13.3
7.5  7.2 12.2  8.4  8.2 12.8  9.1  9.1 13.5
5.2  4.8  9.4  8.2  7.3 12.4  8.4  8.2 12.3
8.6  8.0 13.4 10.0 10.0 13.9  9.2  9.1 13.4
 10.4 10.2 13.9 10.4 10.2 13.9 10.4 10.2 13.9
 10.4 10.2 13.9 10.4 10.2 13.9 10.4 10.2 13.9
 10.0 10.0 13.9 10.0 10.0 13.9 10.0 10.0 13.9
10.2  9.9 13.9 10.3 10.0 13.9 10.2  9.9 13.9
9.0  9.0 13.8  8.6  8.6 13.9  8.9  8.9 13.9
8.1  7.8 12.4  6.5  6.1 11.1  7.6  7.2 12.0
LMOD  HYD1   20    0  2015
1.0  1.0  1.4  1.0  1.0  1.4  1.0  1.0  1.4
0.7  0.7  1.1  0.8  0.7  1.1  0.8  0.7  1.1
0.8  0.8  1.1  0.8  0.8  1.1  0.8  0.8  1.1
1.1  1.1  1.5  1.1  1.1  1.5  1.1  1.1  1.5
1.4  1.3  1.8  1.4  1.3  1.8  1.4  1.3  1.8
1.0  0.8  1.8  0.6  0.3  1.8  0.7  0.4  1.8
0.2  0.0  1.8  0.2  0.0  1.8  0.2  0.0  1.8
0.2  0.0  1.8  0.2  0.0  1.8  0.2  0.0  1.8
0.4  0.0  1.8  0.4  0.0  1.8  0.4  0.0  1.8
0.9  0.8  1.8  0.5  0.3  1.8  0.9  0.7  1.8
1.3  1.3  1.8  1.3  1.3  1.8  1.3  1.3  1.8
1.3  1.2  1.8  1.3  1.3  1.8  1.2  1.2  1.8
CHAM  HYD1   30    0  2015
5.9  5.0 14.0  8.0  7.4 15.5  7.3  6.5 14.9
5.1  3.5 13.2  6.8  5.9 14.4  6.4  5.4 14.0
6.0  4.5 13.3  7.6  6.7 14.2  6.6  5.2 13.5
7.5  6.8 15.0  9.5  8.8 16.8  7.8  7.1 15.1
 11.7 11.1 18.8 16.6 15.9 24.3 11.8 11.3 18.4
 15.5 14.0 25.4 18.7 18.6 27.3 16.9 16.3 26.0
 21.4 20.9 28.7 21.4 20.9 28.7 21.4 20.9 28.7
 14.9 14.7 20.1 14.9 14.7 20.1 14.9 14.7 20.1
 14.5 14.4 20.1 14.5 14.4 20.1 14.5 14.4 20.1
 14.5 13.9 20.1 14.9 14.6 20.1 14.3 13.9 19.5
10.1  9.6 25.2 14.0 13.6 27.3 11.7 11.2 26.2
7.8  6.9 16.2 10.3  9.6 18.4  8.6  7.7 17.0
HEWA  HYD1   15    0  2015
4.2  3.8  6.3  4.4  4.1  6.3  4.4  4.1  6.3
2.7  2.1  5.0  3.0  2.9  5.0  3.1  2.9  5.0
2.6  2.0  4.3  2.8  2.5  4.3  2.8  2.4  4.3
3.2  2.1  6.6  4.5  4.3  6.6  3.8  3.1  6.6
6.9  6.4 12.5  9.0  8.7 13.3  8.3  8.0 13.0
8.8  8.5 13.4  9.7  9.6 13.4  9.7  9.8 13.4
```

```
10.0  9.8 13.4 10.0  9.8 13.4 10.0  9.8 13.4
10.0  9.8 13.4 10.0  9.8 13.4 10.0  9.8 13.4
5.8  3.9 13.4  3.8  0.9 13.4  4.8  2.4 13.4
10.0  9.8 13.4 10.0  9.8 13.4  9.7  9.3 13.4
8.5  8.4 13.4  9.4  9.4 13.4  9.1  9.1 13.4
5.9  5.4  9.3  6.7  6.4  9.3  6.2  5.8  9.3
PHAW  HYD1    5    0  2017
2.1  2.0  2.9  2.0  2.0  2.9  2.1  2.0  2.9
1.6  1.5  2.4  1.6  1.5  2.4  1.6  1.5  2.4
1.9  1.8  2.7  1.8  1.7  2.7  1.8  1.6  2.7
2.5  2.4  3.6  2.5  2.5  3.6  2.4  2.4  3.6
3.8  3.7  5.1  3.8  3.7  5.1  3.7  3.6  5.0
3.7  3.6  5.1  3.7  3.6  5.1  3.7  3.6  5.1
3.8  3.7  5.1  3.8  3.7  5.1  3.8  3.7  5.1
3.8  3.7  5.1  3.8  3.7  5.1  3.8  3.7  5.1
3.7  3.6  5.1  3.7  3.6  5.1  3.7  3.6  5.1
3.8  3.7  5.1  3.8  3.7  5.1  3.8  3.7  5.1
3.7  3.6  5.1  3.7  3.6  5.1  3.6  3.6  5.1
2.8  2.7  3.9  2.7  2.6  3.9  2.7  2.6  3.9
BALA  HYD1   11    0  2017
0.6  0.5  0.9  0.6  0.5  0.9  0.6  0.5  0.9
0.5  0.5  0.8  0.5  0.4  0.8  0.5  0.5  0.8
0.5  0.5  0.8  0.5  0.4  0.8  0.5  0.4  0.8
0.6  0.6  0.8  0.6  0.5  0.8  0.5  0.5  0.8
0.7  0.5  1.2  0.9  0.8  1.2  0.8  0.7  1.2
1.8  1.1  3.4  2.5  2.5  3.4  2.0  1.8  3.4
6.7  6.4  9.5  6.8  6.5  9.5  5.7  5.0  9.5
6.8  6.5  9.5  6.8  6.6  9.5  6.8  6.6  9.5
4.6  3.6  9.5  6.0  5.7  9.5  5.8  5.3  9.5
2.1  1.0  3.8  2.0  1.4  3.8  2.4  1.8  3.8
1.1  0.9  1.9  1.2  1.0  1.9  1.2  1.0  1.9
0.8  0.6  1.1  0.8  0.6  1.1  0.8  0.7  1.1
USAN  HYD1   15    0  2017
2.0  0.6  9.8  2.0  0.6  9.8  1.9  0.6  9.7
1.6  0.0  8.7  1.6  0.0  8.6  1.5  0.0  8.6
1.7  0.0  8.6  1.8  0.3  8.6  1.7  0.0  8.6
2.1  0.3  9.4  2.4  0.3  9.5  2.0  0.2  9.2
3.3  2.6  9.7  5.5  5.0 10.2  3.9  3.2  9.5
7.5  6.1 13.5  9.8  9.7 13.6  8.9  8.8 13.1
10.1  9.9 13.6 10.1  9.9 13.6 10.1  9.9 13.6
10.1  9.9 13.6 10.1  9.9 13.6 10.1  9.9 13.6
9.8  9.7 13.6  9.5  9.5 13.6  9.8  9.7 13.6
6.6  3.9 13.6  7.8  6.2 13.6  7.3  5.7 12.9
3.6  2.7 13.6  3.9  2.9 13.6  3.3  2.3 13.6
2.6  1.3 10.8  2.6  1.2 10.9  2.3  0.8 10.8
IKHU  HYD1   19    0  2017
7.1  6.8 10.0  6.9  6.5 10.0  7.0  6.6 10.0
5.5  5.5  8.5  5.5  5.5  8.5  5.5  5.5  8.5
5.4  5.0  7.5  5.6  5.5  7.5  5.4  5.0  7.5
6.5  5.7 10.0  6.8  6.3 10.0  7.0  6.7 10.0
 13.7 13.0 20.1 12.5 11.9 20.1 13.6 13.0 20.0
 14.4 14.4 20.1 14.4 14.4 20.1 14.4 14.4 20.1
 14.9 14.7 20.1 14.9 14.7 20.1 14.9 14.7 20.1
 14.9 14.7 20.1 14.9 14.7 20.1 14.9 14.7 20.1
 14.4 14.4 20.1 14.4 14.4 20.1 14.4 14.4 20.1
 14.9 14.7 20.1 14.9 14.7 20.1 14.9 14.6 20.1
 12.9 12.6 20.1 13.6 13.5 20.1 13.6 13.5 20.1
9.2  8.7 13.1  9.3  8.7 13.1  9.0  8.5 13.1
KABA  HYD1   38    0  2018
6.8  6.4  9.6  6.8  6.3  9.6  6.8  6.4  9.6
5.2  5.1  8.0  5.3  5.2  8.0  5.2  5.2  8.0
5.8  5.4  8.1  5.8  5.4  8.1  5.6  4.9  8.1
7.8  7.5 11.5  7.9  7.6 11.5  7.7  7.4 11.5
 16.4 15.9 22.7 16.1 15.7 22.7 15.8 15.2 22.5
 23.7 23.5 32.9 23.7 23.5 32.9 23.6 23.5 32.9
 24.5 24.0 32.9 24.5 24.0 32.9 24.5 24.0 32.9
 24.5 24.0 32.9 24.5 24.0 32.9 24.5 24.0 32.9
```

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 14.2 14.2 19.7 14.2 14.2 19.7 14.2 14.2 19.7
 14.7 14.4 19.7 14.7 14.4 19.7 14.6 14.2 19.7
 13.9 13.8 19.6 13.8 13.8 19.6 13.2 13.1 19.6
8.7  8.1 12.4  8.4  7.7 12.4  8.5  7.8 12.4
LCHE  HYD1    8    0  2018
2.9  2.7  5.1  2.8  2.6  5.0  2.7  2.5  5.0
2.1  1.9  4.2  2.1  1.9  4.3  2.0  1.8  4.2
2.4  2.1  4.2  2.3  2.0  4.2  2.0  1.6  4.1
2.3  2.1  4.3  2.3  2.0  4.3  2.0  1.8  4.2
3.1  2.9  5.2  3.8  3.6  5.7  3.1  2.9  5.1
5.1  4.8  7.7  5.7  5.7  7.9  5.3  5.3  7.6
5.9  5.8  7.9  5.9  5.8  7.9  5.9  5.8  7.9
5.9  5.8  7.9  5.9  5.8  7.9  5.9  5.8  7.9
5.7  5.7  7.9  5.7  5.7  7.9  5.7  5.7  7.9
5.9  5.8  7.9  5.9  5.8  7.9  5.9  5.8  7.9
4.7  4.6  7.9  5.4  5.3  7.9  4.8  4.8  7.9
3.6  3.4  6.0  3.7  3.5  6.1  3.2  3.0  5.8
MAIW  HYD1    14    0  2018
1.5  1.4  2.1  1.5  1.4  2.1  1.5  1.4  2.1
1.1  1.1  1.8  1.1  1.1  1.8  1.1  1.1  1.8
1.3  1.2  1.8  1.3  1.2  1.8  1.2  1.1  1.8
1.7  1.7  2.5  1.7  1.7  2.5  1.7  1.6  2.5
3.6  3.5  5.0  3.5  3.4  5.0  3.3  3.2  4.8
4.4  4.4  6.1  3.8  3.6  6.1  4.3  4.3  6.1
4.5  4.5  6.1  4.1  4.0  6.1  4.5  4.5  6.1
4.5  4.5  6.1  4.5  4.5  6.1  4.5  4.5  6.1
4.4  4.4  6.1  4.4  4.4  6.1  4.4  4.4  6.1
4.5  4.5  6.1  4.5  4.5  6.1  4.4  4.3  6.0
3.0  3.0  4.4  3.1  3.0  4.4  2.8  2.8  4.4
1.9  1.8  2.8  2.0  1.9  2.8  1.9  1.8  2.8
LSAN  HYD1    43    0  2019
5.8  5.6  7.8  5.7  5.5  7.8  5.8  5.7  7.8
4.6  4.5  6.8  4.6  4.5  6.8  4.6  4.5  6.8
5.0  4.9  6.8  5.0  4.8  6.8  5.0  4.8  6.8
6.3  6.3  8.8  6.3  6.3  8.8  6.3  6.3  8.8
 12.9 12.6 17.3 12.9 12.6 17.3 12.7 12.4 17.3
 28.3 28.2 39.3 28.3 28.2 39.3 28.3 28.2 39.3
 29.3 28.7 39.3 29.3 28.7 39.3 29.3 28.7 39.3
 29.3 28.7 39.3 29.3 28.7 39.3 29.3 28.7 39.3
 28.3 28.2 39.3 28.3 28.2 39.3 28.3 28.2 39.3
 22.7 22.3 30.5 22.7 22.3 30.5 22.7 22.3 30.5
 10.3 10.2 14.2 10.3 10.2 14.2 10.2 10.2 14.2
7.6  7.4 10.2  7.6  7.4 10.2  7.6  7.4 10.2
BALB  HYD1    19    0  2019
5.8  5.5  8.1  5.6  5.2  8.1  5.7  5.3  8.1
4.7  4.7  7.0  4.4  4.4  7.0  4.5  4.5  7.0
4.9  4.6  6.8  4.7  4.3  6.8  4.7  4.3  6.8
5.4  5.3  7.7  5.3  5.1  7.7  5.2  5.0  7.7
8.0  7.7 11.4  8.5  8.3 11.4  7.9  7.7 11.4
 13.1 13.0 19.0 13.7 13.7 19.0 13.7 13.6 19.0
 14.2 13.9 19.0 14.2 13.9 19.0 14.2 13.9 19.0
 14.2 13.9 19.0 14.2 13.9 19.0 14.2 13.9 19.0
 13.7 13.7 19.0 13.7 13.7 19.0 13.7 13.7 19.0
 14.2 13.9 19.0 14.1 13.8 19.0 14.1 13.8 19.0
10.0  9.9 15.2 10.0  9.9 15.2 10.1 10.1 15.2
6.4  5.8 10.8  7.0  6.5 10.8  6.1  5.5 10.8
TRIB  HYD1    37    0  2020
 24.6 24.2 33.1 24.6 24.2 33.1 24.6 24.1 33.1
 19.6 19.6 29.2 19.6 19.6 29.2 19.6 19.6 29.2
 21.8 21.3 29.2 21.8 21.3 29.2 21.7 21.3 29.2
 23.9 23.8 33.1 23.8 23.8 33.1 23.8 23.8 33.1
 24.6 24.1 33.1 24.6 24.2 33.1 24.6 24.2 33.1
 23.9 23.8 33.1 23.9 23.8 33.1 23.8 23.8 33.1
 24.6 24.2 33.1 24.6 24.2 33.1 24.6 24.2 33.1
 24.6 24.2 33.1 24.6 24.2 33.1 24.6 24.2 33.1
 23.9 23.8 33.1 23.9 23.8 33.1 23.9 23.8 33.1
 24.6 24.2 33.1 24.6 24.2 33.1 24.6 24.2 33.1
```

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 23.9 23.8 33.1 23.9 23.8 33.1 23.9 23.8 33.1
 24.6 24.2 33.1 24.6 24.2 33.1 24.6 24.2 33.1
UMSY  HYD2    45     0  2016
5.7  2.9 30.0  5.4  2.8 29.2  3.7  0.8 28.6
4.3  1.8 23.4  4.4  1.7 23.4  2.8  0.5 21.7
4.5  2.1 24.3  5.2  2.9 24.6  2.9  0.6 22.1
5.5  3.4 27.5  6.3  3.7 27.8  3.1  0.9 24.6
7.4  4.7 29.1  9.1  6.4 25.2  4.7  2.0 25.1
11.5  6.6 37.9 19.7 15.1 45.2  9.8  2.5 38.3
 25.5 21.8 45.2 30.4 29.3 45.2 28.6 26.0 45.2
 32.9 32.0 45.2 33.6 33.0 45.2 33.4 32.7 45.2
 25.0 21.6 45.2 25.5 22.4 45.2 23.0 18.6 45.2
14.1  6.6 45.2 15.1  6.6 45.2 11.7  3.2 41.2
10.2  6.4 45.2 11.3  7.4 45.2  6.7  2.0 45.2
7.8  4.5 34.0  7.7  4.3 33.6  4.4  1.0 31.6
UTAK  HYD2   456     0  2017
 90.5 50.2361.6 78.5 35.4354.4 84.8 44.3356.4
 70.7 50.2327.0 60.0 35.4308.1 69.2  0.3321.6
74.8  9.6319.3 63.7  2.4310.7 71.8  8.4315.5
 86.0 24.7344.3 77.5 12.7333.1 77.6 13.3334.5
144.0119.2369.6171.1149.5352.3138.1112.6348.5
309.2305.8442.9291.1279.1442.9300.2297.0436.3
329.5323.3442.9329.5323.3442.9329.5323.3442.9
329.5323.3442.9329.5323.3442.9329.5323.3442.9
318.9318.0442.9318.9318.0442.9318.9318.0442.9
326.5315.4442.9328.6321.0442.9304.9287.2434.3
176.8157.6398.6183.6160.3398.6175.3154.7398.6
121.5 84.3397.3115.1 70.9396.7120.7 81.2396.2
RASG  HYD2   111     0  2017
 34.9 33.6 49.2 34.8 33.3 49.2 35.7 34.5 49.2
 28.2 28.1 43.9 27.6 27.4 43.9 28.3 28.2 43.9
 31.5 30.0 43.9 30.7 28.7 43.9 31.0 28.8 43.9
 37.5 36.9 55.8 39.2 39.1 55.8 37.4 36.7 55.8
 65.6 63.4 97.2 74.8 73.0103.8 70.0 67.8100.2
 76.6 76.5106.3 76.6 76.5106.3 76.6 76.5106.3
 79.1 77.6106.3 79.1 77.6106.3 74.4 71.0106.3
 79.1 77.6106.3 71.0 68.3106.3 79.1 77.6106.3
 76.6 76.5106.3 76.6 76.5106.3 76.6 76.5106.3
 78.9 77.1106.3 78.8 77.0106.3 79.1 77.6106.3
 61.4 61.3 91.7 61.4 61.3 91.7 62.5 62.4 91.7
 45.5 44.4 62.5 43.8 42.0 62.5 44.4 42.7 62.5
TRIA  HYD2    60     0  2020
 39.2 38.5 52.7 39.2 38.5 52.7 39.2 38.5 52.7
 31.3 31.2 46.5 31.3 31.2 46.5 31.3 31.2 46.5
 34.6 34.0 46.5 34.6 34.0 46.5 34.6 33.9 46.5
 38.0 37.9 52.7 38.0 37.9 52.7 37.9 37.9 52.7
 39.2 38.5 52.7 39.2 38.5 52.7 38.6 37.8 52.2
 38.0 37.9 52.7 38.0 37.9 52.7 38.0 37.9 52.7
 39.2 38.5 52.7 39.2 38.5 52.7 38.7 37.7 52.7
 39.2 38.5 52.7 39.2 38.5 52.7 39.2 38.5 52.7
 38.0 37.9 52.7 38.0 37.9 52.7 38.0 37.9 52.7
 39.2 38.5 52.7 39.2 38.5 52.7 39.2 38.4 52.7
 38.0 37.9 52.7 38.0 37.9 52.7 38.0 37.9 52.7
 39.2 38.5 52.7 39.2 38.5 52.7 39.2 38.5 52.7
BUDG  HYD2   600   200  2022
 44.3 19.0195.5 48.8 25.3195.2 40.5 15.1191.9
34.1  0.0175.4 38.4  0.4178.2 31.5  0.0170.5
39.3  3.0173.3 45.7 15.1173.6 39.5  4.5172.3
 58.5 33.0191.3 69.3 37.9197.7 59.2 29.1191.4
107.8 97.2220.4138.1124.1239.8110.5100.2213.2
204.8182.9338.4253.2253.0353.4223.7217.4333.5
263.0258.0353.4263.0258.0353.4263.0258.0353.4
178.6169.8255.3164.6153.6255.3177.4169.9255.3
183.8183.0255.3183.8183.0255.3183.8183.0255.3
156.5123.1255.3157.2129.5255.3160.3139.8251.6
 90.7 74.1352.2 94.2 76.2349.9 81.8 63.4351.0
 63.8 42.3216.7 58.6 30.4217.5 54.0 28.1214.9
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```
MTMR  HYD2    75     0  2027
 28.0 26.4 47.3 26.4 24.9 45.5 26.9 25.4 46.0
 20.7 19.3 40.6 20.1 18.4 39.9 20.5 19.2 40.1
 24.9 22.8 41.9 22.3 20.1 39.0 22.7 19.8 40.1
 30.4 29.6 49.9 35.5 34.6 55.8 31.0 30.0 50.7
 51.0 50.0 69.5 51.1 50.0 69.7 49.6 48.5 67.7
 50.3 50.2 69.9 50.3 50.2 69.9 50.3 50.2 69.9
 52.0 51.0 69.9 52.0 51.0 69.9 52.0 51.0 69.9
 52.0 51.0 69.9 52.0 51.0 69.9 52.0 51.0 69.9
 50.3 50.2 69.9 50.3 50.2 69.9 50.3 50.2 69.9
 52.0 51.0 69.9 52.0 51.0 69.9 51.5 50.5 69.4
 48.8 48.8 69.9 49.3 49.2 69.9 46.8 46.5 69.9
 34.0 32.4 54.8 35.2 33.5 56.4 34.9 33.1 56.3
UTAM  HYD2   415     1  2030
 74.0 46.2271.9 69.8 42.6267.3 71.3 44.1268.1
54.6  0.7245.5 53.1  3.5240.6 54.3  0.3242.8
 65.8 25.7240.4 59.1 15.7235.0 60.3 19.5236.8
 80.0 42.9263.0 93.9 51.0271.4 82.0 43.3262.4
164.6151.1317.7205.3189.3340.0161.0146.9303.0
289.5289.4409.4294.8294.0409.4284.1284.0399.5
304.6298.8409.4304.6298.8409.4304.6298.8409.4
304.6298.8409.4304.6298.8409.4302.8296.7409.4
294.8294.0409.4294.8294.0409.4294.8294.0409.4
271.9238.0409.4282.3266.6409.4267.8249.2393.8
133.9116.5409.4162.0142.4409.4138.7120.4409.4
 91.6 64.3299.1 91.7 59.3301.4 94.1 64.3304.2
```

4.1.4 Congen

Data type 4 shows Minimum and maximum permissible reserve margin (% of peak load) in critical period (-30%, 25%). The values are fixed by iterations so that the model configurations of all year are generated. If the capacity of fixed system (FIXSYS) in the initial years is insufficient and new capacity (VARSYS) cannot be added for these years (i.e. total capacity below the peak load of the critical period), a negative value for the minimum reserve margin can be used to guarantee that the configurations (with zero additions) are accepted. Data type 2 shows minimum number of sets (0 to 14) for each thermal plant and hydro plant, data type 3 shows tunnel width (addition to minimum number or difference between maximum and minimum number) for each thermal plant and hydro plant type.
Based on addition of plants in varsys, year by year configuration is assigned. 16 type 1 and 7 type 2 pants will be added by 2030.

CONGEN.dat

```
       Demonstration Case (Variable Expansion)           0
  4
     -30       25
  8
  1
  2
  0  0  0  0  0
  3
  0  0  0  0  0
  1        (END OF YEAR 2011)
  2
  0  0  0  0  0
  3
  0  0  0  0  0
  1        (END OF YEAR 2012)
  2
  0  0  0  0  0
  3
```

```
0   0   0   0   0
1         (END OF YEAR 2013)
2
0   0   0   0   0
3
0   0   0   0   0
1         (END OF YEAR 2014)
2
0   0   0   4   0
3
1   1   1   2   0
1         (END OF YEAR 2015)
2
0   0   0   6   0
3
1   1   1   0   1
1         (END OF YEAR 2016)
2
1   1   1   8   2
3
1   1   1   2   1
1         (END OF YEAR 2017)
2
1   1   1 11   3
3
1   1   1   2   0
1         (END OF YEAR 2018)
2
1   1   1  13   3
3
1   1   1   2   0
1         (END OF YEAR 2019)
2
1   1   1  15   3
3
1   1   1   1   1
1         (END OF YEAR 2020)
2
1   1   1  15   4
3
1   1   1   1   0
1         (END OF YEAR 2021)
2
1   1   1  15   4
3
1   1   1   1   1
1         (END OF YEAR 2022)
2
1   1   1  15   5
3
1   1   1   1   0
1         (END OF YEAR 2023)
2
1   1   1  15   5
3
1   1   1   1   0
1         (END OF YEAR 2024)
2
1   1   1  15   5
3
1   1   1   1   0
1         (END OF YEAR 2025)
2
1   1   1  15   5
3
1   1   1   1   0
1         (END OF YEAR 2026)
```

```
 2
 2  2  2  16   5
 3
 0  0  0  0  1
 1         (END OF YEAR 2027)
 2
 2  2  2  16   6
 3
 0  0  0  0  0
 1         (END OF YEAR 2028)
 2
 2  2  2  16   6
 3
 0  0  0  0  0
 1         (END OF YEAR 2029)
 2
 2  2  2  16   7
 3
 0  0  0  0  0
 1         (END OF YEAR 2030)
```

V. Mersim

Data type 2 shows loading order instructions, multiplier of period peak load (PKMW) for calculating the required spinning reserve, and loading order calculation option. Type 5 record shows number of Fourier coefficients, which is 50.

MERSIM.dat

```
         Demonstration Case (Variable Expansion)                 0       0
  2
 1.0        0   -1
  4
  0
  5
 50
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
  1
```

4.1.5 Dynpro

2011 is taken as first year of study, base year for cost discounting calculation and cost escalation calculation. 20 years are considered for the economic comparison. Single domestic discount rate and foreign discount rate is set to be 10%. Plant life of thermal is 25 year and 50 year for hydro.Interest during construction is taken as 10%. The capital cost of project is obtained from the feasibility study reports, web sites and references. Depreciation on capital cost for hydro plant is 3% per annum (25% domestic and 75% foreign). Critical value of LOLP (data type 12) is set to 25% as an initial value. Cost of energy not served (type 11) is 55 cents/kwh (similar to VALORAGUA)

DYNPRO.dat

```
       Demonstration Case (Variable Expansion)          0   2
2011 2011 2011   20
    10.      10.
 2
  100.   900.    25.     0.     0.    10.     3.          THRM
  100.  1400.    25.     0.     0.    10.     3.          MULT
    0.     0.    25.     0.     0.    10.     2.          PRCH
            50.
  500.  1500.                       10.     5.          KHAN
  630.  1890.                       10.     5.          BARA
  720.  2170.                       10.     5.          KUL3
  450.  1800.                       10.     5.          LMOD
  900.  2800.                       10.     5.          CHAM
  280.   830.                       10.     5.          HEWA
  500.  1500.                       10.     5.          PHAW
  600.  1900.                       10.     5.          BALA
  750.  2250.                       10.     5.          USAN
  500.  1500.                       10.     5.          IKHU
  550.  1650.                       10.     5.          KABA
  940.  2820.                       10.     5.          LCHE
  690.  2060.                       10.     5.          MAIW
  750.  2250.                       10.     5.          LSAN
  640.  1930.                       10.     5.          BALB
  690.  2070.                       10.     5.          TRIB
            50.
  930.  2780.                       10.     5.          UMSY
  360.  1090.                       10.     5.          UTAK
  550.  1650.                       10.     5.          RASG
  780.  2350.                       10.     5.          TRIA
 1390.  4180.                       10.     7.          BUDG
  550.  1650.                       10.     5.          MTMR
  550.  1660.                       10.     6.          UTAM
 13
 10
 16
  1
 11
  0.55     0     0
 12
   25
  1                                 (End of year 2011)
  1                                 (End of year 2012)
  1                                 (End of year 2013)
  1                                 (End of year 2014)
  1                                 (End of year 2015)
  1                                 (End of year 2016)
  1                                 (End of year 2017)
  1                                 (End of year 2018)
  1                                 (End of year 2019)
  1                                 (End of year 2020)
  1                                 (End of year 2021)
  1                                 (End of year 2022)
  1                                 (End of year 2023)
  1                                 (End of year 2024)
  1                                 (End of year 2025)
  1                                 (End of year 2026)
  1                                 (End of year 2027)
  1                                 (End of year 2028)
  1                                 (End of year 2029)
```

```
  1                                  (End of year 2030)
```

4.1.6 Reprobat

Following print out options (Type 2 data) are assigned in Reprobat.
Load system description (LOADSY), fixed system description (FIXSYS), variable system description (VARSYS), constraints in configuration generator module (CONGEN), economic parameters and additional constraints (DYNPRO), expected cost of operation (MERSIM)

REPROBAT.dat

```
        Demonstration Case (Variable Expansion)
 2011 2030 2011 2030
   2
   1  2  3  4     6  0  0
   3
   0  0  0
   5
N   3/9/2014
N
   6
   1
```

4.2 BASE CASE OUTPUT OF WASP

4.2.1 Output of optimization module DYNPRO

The output of DYNPRO for base case is given in the following pages. After the given data part and objective function computation part, the output displays the solution for least cost expansion. The net present worth value of each year is computed from the construction costs, salvage value, operation cost and energy not served cost, LOLP and configuration of each year. The LOLP value for 2015 to 2030 is in the range of 0.435% to 11.027%. From 2011-2014 (past and current year), only 23 existing plants are in place. Therefore, the LOLP increases during this period.

4.2.2 Reprobat output

Reprobat shows the summary of data on load, fixed system, variable system, configurations, capital costs, constraints and parameters, and cost of operation.
Hydropower generation in the fixed system is 648 MW. In the variable system, the total installed capacity is 1762 MW. With 500MW import considered in fixed system, the total installed capacity in thermal-import system is 550 MW. In the variable system, additional 500MW is considered in thermal-import system. Therefore, total installed power by 2030 is 3460MW. As the forecasted peak demand is 4155MW, the reserve margin has to be set up at -30%, 25% to run the model. Base load and peak load is also displayed in year to year basis from the output of fixsys and varsys in the report.

Dynpro output

```
WASP  COMPUTER  PROGRAM  PACKAGE
DYNPRO  MODULE
CASE  STUDY
                  Demonstration Case (Variable Expansion)


                  **************************************
                  *                          *
                  *   LIST OF VAR. EXPAN. CANDIDATES   *
                  *                          *
                  **************************************
                  *        THERMAL   PLANTS        *
                  *                          *
                  *     SEQU.NUMBER      NAME       *
                  *         1           THRM       *
                  *         2           MULT       *
                  *         3           PRCH       *
                  *                          *
                  **************************************
                  *       HYDROELECTRIC PLANTS       *
                  *                          *
                  *     SEQU.NUMBER      NAME       *
                  *         4           HYD1       *
                  *         5           HYD2       *
                  *                          *
                  **************************************

 ALL COSTS WILL BE DISCOUNTED TO THE YEAR   2011
 BASE YEAR FOR COST ESCALATION CALCULATION  2011
 FIRST YEAR OF STUDY = 2011
DURATION  OF  STUDY =   20 YEARS
 DISCOUNT RATE APPLIED TO ALL DOMESTIC COSTS - %/YR =  10.00
 DISCOUNT RATE APPLIED TO ALL FOREIGN  COSTS - %/YR =  10.00

                              *****  INPUT OF YEAR 2011  *****
 INDEX =    2
       -- C A P I T A L   C O S T S  ($/KW) --    PLANT             CONSTR.
       (DEPRECIABLE PART)  (NON-DEPREC.PART)    LIFE     I.D.C.    TIME
 PLANT    DOMESTIC FOREIGN    DOMESTIC FOREIGN    (YEARS)    (%)     (YEARS)
THRM      100.0     900.0       0.0       0.0       25.     10.00       3.0
MULT      100.0    1400.0       0.0       0.0       25.     10.00       3.0
PRCH       0.0       0.0       0.0       0.0       25.     10.00       2.0
HYD1  HYDRO PROJECT(S) CAPITAL COSTS
KHAN      500.0    1500.0                           50.     10.00       5.0
BARA      630.0    1890.0                           50.     10.00       5.0
KUL3      720.0    2170.0                           50.     10.00       5.0
LMOD      450.0    1800.0                           50.     10.00       5.0
CHAM      900.0    2800.0                           50.     10.00       5.0
HEWA      280.0     830.0                           50.     10.00       5.0
PHAW      500.0    1500.0                           50.     10.00       5.0
BALA      600.0    1900.0                           50.     10.00       5.0
USAN      750.0    2250.0                           50.     10.00       5.0
IKHU      500.0    1500.0                           50.     10.00       5.0
KABA      550.0    1650.0                           50.     10.00       5.0
LCHE      940.0    2820.0                           50.     10.00       5.0
MAIW      690.0    2060.0                           50.     10.00       5.0
LSAN      750.0    2250.0                           50.     10.00       5.0
BALB      640.0    1930.0                           50.     10.00       5.0
TRIB      690.0    2070.0                           50.     10.00       5.0
HYD2  HYDRO PROJECT(S) CAPITAL COSTS
UMSY      930.0    2780.0                           50.     10.00       5.0
UTAK      360.0    1090.0                           50.     10.00       5.0
RASG      550.0    1650.0                           50.     10.00       5.0
TRIA      780.0    2350.0                           50.     10.00       5.0
BUDG     1390.0    4180.0                           50.     10.00       7.0
MTMR      550.0    1650.0                           50.     10.00       5.0
UTAM      550.0    1660.0                           50.     10.00       6.0
 INDEX =   13
 NUMBER OF BEST SOLUTIONS REQUESTED IS   10
 INDEX =   16
 USE SINKING FUND DEPRECIATION METHOD FOR SALVAGE VALUE CALCULATION
```

```
INDEX =   11
COEFFICIENTS FOR CALCULATION OF COST OF ENERGY NOT SERVED - IN $/KWH :
        CF1 =   0.5500    CF2 =   0.0000    CF3 =   0.0000
INDEX =   12
CRITICAL LOSS-OF-LOAD PROBABILITY - IN (%) =    25.0000
INDEX =    1
OBJECTIVE FUNCTION STATE    1 TO    1
     92167.
         1

                         *****  INPUT OF YEAR 2012  *****
INDEX =    1
OBJECTIVE FUNCTION STATE    2 TO    2
    208830.
         1

                         *****  INPUT OF YEAR 2013  *****
INDEX =    1
OBJECTIVE FUNCTION STATE    3 TO    3
    362484.
         2

                         *****  INPUT OF YEAR 2014  *****
INDEX =    1
OBJECTIVE FUNCTION STATE    4 TO    4
    562273.
         3

                         *****  INPUT OF YEAR 2015  *****
INDEX =    1
OBJECTIVE FUNCTION STATE    5 TO   22
    877396.    941675.    926170.   1013717.    792737.    876593.    923781.    992666.    975287.   1065988.
    846301.    930448.    925506.    996838.    978509.   1070804.    851743.    936073.
         4          4          4          4          4          4          4          4          4          4
         4          4          4          4          4          4          4          4

                         *****  INPUT OF YEAR 2016  *****
INDEX =    1
OBJECTIVE FUNCTION STATE   23 TO   38
         0.   1198792.   1203972.   1249984.   1007352.   1107605.   1079674.   1182651.         0.   1269528.
   1272910.   1322137.   1081154.   1181848.   1153754.   1257073.
         0         18         19         20         21         21         21         21          0         18
        19         20         21         21         21         21

                         *****  INPUT OF YEAR 2017  *****
INDEX =    1
OBJECTIVE FUNCTION STATE   39 TO   41
   1629628.   1647896.   1661668.
        27         27         27

                         *****  INPUT OF YEAR 2018  *****
INDEX =    1
OBJECTIVE FUNCTION STATE   42 TO   47
   1871828.   1932060.   1882284.   1942550.   1896141.   1956429.
        39         39         39         39         39         39

                         *****  INPUT OF YEAR 2019  *****
INDEX =    1
OBJECTIVE FUNCTION STATE   48 TO   56
   1991212.   2061838.   2042841.   2030958.   2101697.   2082702.   2045232.   2116062.   2097064.
        42         42         42         42         42         42         42         42         42

                         *****  INPUT OF YEAR 2020  *****
INDEX =    1
OBJECTIVE FUNCTION STATE   57 TO   72
   2143130.   2202800.   2186652.   2247584.   2166185.   2226420.   2210164.   2271478.   2186966.   2247501.
   2231190.   2292706.   2210432.   2271404.   2255022.   2316839.
        48         48         48         48         48         48         48         48         48         48
        48         48         48         48         48         48

                         *****  INPUT OF YEAR 2021  *****
INDEX =    1
OBJECTIVE FUNCTION STATE   73 TO   82
   2290549.   2340175.   2326694.   2378026.   2281796.   2308560.   2358946.   2345288.   2397115.   2301137.
        65         65         65         65         65         69         69         69         69         69
```

```
                    *****  INPUT OF YEAR 2022  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE   83 TO  106
   2406164.  2444289.  2434126.  2474955.  2382341.  2427736.  2415091.  2417756.  2457021.  2446464.
   2488164.  2397337.  2442932.  2430276.  3067145.  3110654.  3098776.  3143314.  3052730.  3080857.
   3124823.  3112862.  3157721.  3068619.
       73        73        73        73        77        77        77        78        78        78
       78        82        82        82        73        73        73        73        77        78
       78        78        78        82

                    *****  INPUT OF YEAR 2023  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE  107 TO  120
   3086087.  3119307.  3110026.  3145395.  3051174.  3089697.  3078932.  3092502.  3126784.  3117397.
   3153332.  3062727.  3101395.  3090619.
       83        83        85        85        87        87        87        90        90        90
       90        94        94        94

                    *****  INPUT OF YEAR 2024  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE  121 TO  136
   3209602.  3230457.  3225449.  3249877.  3153246.  3184285.  3175554.  3207147.  3209754.  3231930.
   3226267.  3251925.  3161171.  3192450.  3183638.  3215410.
      107       107       107       107       111       111       111       111       114       114
      114       114       118       118       118       118

                    *****  INPUT OF YEAR 2025  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE  137 TO  152
   3359596.  3360984.  3361600.  3372890.  3264299.  3287832.  3281168.  3305603.  3350528.  3356145.
   3355064.  3368680.  3267928.  3291850.  3285088.  3309818.
      121       122       123       122       125       125       125       125       129       130
      131       130       133       133       133       133

                    *****  INPUT OF YEAR 2026  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE  153 TO  168
   3546044.  3518547.  3530069.  3517496.  3389178.  3404286.  3399930.  3416821.  3525879.  3504679.
   3513714.  3506018.  3387398.  3403317.  3398762.  3416155.
      137       138       139       140       141       141       141       141       145       146
      147       148       149       149       149       149

                    *****  INPUT OF YEAR 2027  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE  169 TO  170
   3539496.  3543640.
      167       167

                    *****  INPUT OF YEAR 2028  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE  171 TO  171
   3677943.
      170

                    *****  INPUT OF YEAR 2029  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE  172 TO  172
   3827390.
      171

                    *****  INPUT OF YEAR 2030  *****
 INDEX =    1
 OBJECTIVE FUNCTION STATE  173 TO  173
   3971493.
      172
SOLUTION #  1 VARIABLE ALTERNATIVES BY YEAR
  YEAR------ PRESENT WORTH COST OF THE YEAR ( K$ )------  OBJ.FUN.  LOLP  THRM    PRCH    HYD2
CONCST    SALVAL    OPCOST    ENSCST     TOTAL  (CUMM.)   %       MULT    HYD1
  - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  2030   149961   136211    99525    30828    144103   3971493 10.335   2   2   2  16   7
  2029        0        0   116176    33271    149447   3827390 11.027   2   2   2  16   6
  2028        0        0   113949    20355    134304   3677943  7.218   2   2   2  16   6
  2027    79435    52754   108001    10196    144878   3543640  3.993   2   2   2  16   6+
  2026    35909    20912   105142    10696    130834   3398762  4.006   1-  2+  2+ 16+  5
```

```
 2025       0       0    99272     7485    106757   3267928  2.747   1-  1-  2+ 16+  5
 2024       0       0    94693     3751     98445   3161171  1.402   1-  1-  2+ 16+  5
 2023  1064865   491886    90645     1767    665390   3062727  0.694   1-  1-  2+ 16+  5
 2022       0       0    93802     2398     96200   2397337  0.857   1-  1-  2+ 16+  4-
 2021       0       0    89468     1237     90705   2301137  0.435   1-  1-  2+ 16+  4
 2020   198372    68421    84255     5015    219221   2210433  1.553   1-  1-  1- 16+  4+
 2019    31993    10007    92574     4823    119384   1991212  1.408   1-  1-  1- 13-  3
 2018   210805    59776    88467     2704    242200   1871828  0.804   1-  1-  1- 11-  3
 2017   686203   162807    96550     2330    622276   1629628  0.678   1-  1-  1-  8-  2-
 2016       0       0   140214    15395    155609   1007352  3.437   0   0   1+  6   0
 2015   193423    40794   127810     9031    289470    851743  2.123   0   0   1+  6+  0
 2014       0       0   125943    73846    199789    562273 16.433   0   0   0   0   0
 2013       0       0   114146    39509    153655    362484  9.442   0   0   0   0   0
 2012       0       0    97238    19424    116662    208830  4.691   0   0   0   0   0
 2011       0       0    81827    10340     92167     92167  2.371   0   0   0   0   0
*****  ALL POSSIBLE PATHS TRACED  *****
```

Glimpses of Reprobat output of base case (partial output)

```
                              SUMMARY REPORT
                          ON A GENERATION EXPANSION PLAN FOR
                        Demonstration Case (Variable Expansion)
                    PROCESSED BY THE WASP-IV COMPUTER PROGRAM PACKAGE
                                  OF THE IAEA


STUDY  PERIOD

                                  2011 - 2030


                                PLANNING PERIOD

                                  2011 - 2030


                               CONSTRUCTION COSTS
                                  IN MILLION $
                               ARE REPORTED ONLY FOR
                               PLANTS COMMISSIONED
DURING THE PLANNING PERIOD.
                          ALL OTHER INFORMATION IS GIVEN
FOR THE WHOLE STUDY PERIOD.





        DATE OF REPORT      :  3/9/2014
        STUDY CARRIED OUT BY :

PAGE  3


        INFORMATION SUPPLIED BY USER :


PAGE  4

                THIS IS A LIST OF THE DIFFERENT TYPES OF ELECTRIC POWER PLANTS
                                USED IN THE STUDY.
                     THE NUMERIC CODES ARE USED BY THE COMPUTER PROGRAMS



0  HETU  HET THERMAL PLANTS
1  MULT  MULTIFUEL PLANTS
2  PRC1  PURCHASE1
3  PRC2  PURCHASE2
4  ****  NOT APPLICABLE
5  ****  NOT APPLICABLE
6  ****  NOT APPLICABLE
7  ****  NOT APPLICABLE
8  ****  NOT APPLICABLE
```

```
9  ****  NOT APPLICABLE

                    SYSTEM WITHOUT PUMPED STORAGE PROJECTS:


HYD1  HYDRO PLANTS GROUP 1
HYD2  HYDRO PLANTS GROUP 2
PAGE  5


                         ANNUAL LOAD DESCRIPTION
                         PERIOD(S) PER YEAR : 12
          YEAR    PEAKLOAD  GR.RATE  MIN.LOAD  GR.RATE    ENERGY   GR.RATE LOADFACTOR
                  MW       %       MW       %       GWH       %       %


          2011      967.1     -      421.9     -      5182.8     -     61.18
          2012     1056.9    9.3      461.1    9.3     5664.1    9.3    61.18
          2013     1163.2   10.1      507.5   10.1     6233.8   10.1    61.18
          2014     1271.7    9.3      554.8    9.3     6815.2    9.3    61.18
          2015     1387.2    9.1      605.2    9.1     7434.2    9.1    61.18
          2016     1510.0    8.9      658.8    8.9     8092.3    8.9    61.18
          2017     1640.8    8.7      715.8    8.7     8793.3    8.7    61.18
          2018     1770.2    7.9      772.3    7.9     9486.8    7.9    61.18
          2019     1906.9    7.7      831.9    7.7    10219.4    7.7    61.18
          2020     2052.0    7.6      895.2    7.6    10997.0    7.6    61.18
          2021     2206.0    7.5      962.4    7.5    11822.3    7.5    61.18
          2022     2363.0    7.1     1030.9    7.1    12663.7    7.1    61.18
          2023     2545.4    7.7     1110.5    7.7    13641.2    7.7    61.18
          2024     2741.1    7.7     1195.8    7.7    14690.0    7.7    61.18
          2025     2951.1    7.7     1287.5    7.7    15815.4    7.7    61.18
          2026     3176.7    7.6     1385.9    7.6    17024.4    7.6    61.18
          2027     3418.9    7.6     1491.5    7.6    18322.4    7.6    61.18
          2028     3679.1    7.6     1605.1    7.6    19716.9    7.6    61.18
          2029     3913.0    6.4     1707.1    6.4    20970.4    6.4    61.18
          2030     4155.6    6.2     1812.9    6.2    22270.6    6.2    61.18
PAGE  6


                           FIXED SYSTEM
                    SUMMARY DESCRIPTION OF THERMAL PLANTS IN YEAR 2011
HEAT  RATES    FUEL COSTS      FAST
              NO. MIN.  CAPA   KCAL/KWH        CENTS/         SPIN  FOR   DAYS  MAIN  O&M   O&M
OF  LOAD  CITY  BASE   AVGE   MILLION  KCAL  FUEL  RES       SCHL  CLAS (FIX) (VAR)
      NO. NAME  SETS  MW    MW   LOAD   INCR   DMSTC   FORGN  TYPE   %    %    MAIN   MW  $/KWM $/MWH

3  HETU    1    3.   10.  2180.  2010.  240.0  2160.0    0    0  20.0    55    10.  5.30  2.60
4  MULT    6    1.    6.  2180.  2010.  240.0  2160.0    1    0  20.0    55    25.  5.30  2.60
5  PRC1    1    1.  300. 10000. 10000.    0.0   638.0    3    0  10.0    10    20.  0.00  0.00
6  PRC2    1    1.  200. 10000. 10000.    0.0   638.0    3    0  10.0    10    30.  0.00  0.00
PAGE  7


                           FIXED SYSTEM
                   SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD1
                        *** CAPACITY IN MW * ENERGY IN GWH ***
                         FIXED O&M COSTS : 2.100 $/KW-MONTH
     P     HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
     R  P     PROB.: 0.20       PROB.: 0.20       PROB.: 0.60
     O  E   CAPACITY  ENERGY  CAPACITY  ENERGY  CAPACITY  ENERGY
YEAR  J  R  BASE  PEAK        BASE  PEAK        BASE  PEAK


   2011 18  1   132.   0.  96.  134.   0.  98.  133.   0.   97.
2   115.   0.  84.  116.   0.  85.  113.   0.  82.
3   129.   0.  94.  134.   0.  98.  130.   0.  95.
4   134.   0.  98.  135.   0.  99.  134.   0.  98.
5   161.   0.  118.  179.   0.  131.  173.   0.  126.
6   201.   0.  147.  205.   0.  149.  201.   0.  147.
7   207.   0.  152.  203.   0.  148.  205.   2.  151.
8   198.   0.  145.  199.   0.  146.  199.   0.  145.
9   173.   0.  127.  174.   0.  127.  172.   0.  126.
10   179.   0.  131.  177.   0.  129.  180.   1.  132.
11   185.   0.  135.  186.   0.  136.  185.   0.  135.
12   149.   0.  109.  145.   0.  106.  149.   0.  109.
       INST.CAP.  245.
       TOTAL ENERGY    1435.          1450.          1444.
```

```
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                              FIXED SYSTEM
               SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD2
                      *** CAPACITY IN MW * ENERGY IN GWH ***
                        FIXED O&M COSTS : 2.100 $/KW-MONTH
       P     HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
       R  P     PROB.: 0.20      PROB.: 0.20      PROB.: 0.60
       O  E   CAPACITY  ENERGY  CAPACITY  ENERGY  CAPACITY  ENERGY
YEAR  J  R  BASE  PEAK       BASE  PEAK       BASE  PEAK

2011  5  1   224.   55.  171.  243.   49.  185.  247.   48.  187.
2   202.   48.  152.  211.   50.  159.  214.   44.  159.
3   224.   46.  172.  239.   43.  183.  229.   47.  177.
4   252.   43.  188.  268.   42.  202.  266.   38.  199.
5   293.   33.  219.  324.   19.  242.  328.   17.  244.
6   339.   27.  254.  308.   39.  234.  338.   26.  252.
7   331.   25.  247.  317.   34.  238.  338.   20.  252.
8   352.    5.  259.  376.    0.  275.  364.    4.  267.
9   337.   15.  249.  338.   12.  248.  346.    7.  253.
10   351.   27.  263.  347.   28.  263.  362.   16.  270.
11   328.   45.  243.  319.   53.  239.  324.   46.  240.
12   269.   50.  205.  263.   56.  202.  258.   60.  198.
        INST.CAP.  403.
        TOTAL ENERGY    2623.            2669.            2699.
PAGE  9


                              FIXED SYSTEM
                        SUMMARY OF INSTALLED CAPACITIES
                          (NOMINAL CAPACITIES (MW))

       HYDROELECTRIC                        THERMAL                       TOTAL
       HYD1     HYD2                  F U E L   T Y P E
                    0     1     2     3     4     5     6     7     8     9
YEAR PR.CAP  PR.  CAP   HETU   MULT   PRC1   PRC2  ****  ****  ****  ****  ****  ****

2011 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2012 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2013 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2014 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2015 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2016 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2017 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2018 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2019 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2020 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2021 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2022 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2023 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2024 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2025 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2026 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2027 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2028 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2029 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
2030 18   245.5   403.    10.    39.    0.  500.    0.    0.    0.    0.    0.    0.  1197.
                                                                  PAGE 10


                             VARIABLE SYSTEM
                     SUMMARY DESCRIPTION OF THERMAL PLANTS
HEAT  RATES     FUEL COSTS       FAST
            NO. MIN.  CAPA   KCAL/KWH        CENTS/         SPIN  FOR   DAYS  MAIN  O&M   O&M
OF  LOAD  CITY  BASE   AVGE   MILLION  KCAL  FUEL  RES        SCHL  CLAS (FIX) (VAR)
      NO. NAME  SETS  MW    MW   LOAD   INCR   DMSTC   FORGN  TYPE   %    %   MAIN   MW  $/KWM $/MWH

1  THRM    0   10.  200.  3590.  2650.  500.0  2500.0    1    0  20.0    37    12.  2.80  2.60
2  MULT    0   10.  100.  2180.  2010.  240.0  2160.0    3    0  20.0    55    20.  5.30  2.60
3  PRCH    0    1.  500. 10000. 10000.    0.0   638.0    4   15  10.0     0    25.  0.00  0.00
                                                                  PAGE 11


                             VARIABLE SYSTEM
               SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD1
                      *** CAPACITY IN MW * ENERGY IN GWH ***
                        FIXED O&M COSTS : 2.100 $/KW-MONTH
       P     HYDROCONDITION 1  HYDROCONDITION 2  HYDROCONDITION 3
```

```
         R  P      PROB.: 0.20       PROB.: 0.20       PROB.: 0.60
         O  E   CAPACITY  ENERGY  CAPACITY  ENERGY  CAPACITY  ENERGY
YEAR  J  R  BASE  PEAK       BASE  PEAK       BASE  PEAK

2015  1  1    5.   0.   4.   5.   0.   3.   5.   0.   4.
2    4.   0.   3.   4.   0.   3.   4.   0.   3.
3    4.   0.   3.   4.   0.   3.   4.   0.   3.
4    5.   0.   4.   5.   0.   3.   5.   0.   4.
5    8.   0.   6.   8.   0.   6.   8.   0.   6.
6   25.   0.  18.  26.   0.  19.  25.   0.  18.
7   38.   0.  27.  38.   0.  27.  38.   0.  27.
8   38.   0.  27.  38.   0.  27.  38.   0.  27.
9   37.   0.  27.  37.   0.  27.  37.   0.  27.
10    27.   0.  20.  27.   0.  20.  24.   0.  17.
11   12.   0.   8.  12.   0.   8.  11.   0.   8.
12    7.   0.   5.   7.   0.   5.   7.   0.   5.
INST.CAP.   30.
          TOTAL ENERGY     154.            152.            150.

2015  2  1    6.   0.   4.   5.   0.   4.   5.   0.   4.
2    5.   0.   4.   5.   0.   4.   5.   0.   4.
3    5.   0.   4.   5.   0.   3.   5.   0.   3.
4    6.   0.   4.   5.   0.   4.   6.   0.   4.
5    9.   0.   7.   9.   0.   6.   9.   0.   6.
6   27.   0.  20.  28.   0.  20.  27.   0.  20.
7   41.   0.  30.  40.   0.  30.  41.   0.  30.
8   41.   0.  30.  41.   0.  30.  41.   0.  30.
9   41.   0.  30.  41.   0.  30.  41.   0.  30.
10    29.   0.  21.  29.   0.  21.  26.   0.  19.
11    13.   0.   9.  13.   0.   9.  12.   0.   9.
12    8.   0.   6.   8.   0.   6.   8.   0.   6.
INST.CAP.   34.
          TOTAL ENERGY     169.            167.            165.

2015  3  1    14.   0.  10.  15.   0.  11.  16.   0.  12.
2   13.   0.   9.  14.   0.  10.  15.   0.  11.
3   15.   0.  11.  17.   0.  12.  17.   0.  13.
4   16.   0.  12.  17.   0.  12.  18.   0.  13.
5   17.   0.  12.  20.   0.  15.  20.   0.  15.
6   39.   0.  28.  41.   0.  30.  39.   0.  29.
7   55.   0.  40.  54.   0.  40.  55.   0.  40.
8   55.   0.  40.  55.   0.  40.  55.   0.  40.
9   54.   0.  40.  54.   0.  40.  54.   0.  40.
10    43.   0.  31.  43.   0.  31.  39.   0.  29.
11    25.   0.  18.  25.   0.  18.  25.   0.  18.
12    19.   0.  14.  17.   0.  12.  18.   0.  13.
INST.CAP.   48.
          TOTAL ENERGY     267.            272.            273.
```

4.3 PERTURBATION IN BASIC CASE FOR COMPUTING LRMC

All other data files in WASP are similar to the base case except Loadsy. In Loadsy, the annual peak load of base case scenario is increased by 50 MW each year.

The optimization output of perturbation case is given below. As the load is increased, the LOLP and cost is increased.

DYNPRO output of perturbation case

```
SOLUTION #  1 VARIABLE ALTERNATIVES BY YEAR
  YEAR------ PRESENT WORTH COST OF THE YEAR ( K$ )------  OBJ.FUN.  LOLP  THRM    PRCH    HYD2
CONCST    SALVAL    OPCOST    ENSCST     TOTAL   (CUMM.)    %       MULT    HYD1
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 2030   149961   136212   101633    35419   150802  4179416 11.454  2  2  2 16  7
 2029        0        0   118696    37871   156567  4028614 12.139  2  2  2 16  6
 2028        0        0   116953    23305   140258  3872047  7.952  2  2  2 16  6
 2027    79435    52754   111336    11912   149928  3731789  4.518  2  2  2 16  6+
 2026    35909    20912   108577    12588   136161  3581861  4.571  1-  2+  2+ 16+  5
 2025        0        0   102651     8926   111578  3445700  3.204  1-  1-  2+ 16+  5
 2024        0        0    97976     4565   102541  3334122  1.653  1-  1-  2+ 16+  5
 2023  1064865   491886    94061     2219   669258  3231581  0.842  1-  1-  2+ 16+  5
 2022        0        0    97988     3013   101001  2562323  1.034  1-  1-  2+ 16+  4-
 2021        0        0    93709     1580    95289  2461322  0.547  1-  1-  2+ 16+  4
 2020   198372    68421    88585     6343   224878  2366032  1.901  1-  1-  1- 16+  4+
 2019    31993    10007    97477     6133   125597  2141154  1.738  1-  1-  1- 13-  3
 2018   210805    59776    93585     3554   248168  2015558  0.999  1-  1-  1- 11-  3
 2017   686203   162807   102533     3114   629042  1767389  0.856  1-  1-  1-  8-  2-
 2016        0        0   149879    19319   169199  1138347  4.178  0  0  1+  6  0
 2015   193423    40794   138620    11810   303058   969149  2.605  0  0  1+  6+  0
 2014        0        0   135273    98990   234263   666091 20.122  0  0  0  0  0
 2013        0        0   125730    55772   181501   431828 12.471  0  0  0  0  0
 2012        0        0   110618    28867   139486   250326  6.694  0  0  0  0  0
 2011        0        0    95480    15361   110841   110841  3.382  0  0  0  0  0
*****  ALL POSSIBLE PATHS TRACED  *****
```

4.4 LRMC FOR BASIC SCENARIO

The generated energy and the corresponding net present value for both base case and perturbation case is extracted from Reprobat and Dynpro output to compute LRMC for the basic scenario. LRMC value obtained with 20 years of output for the hydrothermal system is 3.9 Cents/KWh.

4.4.1 LRMC computation

E1: Generated energy for base case
E2: Generated energy for perturbation case
NPV1: Net present value for base case
NPV2: Net present value for perturbation case

Year	**E1(Gwh)**	**E2(Gwh)**	**NPV1 (K$)**	**NPV2 (K$)**
2030	22270.6	22538.6	144103	150802
2029	20970.4	21238.3	149447	156567
2028	19716.9	19984.8	134304	140258
2027	18322.4	18590.4	144878	149928
2026	17024.4	17292.4	130834	136161
2025	15815.4	16083.4	106757	111578
2024	14690	14957.9	98445	102541
2023	13641.2	13909.2	665390	669258
2022	12663.7	12931.6	96200	101001
2021	11822.3	12090.3	90705	95289
2020	10997	11264.9	219221	224878
2019	10219.4	10487.3	119384	125597
2018	9486.8	9754.7	242200	248168
2017	8793.3	9061.3	622276	629042
2016	8092.3	8360.3	155609	169199
2015	7434.2	7702.2	289470	303058
2014	6815.2	7083.2	199789	234263
2013	6233.8	6501.7	153655	181501
2012	5664.1	5932.1	116662	139486
2011	5182.8	5450.8	92167	110841

LRMC= (difference in total cost/difference in energy) =3.9 Cents/Kwh

Appendix -5

Generation of various Scenarios

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List of Tables:

5. GENERATION OF VARIOUS SCENARIOS

Following scenarios are performed in this study:
1. Basic model: Hydro plants with Thermal and without export, design flow
The details of this scenario with input and output of models is already presented in section 4.3 and 4.4 as a basic case.
2. Export option: Export (700MW) option in basic model
3. Seasonal model: Seasonal breakdown in scenario1
Dry season: Jan-Apr
Wet season: May-Dec
4. GDP change: Hydro plants with Thermal and without export for adopted design flow, considering 5%, 7.5% and 10% GDP growth
5. Storage projects: Hydro plants with Thermal and without export for adopted design flow adding more storage projects in the basic scenario
6. Consideration of major existing, under-construction and planned projects
7. Consideration of time horizon (long term, short term and medium term)

5.1 VALORAGUA DATABASE

Scenarios 1, 2, 3, and 4 contain 18 cascades with 46 hydro plants (23 existing and 23 expansions). The hydro plants are same in all scenarios.

In VALORAGUA, change is done in CADIR file only for different scenarios. Twelve periods are considered for generating VWASP for WASP model. There is no change in the VALORAGUA database for scenario 1, 3, and 4. The change condition in these scenarios is reflected in WASP. In scenario 2, export option of 700MW is added in CADIR file.

Change in scenario2 in CADIR file

```
              ********* EXPORT OPTION ********
 1
S.DEM1   1
S.DEM1   9.00   0.01
  700
    0
```

In Scenario 5, Khani khola, Bijyapur and Andhi ROR hydro projects are discarded from scenario1 and Dudhkoshi, Tanahu and West Seti storage projects are included in the CADIR file. The total number of cascades and hydro plants is same as scenario 1.

Table 5-1: Salient features of three storage projects

Project	Flow (m^3/s)	Installed capacity (MW)
Dudhkoshi	136	300
Tanahu (Seti)	127	128
West Seti	330	750

In scenario6, major existing projects, major projects under-construction and major planned projects are considered. The total number of cascade in this case is also 18. The total number of hydro plants is 48 (20 existing, 28 expansions). According to this scenario, the total installed capacity will be 4388MW by the end of 2030. The load forecast for 2030 is 4155 MW. Hence, this expansion plan will be sufficient to meet the energy demands for 20 year time horizon.

Table 5-2: Major projects considered for scenario6

Existing plants	**Installed capacity (MW)**
KALI GANDAKI	144
MIDDLE MARSYANGDI	70
MARSYANGDI	69
KULEKHANI-1	60
KULEKHANI-2	32
KHIMTI-1	60
UPPER BHOTEKOSHI	45
PUWA	6.2
MAI	15.6
PILUWA	3.0
SIPRIN	9.6
CHAKU	3
SUNKOSHI SMALL	2.5
SUNKOSHI	10
CHILIME	22
TRISHULI	24
DEVIGHAT	15
KHUDI	4
MODI	15
JHIMRUK	12
Total:	**622MW**

Under construction/planned projects	**Installed capacity (MW)**
UPPER TAMAKOSHI	456
RASUWAGADHI	111
MIDDLE BHOTEKOSHI	102
TRISHULI3A	60
TANAHU STORAGE (SETI)	128
BUDHI GANDAKI STORAGE	600
DUDH KOSHI STORAGE	300
NALSING GAD STORAGE	400
WEST SETI STORAGE	750
MIDDLE TAMOR	75
UPPER TAMOR	415
BARAMCHI	4

KULEKHANI-3	14
LOWER MODI	20
CHAMELIYA	30
HEWA	15
RAHUGHAT	32
PHAWA	5
BALEPHI-A	11
UPPER SANJEN	15
IKHUWA	19
KABELI-A	38
LOWER CHEPE	8
MAIWA	14
LOWER SANJEN	43
BALEPHI-B	19
TRISHULI2B	37
UPPER MARSYANGDI	45
Total:	**3766 MW**

In scenario6, major existing projects, major projects under-construction and major planned projects are considered (as discussed in chapter 5). The total number of cascade in this case is also 18. The total number of hydro plants is 48 (20 existing, 28 expansions).

In scenario 7, database is prepared for three time horizons.

Short term: 2011-2020 (10 years), 23 existing (same as scenario 1), 23 expansion

Table 5-3:Expansion plants

KHANI	KABELI-A
BARAMCHI	LOWER CHEPE
KULEKHANI-3	MAIWA
LOWER MODI	LOWER SANJEN
CHAMELIYA	BALEPHI-B
HEWA	TRISHULI3B
RAHUGHAT	UPPER MARSYANGDI
PHAWA	UPPER TAMAKOSHI
BALEPHI-A	RASUWAGADHI
UPPER SANJEN	MIDDLE BHOTEKOSHI
IKHUWA	TANAHU
TRISHULI2A	

Medium term: 2011-2020 (20 years), same case as scenario 1

Long term: 2011-2035 (25 years), 19 existing, 29 expansion

Table 5-4:Existing

MIDDLE MARSYANGDI	SIPRIN
MARSYANGDI	CHAKU
KULEKHANI-1	SUNKOSHI SMALL
KULEKHANI-2	SUNKOSHI
KHIMTI-1	CHILIME
UPPER BHOTEKOSHI	TRISHULI
PUWA	DEVIGHAT
MAI	KHUDI
MODI	JHIMRUK

Table 5-5:Expansion

UPPER TAMAKOSHI	UPPER MARSYANGDI
RASUWAGADHI	TRISHULI3B
MIDDLE BHOTEKOSHI	BALEPHI-B
TRISHULI3A	LOWER SANJEN
TANAHU STORAGE (SETI)	MAIWA
BUDHI GANDAKI STORAGE	LOWER CHEPE
DUDH KOSHI STORAGE	KABELI-A
NALSING GAD STORAGE	UPPER SANJEN
WEST SETI STORAGE	BALEPHI-A
MIDDLE TAMOR	PHAWA
UPPER TAMOR	RAHUGHAT
UPPER ARUN	HEWA
ARUN 3	CHAMELIYA
BARAMCHI	LOWER MODI
KULEKHANI-3	

Parts of CADIR file for scenario5

```
                    ********* RESERVOIR CHARACTERISITCS ********
46
  PUWA  01      1.0   1.  .90 .80000+03 .00000+00 .00000+00 .10000+01
   MAI  02      1.0   1.  .90 .31660+03 .00000+00 .00000+00 .10000+01
IKHUWA  03      1.0   1.  .90 .15050+04 .00000+00 .00000+00 .10000+01
PILUWA  04      1.0   1.  .90 .75700+03 .00000+00 .00000+00 .10000+01
UTAMOR  05      1.0   1.  .90 .11700+04 .00000+00 .00000+00 .10000+01
 MAIWA  06      1.0   1.  .90 .79971+03 .00000+00 .00000+00 .10000+01
MTAMOR  07      1.0   1.  .90 .68400+03 .00000+00 .00000+00 .10000+01
 PHAWA  08      1.0   1.  .90 .89200+03 .00000+00 .00000+00 .10000+01
KABE-A  09      1.0   1.  .90 .55640+03 .00000+00 .00000+00 .10000+01
  HEWA  10      1.0   1.  .90 .86200+03 .00000+00 .00000+00 .10000+01
UTAMAK  11      1.0   1.  .90 .20065+04 .00000+00 .00000+00 .10000+01
SIPRIN  12      1.0   1.  .90 .10500+04 .00000+00 .00000+00 .10000+01
 DUDHK  13    687.0   1.  .36 .53000+03  .2453+03 .93000+00 .60000+00
KHIM-1  14      1.0   1.  .90 .12706+04 .00000+00 .00000+00 .10000+01
U-BHOT  15      1.0   1.  .90 .84320+03 .00000+00 .00000+00 .10000+01
```

```
 CHAKU  16      1.0   1.  .90 .77450+03 .00000+00 .00000+00 .10000+01
BARAMC  17      1.0   1.  .90 .10703+04 .00000+00 .00000+00 .10000+01
SUNKOS  18      1.0   1.  .90 .72550+03 .00000+00 .00000+00 .10000+01
SUNKON  19      1.0   1.  .90 .53210+03 .00000+00 .00000+00 .10000+01
BALE-A  20      1.0   1.  .90 .50800+03 .00000+00 .00000+00 .10000+01
BALE-B  21      1.0   1.  .90 .43000+03 .00000+00 .00000+00 .10000+01
INDRAW  22      1.0   1.  .90 .96000+03 .00000+00 .00000+00 .10000+01
U-SANJ  23      1.0   1.  .90 .23360+04 .00000+00 .00000+00 .10000+01
L-SANJ  24      1.0   1.  .90.216280+04 .00000+00 .00000+00 .10000+01
CHILIM  25      1.0   1.  .90 .14905+04 .00000+00 .00000+00 .10000+01
RASGAD  26      1.0   1.  .90.128848+04 .00000+00 .00000+00 .10000+01
TRIS3A  27      1.0   1.  .90 .85200+03 .00000+00 .00000+00 .10000+01
TRIS2B  28      1.0   1.  .90 .54100+03 .00000+00 .00000+00 .10000+01
  TRIS  29      1.0   1.  .90 .20380+03 .00000+00 .00000+00 .10000+01
DEVIGH  30      1.0   1.  .90 .14420+03 .00000+00 .00000+00 .10000+01
KULEK1  31     85.3   1.  .17 .14800+04 .14900+02 .24025+01 .10000+01
KULEK2  32      1.0   1.  .90 .91460+03 .00000+00 .00000+00 .10000+01
KULEK3  33      1.0   1.  .90 .57756+03 .00000+00 .00000+00 .10000+01
BUDHIG  34     3320   1.  .17 .44500+03 .95000+03 .25000+01 .10000+01
UMARSY  35      1.0   1.  .90 .76840+03 .00000+00 .00000+00 .10000+01
MMARSY  36      1.0   1.  .90 .62330+03 .00000+00 .00000+00 .10000+01
 KHUDI  37      1.0   1.  .90 .65540+03 .00000+00 .00000+00 .10000+01
LCHEPE  38      1.0   1.  .90 .87000+03 .00000+00 .00000+00 .10000+01
MARSYG  39      1.0   1.  .90 .32960+03 .00000+00 .00000+00 .10000+01
  TANA  40    295.0   1.  .14 .37100+03 .61400+02 .13000+01 .67000+00
  MODI  41      1.0   1.  .90 .86696+03 .00000+00 .00000+00 .10000+01
 LMODI  42      1.0   1.  .90 .68430+03 .00000+00 .00000+00 .10000+01
KGANDA  43      7.7   1.  .60 .66680+03 .00000+00 .00000+00 .10000+01
  WEST  44    926.0   1.  .70 .11000+04 .17100+01 .64000+01 .45000+00
JHIMRK  45      1.0   1.  .90 .73950+03 .00000+00 .00000+00 .10000+01
CHAMEL  46      7.7   1.  .60 .87830+03 .00000+00 .00000+00 .10000+01
   0                STORAGE BOUNDS
   0         HEIGHT EVAPORATION (MM)
   0             WATER RELEASE (HM3)
                                 ********* SPILLWAYS ********
46
  PUWA   1   2
   MAI   2   0
IKHUWA   3   4
PILUWA   4   0
UTAMOR   5   7
 MAIWA   6   7
MTAMOR   7   0
 PHAWA   8   9
KABE-A   9   0
  HEWA  10   0
UTAMAK  11   0
SIPRIN  12   0
 DUDHK  13   0
KHIM-1  14   0
U-BHOT  15  19
 CHAKU  16  19
BARAMC  17  19
SUNKOS  18  19
SUNKON  19   0
BALE-A  20  21
BALE-B  21   0
INDRAW  22   0
U-SANJ  23  24
L-SANJ  24  25
CHILIM  25  27
RASGAD  26  27
TRIS3A  27  28
TRIS2B  28  29
  TRIS  29  30
DEVIGH  30   0
KULEK1  31  32
KULEK2  32  33
KULEK3  33   0
BUDHIG  34   0
UMARSY  35  36
MMARSY  36  39
 KHUDI  37  39
LCHEPE  38  39
MARSYG  39   0
```

```
  TANA  40   0
  MODI  41  42
 LMODI  42  43
KGANDA  43   0
  WEST  44   0
JHIMRK  45   0
CHAMEL  46   0
                         ********* HYDRO POWER PLANTS ********
46
  PUWA   1    2  0 116.00 0.01   0.85   0.05   0.00 320.00   2.50 480.00
   MAI   2    0  0 1 8.89 0.01   0.90   0.05   0.00 121.60  16.00 195.00
IKHUWA   3    4  0 110.00 0.01   0.90   0.05   0.00 605.00   4.00 900.00
PILUWA   4    0  0 1 5.50 0.01   0.91   0.05   0.00 107.00   3.50 650.00
UTAMOR   5    7  0 120.00 0.01   0.90   0.05   0.00 470.00 105.00 700.00
 MAIWA   6    7  0 110.81 0.01   0.91   0.05   0.00 190.09   8.07 609.62
MTAMOR   7    0  0 1 7.50 0.01   0.86   0.05   0.00  84.00 105.00 600.00
 PHAWA   8    9  0 114.00 0.01   0.90   0.05   0.00 292.00   2.10 600.00
KABE-A   9    0  0 1 5.40 0.01   0.85   0.05   0.00 111.40  37.73 445.00
  HEWA  10    0  0 1 5.50 0.01   0.85   0.05   0.00 212.00   8.12 650.00
UTAMAK  11    0  0 122.00 0.01   0.84   0.05   0.00 800.00  66.001206.50
SIPRIN  12    0  0 110.00 0.01   0.85   0.05   0.00 150.00   7.50 900.00
 DUDHK  13    0  0 112.50 0.01   0.90   0.05   0.00 249.00 136.00 300.00
KHIM-1  14    0  0 134.60 0.01   0.85   0.05   0.00 691.60  10.75 579.00
U-BHOT  15   19  0 1 7.20 0.01   0.80   0.05   0.00 143.20  36.80 700.00
 CHAKU  16   19  0 1 7.50 0.01   0.86   0.05   0.00 124.50   2.70 650.00
BARAMC  17   19  0 125.00 0.01   0.86   0.05   0.00 545.00   0.90 525.30
SUNKOS  18   19  0 1 9.50 0.01   0.85   0.05   0.00 124.50   2.70 601.00
SUNKON  19    0  0 1 1.60 0.01   0.86   0.05   0.00  32.10  40.00 500.00
BALE-A  20   21  0 1 2.00 0.01   0.86   0.05   0.00  48.00  25.00 460.00
BALE-B  21    0  0 1 5.00 0.01   0.86   0.05   0.00  80.00  30.00 350.00
INDRAW  22    0  0 1 5.00 0.01   0.85   0.05   0.00  60.00  15.00 900.00
U-SANJ  23   24  0 1 5.30 0.01   0.85   0.05   0.00 156.00  11.102180.00
L-SANJ  24   25  0 1 9.20 0.01   0.85   0.05   0.00 432.80  11.601730.00
CHILIM  25   27  0 117.70 0.01   0.89   0.05   0.00 354.50   8.251136.00
RASGAD  26   27  0 1 9.42 0.01   0.89   0.05   0.00 158.48  80.001130.00
TRIS3A  27   28  0 112.50 0.01   0.85   0.05   0.00 132.00  51.00 720.00
TRIS2B  28   29  0 113.24 0.01   0.81   0.05   0.00  87.00  51.00 454.00
  TRIS  29   30  0 1 2.80 0.01   0.92   0.05   0.00  56.75  45.30 147.05
DEVIGH  30    0  0 1 1.50 0.01   0.86   0.05   0.00  39.00  45.30 105.20
KULEK1  31   32  0 129.00 0.01   0.86   0.05   0.00 589.00  12.10 916.00
KULEK2  32   33  0 115.60 0.01   0.86   0.05   0.00 313.60  13.50 601.00
KULEK3  33    0  0 1 7.24 0.01   0.86   0.05   0.00 102.56  16.00 475.00
BUDHIG  34    0  0 112.00 0.01   0.86   0.05   0.00 185.00 430.00 312.00
UMARSY  35   36  0 1 4.80 0.01   0.86   0.05   0.00 118.40  48.74 650.00
MMARSY  36   39  0 1 4.50 0.01   0.86   0.05   0.00  98.00  80.00 525.30
 KHUDI  37   39  0 110.00 0.01   0.86   0.05   0.00 105.40   4.55 550.00
LCHEPE  38   39  0 110.00 0.01   0.86   0.05   0.00 135.00   7.53 735.00
MARSYG  39    0  0 1 4.40 0.01   0.86   0.05   0.00  87.10  91.50 242.50
  TANA  40    0  0 1 3.30 0.01   0.90   0.05   0.00 112.50 127.00 289.00
  MODI  41   42  0 1 3.04 0.01   0.86   0.05   0.00  66.96  27.50 800.00
 LMODI  42   43  0 1 3.70 0.01   0.86   0.05   0.00  84.30  29.00 600.00
KGANDA  43    0  0 1 6.80 0.01   0.86   0.05   0.00 136.80 134.00 530.00
  WEST  44    0  0 113.00 0.01   0.90   0.05   0.00 259.00 330.00 400.00
JHIMRK  45    0  0 1 9.50 0.01   0.86   0.05   0.00 189.50   8.00 550.00
CHAMEL  46    0  0 1 9.70 0.01   0.86   0.05   0.00  94.00  36.00 784.30
  PUWA  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5
  PUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
   MAI  3.0  2.5  2.4  2.7  4.5 16.0 16.0 16.0 16.0 16.0  6.0  3.6
   MAI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
IKHUWA  2.0  1.7  1.5  2.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  2.6
IKHUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
PILUWA  2.8  2.1  1.9  2.8  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
PILUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
UTAMOR105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0
UTAMOR  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 MAIWA  2.2  1.8  1.9  2.6  5.2  8.1  8.1  8.1  8.1  8.1  4.5  2.9
 MAIWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MTAMOR105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0105.0
MTAMOR  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 PHAWA  1.2  1.0  1.1  1.5  2.1  2.1  2.1  2.1  2.1  2.1  2.1  1.6
 PHAWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KABE-A 11.0  9.2  9.3 13.2 26.0 37.7 37.7 37.7 37.7 37.7 22.4 14.2
KABE-A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
  HEWA  3.8  3.0  2.6  4.0  8.1  8.1  8.1  8.1  8.1  8.1  8.1  5.6
  HEWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
```

```
UTAMAK 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0 66.0
UTAMAK  0.1  0.1  0.1  0.1  0.0  0.0  0.0  0.0  0.0  0.0  0.1  0.1
SIPRIN  1.8  1.6  1.5  1.8  3.2  7.5  7.5  7.5  7.5  7.5  4.0  2.6
SIPRIN  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 DUDHK136.0136.0136.0136.0136.0136.0136.0136.0136.0136.0136.0136.0
 DUDHK 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
KHIM-1  6.1  5.1  5.0  5.3  9.0 10.8 10.8 10.8 10.8 10.8 10.8  8.3
KHIM-1  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.1  0.1  0.1  0.1  0.1
U-BHOT 23.0 21.0 21.0 24.0 36.8 36.8 36.8 36.8 36.8 36.8 36.8 27.0
U-BHOT  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
 CHAKU  0.6  0.6  0.6  0.7  1.2  2.2  2.7  2.7  2.7  2.7  1.1  0.8
 CHAKU  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BARAMC  0.2  0.2  0.1  0.2  0.3  0.5  0.9  0.9  0.9  0.6  0.3  0.2
BARAMC  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
SUNKOS  1.8  1.6  1.7  1.9  2.7  2.7  2.7  2.7  2.7  2.7  2.7  2.2
SUNKOS  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
SUNKON 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0
SUNKON  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
BALE-A  2.3  2.0  2.0  2.2  3.2  9.0 25.0 25.0 25.0 10.0  5.0  3.0
BALE-A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BALE-B 12.7 11.1 10.7 12.1 18.0 30.0 30.0 30.0 30.0 30.0 24.0 17.0
BALE-B  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
INDRAW  7.0  6.0  6.0  6.6 10.0 15.0 15.0 15.0 15.0 15.0 13.1  9.1
INDRAW  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
U-SANJ 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1 11.1
U-SANJ  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
L-SANJ  2.3  2.0  2.0  2.6  5.1 11.6 11.6 11.6 11.6  9.0  4.2  3.0
L-SANJ  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
CHILIM  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3
CHILIM  0.0  0.0  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
RASGAD 37.0 33.0 33.0 42.0 80.0 80.0 80.0 80.0 80.0 80.0 69.0 47.0
RASGAD  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
TRIS3A 51.0 45.0 45.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0
TRIS3A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
TRIS2B 51.0 45.0 45.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0 51.0
TRIS2B  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  TRIS 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3
  TRIS  0.1  0.1  0.0  0.0  0.0  0.0  0.0  0.1  0.1  0.1  0.1  0.1
DEVIGH 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3
DEVIGH  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
KULEK1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1
KULEK1  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KULEK2 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5
KULEK2  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KULEK3 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4 21.4
KULEK3  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BUDHIG430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0
BUDHIG  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
UMARSY 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7 48.7
UMARSY  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MMARSY 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0
MMARSY  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 KHUDI  3.0  2.0  2.0  3.0  4.5  4.5  4.5  4.5  4.5  4.5  4.5  3.0
 KHUDI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
LCHEPE  5.0  4.0  4.0  4.0  6.0  7.5  7.5  7.5  7.5  7.5  7.5  6.0
LCHEPE  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MARSYG 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5
MARSYG  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  TANA127.0127.0127.0127.0127.0127.0127.0127.0127.0127.0127.0127.0
  TANA 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
  MODI 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5
  MODI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 LMODI 10.0  8.0  8.0 11.0 18.0 29.0 29.0 29.0 29.0 29.0 18.0 13.0
 LMODI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KGANDA134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0
KGANDA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  WEST330.0330.0330.0330.0330.0330.0330.0330.0330.0330.0330.0330.0
  WEST 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.25 0.25 0.25 0.00 0.00
JHIMRK  4.0  4.0  3.0  3.0  3.0  8.0  8.0  8.0  8.0  8.0  8.0  5.0
JHIMRK  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
CHAMEL 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0
CHAMEL  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
```

5.2 VALORAGUA OUTPUT

The main VALORAGUA outputs RESEX.prn and VWASP.prn for scenario 1, 3 and 4 are same. The main part of output of RESEX.prn for scenario 2 and 5 is presented below.

Power balance for scenario2

```
                    POWER BALANCE EQUATION - MARGINAL COSTS

                              HYDRO          NET
                  FIXED  SECONDARY  THERMAL  ELECTRIC  PUMPING   TRANS          MARGINAL
 ELECTRIC  LOAD       POWER    POWER    POWER    POWER    POWER   PORTED    POWER   COST OF   VALUE OF
  NODE    STEP      DEMAND   DEMAND   OUTPUT   OUTPUT   CONSUMPT.  POWER   EXCESS   GENERATION GENERATION
                   MW      MW      MW      MW      MW      MW      MW    CTS/KWH    MILL.US$


 SYSTEM     1       2953.55     0.00  -1016.76  -1936.80     0.00     0.00    -0.008     22.075    228.458
            2     2625.44     0.00   -840.45  -1784.99     0.00     0.00    -0.006     21.900    554.049
            3     2234.75    33.35   -644.82  -1623.29     0.00     0.00    -0.009     21.673    775.119
            4     1949.21   111.40   -552.89  -1507.73     0.00     0.00    -0.012     20.656   1118.608
            5     1785.40   157.31   -502.62  -1440.12     0.00     0.00    -0.019     19.954   1256.433

      TOTAL (GWH)  17997.91    855.23  -5264.96 -13588.30     0.00     0.00    -0.116     20.859   3932.666
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Summary report of hydroelectric power plants for scenario2

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                         HYDROELECTRIC POWER PLANTS

                           SUMMARY REPORT


 HYDRO   AVERAGE   AVERAGE                          MARGINAL  VALUE     VALUE
 POWER    NET    ENERGETIC TURBINED    ENERGY   UTILIZATION VALUE OF   OF       OF      NET    UNITARY
 PLANT    HEAD     COEF.   VOLUME   GENERATION   FACTOR    WATER    WATER   GENERATION BENEFIT  BENEFIT
          M     KWH/M3   MILL.M3      GWH        %      CTS/M3  MILL.US$   MILL.US$  MILL.US$ US$/KW

PUWA      320.00    0.733    58.58     42.94     87.50    7.299     4.28      8.04     8.04   1434.12
MAI      121.60    0.295   256.61     75.69    100.00    0.181     0.46      9.75     9.75   1163.93

IKHUWA    605.00    1.467    91.66    134.51     98.07    5.409     4.96     21.46    21.46   1370.68
PILUWA    107.00    0.262    90.76     23.82    100.00    1.115     1.01      4.22     4.22   1559.74

UTAMOR    470.00    1.140  1873.49   2135.75     61.94    8.958   167.82    294.29   294.29    747.60
MAIWA     115.71    0.284   127.16     36.08    100.00    0.856     1.09      5.30     5.30   1291.79
MTAMOR     84.00    0.195  2515.91    489.81     86.99    1.750    44.02     81.51    81.51   1268.05
PHAWA     292.00    0.708    51.34     36.36    100.00    2.687     1.38      6.14     6.14   1490.48
KABE-A    111.40    0.255   642.66    164.00     99.85    0.539     3.46     24.22    24.22   1291.65
HEWA      212.00    0.486   178.28     86.58     95.88    2.099     3.74     13.09    13.09   1269.94


UTAMAK    800.00    1.962  1165.13   2285.95     63.43    8.918   103.91    317.79   317.79    772.49
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SIPRIN   150.00   0.344  130.97    45.00    100.00  0.780   1.02    6.13   6.13  1209.59


KHANI    940.00   2.153   70.48   151.76     91.56  6.841   4.82   18.79  18.79   993.14


KHIM-1   691.60   1.622  234.78   380.71     98.69  7.347  17.25   63.21  63.21  1435.28

U-BHOT   143.20   0.309  823.35   254.20     98.89  1.491  12.28   45.79  45.79  1560.59
CHAKU    124.50   0.289   43.33    12.50     96.57  0.987   0.43    1.75   1.75  1183.15
BARAMC   538.20   1.247   12.47    15.55     96.63  2.798   0.35    2.16   2.16  1175.97
SUNKOS   124.50   0.285   67.77    19.33    100.00  1.126   0.76    3.41   3.41  1582.17
SUNKON    32.10   0.074  992.62    73.85     93.40  0.878   8.71   14.66  14.66  1624.33


BALE-A    48.00   0.111  251.35    27.96     90.40  0.590   1.48    3.34   3.34   946.98
BALE-B    80.00   0.185  630.75   116.95    100.00  0.330   2.08   18.23  18.23  1403.38


INDRAW    60.00   0.144  282.06    40.59     98.77  0.779   2.20    6.70   6.70  1427.18


U-SANJ   156.00   0.357  176.95    63.24     54.89  2.811   4.97    8.49   8.49   645.61
L-SANJ   432.80   0.991  191.79   190.15    100.00  0.000   0.00   25.37  25.37  1183.79


CHILIM   354.50   0.783  216.30   169.46     97.89  5.257  11.37   30.61  30.61  1549.06
RASGAD   158.48   0.389 1796.73   698.32    100.00  1.908  34.28  112.03 112.03  1420.79

TRIS3A   132.00   0.302 1496.90   452.63    100.00  0.000   0.00   92.60  92.60  1951.23
TRIS2B    87.00   0.190 1495.03   283.93    100.00  0.000   0.00   58.08  58.08  2061.40
TRIS      56.75   0.130 1277.64   166.09    100.00  0.000   0.00   34.90  34.90  1916.10
DEVIGH    39.00   0.084 1222.06   102.76    100.00  0.000   0.00   22.54  22.54  1980.74


KULEK1   647.53   1.588  249.87   396.80     74.21 24.710  61.74   80.97  80.97  1326.40
KULEK2   313.60   0.693  326.41   226.21     90.06  6.113  19.95   44.15  44.15  1539.80
KULEK3   102.56   0.254  416.74   105.97     92.86  2.595  10.81   21.06  21.06  1616.31

BUDHIG   128.85   0.292 4974.84  1451.06     50.39  2.318 115.32  197.51 197.51   600.88


UMARSY   118.40   0.271  535.49   145.24     38.09  2.530  13.55   18.93  18.93   434.85
MMARSY    98.00   0.209 1858.73   387.82     88.82  2.076  38.58   68.93  68.93  1383.02
KHUDI    105.40   0.244  102.04    24.93     98.34  1.202   1.23    4.10   4.10  1416.46
LCHEPE   135.00   0.313  156.55    48.98     89.89  2.626   4.11    7.78   7.78  1250.24
MARSYG    87.10   0.214 2596.79   554.70    100.00  1.141  29.62  112.42 112.42  1792.93
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BIJAYP    65.40    0.152  104.68     15.87      85.31   0.644    0.67      1.97     1.97    928.32

MODI      66.96    0.155  547.82     85.02      69.33   1.431    7.84     12.75    12.75    910.92
LMODI     17.50    0.041  356.17     14.45     100.00   0.000    0.00      2.65     2.65   1662.21
KGANDA   136.80    0.313 3473.61   1088.54      90.59   3.445  119.66    194.32   194.32   1416.59

ANDHI    242.60    0.562  103.46     58.17      99.34   2.183    2.26     10.15    10.15   1518.04

JHIMRK   189.50    0.439  149.51     65.67      96.90   2.336    3.49     11.08    11.08   1432.61

CHAMEL    94.00    0.233  611.06    142.42      66.92   2.238   13.67     23.16    23.16    953.32


SYSTEM   346.18    0.388 35028.65 13588.30      73.84   2.514  880.66   2166.52  2166.52   1031.35
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Power balance equation for scenario5

```
                            HYDRO          NET
               FIXED  SECONDARY  THERMAL  ELECTRIC  PUMPING   TRANS          MARGINAL
 ELECTRIC  LOAD      POWER    POWER    POWER    POWER    POWER   PORTED    POWER   COST OF   VALUE OF
  NODE    STEP      DEMAND   DEMAND   OUTPUT   OUTPUT  CONSUMPT.  POWER   EXCESS  GENERATION GENERATION
                 MW       MW       MW       MW       MW       MW       MW     CTS/KWH   MILL.US$


 SYSTEM     1       2953.55    61.05   -267.65  -3015.52     0.00     0.00  -268.582     4.393    50.538
            2       2625.44    61.66   -241.78  -2838.01     0.00     0.00  -392.697     4.256   126.290
            3       2234.75    62.35   -202.74  -2627.47     0.00     0.00  -533.109     4.053   180.850
            4       1949.21    62.56   -167.63  -2472.74     0.00     0.00  -628.609     3.727   258.579
            5       1785.40    62.63   -150.06  -2370.89     0.00     0.00  -672.925     3.496   285.689

      TOTAL (GWH)  17997.91   546.50  -1573.36 -22117.24     0.00     0.00 -5146.189     3.807   901.946
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Water balance equation for scenario5

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WATER BALANCE EQUATION - WATER VALUES IN MILLION M3

                 UP     DOWN     UP          DOWN     UP     DOWN                      MARGINAL
         INITIAL  STREAM  STREAM   STREAM  TRIBU-   STREAM   STREAM   STREAM  EVAPOR.  MANDATORY  FINAL  VALUE OF VALUE OF
RESERVOIR  STORAGE  TURBINED  PUMPED  SPILLED   TARY  TURBINED  PUMPED  SPILLED   VOLUME   RELEASES  STORAGE  WATER    INFLOW
               VOLUME   VOLUME   VOLUME  INFLOW   VOLUME   VOLUME   VOLUME                      CTS/M3  MILL.US$

PUWA        1.00    0.00    0.00    0.00  240.60   -52.02    0.00  -188.53   0.000     0.00    1.00   0.501    1.205
MAI         1.00   52.02    0.00  188.53  465.89  -173.33    0.00  -523.43   0.000     0.00    1.00   0.004    0.027

IKHUWA      1.00    0.00    0.00    0.00  231.56   -90.10    0.00  -141.44   0.000     0.00    1.00   0.666    1.542
PILUWA      1.00   90.10    0.00  141.44  288.63   -93.98    0.00  -426.42   0.000     0.00    1.00   0.001    0.006

UTAMOR      1.00    0.00    0.00    0.00 3410.51 -1741.48    0.00 -1663.55   0.000     0.00    1.00   1.297   44.250
MAIWA       1.00    0.00    0.00    0.00  318.87  -113.24    0.00  -207.63   0.000     0.00    1.00   0.113    0.362
MTAMOR      1.00 1854.71    0.00 1871.17 3816.05 -2515.98    0.00 -5031.71   0.000     0.00    1.00   0.183   13.816
PHAWA       1.00    0.00    0.00    0.00  180.65   -48.68    0.00  -131.87   0.000     0.00    1.00   0.235    0.425
KABE-A      1.00   48.68    0.00  131.87 1592.80  -588.13    0.00 -1179.71   0.000     0.00    1.00   0.066    1.178
HEWA        1.00    0.00    0.00    0.00  394.50  -176.13    0.00  -220.17   0.000     0.00    1.00   0.368    1.453

UTAMAK      1.00    0.00    0.00    0.00 2683.42 -1177.75    0.00 -1500.32   0.000     0.00    1.00   1.688   45.302
SIPRIN      1.00    0.00    0.00    0.00  307.55  -123.04    0.00  -185.71   0.000     0.00    1.00   0.099    0.305

DUDHK     679.58    0.00    0.00    0.00 6629.19 -1882.82    0.00 -4725.26   0.000     0.00  686.90   0.477   31.599

KHIM-1      1.00    0.00    0.00    0.00 1002.90  -234.06    0.00  -768.95   0.000     0.00    1.00   0.509    5.103
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U-BHOT     1.00    0.00    0.00    0.00  2432.91  -717.49    0.00 -1711.34   0.000     0.00    1.00   0.151    3.663
CHAKU      1.00    0.00    0.00    0.00    68.49   -42.01    0.00   -26.93   0.000     0.00    1.00   0.156    0.107
BARAMC     1.00    0.00    0.00    0.00    17.13   -11.15    0.00    -6.14   0.000     0.00    1.00   0.503    0.086
SUNKOS     1.00    0.00    0.00    0.00   193.96   -53.31    0.00  -140.90   0.000     0.00    1.00   0.117    0.227
SUNKON     1.00  823.96    0.00 1885.32   485.00  -580.53    0.00 -2221.86   0.000     0.00    1.00   0.072    2.298

BALE-A     1.00    0.00    0.00    0.00   290.03  -242.71    0.00   -54.31   0.000     0.00    1.00   0.065    0.187
BALE-B     1.00  242.71    0.00   54.31  1600.98  -597.40    0.00 -1304.78   0.000     0.00    1.00   0.035    0.670

INDRAW     1.00    0.00    0.00    0.00   870.08  -284.57    0.00  -585.53   0.000     0.00    1.00   0.081    0.701

U-SANJ     1.00    0.00    0.00    0.00   285.55  -176.59    0.00  -110.21   0.000     0.00    1.00   0.418    1.195
L-SANJ     1.00  176.59    0.00  110.21   323.61  -190.44    0.00  -418.87   0.000     0.00    1.00   0.000    0.000
CHILIM     1.00  190.44    0.00  418.87   223.48  -214.17    0.00  -618.51   0.000     0.00    1.00   0.482    4.014
RASGAD     1.00    0.00    0.00    0.00  5234.26 -1761.19    0.00 -3476.82   0.000     0.00    1.00   0.206   10.780
TRIS3A     1.00 1975.36    0.00 4095.33  7204.24 -1483.88    0.00 -11786.6   0.000     0.00    1.00   0.000    0.000
TRIS2B     1.00 1483.88    0.00 11786.62 7259.74 -1460.69    0.00 -19073.6   0.000     0.00    1.00   0.000    0.000
TRIS       1.00 1460.69    0.00 19073.55 1970.39 -1257.28    0.00 -21253.6   0.000     0.00    1.00   0.000    0.000
DEVIGH     1.00 1257.28    0.00 21253.59 6582.46  -778.60    0.00 -27934.8   0.000     0.00    1.00   0.000    0.000

KULEK1    84.10    0.00    0.00    0.00   288.16  -204.38    0.00   -81.61   0.000     0.00   85.28   2.413    6.953
KULEK2     1.00  204.38    0.00   81.61   288.16  -298.21    0.00  -276.86   0.000     0.00    1.00   1.053    6.047
KULEK3     1.00  298.21    0.00  276.86   327.04  -340.12    0.00  -564.59   0.000     0.00    1.00   0.233    2.103

BUDHIG     3.26    0.00    0.00    0.00  7763.11 -4505.15    0.00 -3358.14   0.000     0.00    3.30   0.382   29.665

UMARSY     1.00    0.00    0.00    0.00   706.31  -526.21    0.00  -204.96   0.000     0.00    1.00   0.338    2.384
MMARSY     1.00  526.21    0.00  204.96  5516.77 -1899.43    0.00 -4320.67   0.000     0.00    1.00   0.227   14.176
KHUDI      1.00    0.00    0.00    0.00   262.65   -93.61    0.00  -169.50   0.000     0.00    1.00   0.130    0.341
LCHEPE     1.00    0.00    0.00    0.00   543.87  -147.05    0.00  -397.83   0.000     0.00    1.00   0.206    1.118
MARSYG     1.00 2140.08    0.00 4888.00  5534.67 -2650.46    0.00 -9913.54   0.000     0.00    1.00   0.064    8.084

TANA     290.63    0.00    0.00    0.00  3855.47 -1481.13    0.00 -2375.39   0.000     0.00  294.85   0.331   12.768

MODI       1.00    0.00    0.00    0.00  1373.92  -525.86    0.00  -852.33   0.000     0.00    1.00   0.157    2.160
LMODI      1.00  525.86    0.00  852.33  1487.01  -190.03    0.00 -2533.05   0.000     0.00    1.00   0.000    0.000
KGANDA     7.64  190.03    0.00 2533.05  9168.75 -3471.74    0.00 -8605.98   0.000     0.00    7.69   0.300   35.616

WEST     920.73    0.00    0.00    0.00  5885.39 -3947.79    0.00 -1809.08   0.000     0.00  925.36   2.990  175.999

JHIMRK     1.00    0.00    0.00    0.00   610.93  -133.55    0.00  -479.40   0.000     0.00    1.00   0.157    0.958

CHAMEL     7.64    0.00    0.00    0.00  1250.95  -574.90    0.00  -685.30   0.000     0.00    7.69   0.258    3.225


SYSTEM  2032.50 13541.20   0.00 69847.59 101468.6 -39852.4   0.00 -144248.   0.000     0.00 2050.08   0.255  472.098
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HYDROELECTRIC POWER PLANTS SUMMARY FOR SCENARIO5

HYDRO POWER PLANT	AVERAGE NET HEAD M	AVERAGE ENERGETIC COEF. KWH/M3	TURBINED VOLUME MILL.M3	ENERGY GENERATION GWH	UTILIZATION FACTOR %	MARGINAL VALUE OF WATER CTS/M3	VALUE OF WATER MILL.US$	VALUE OF GENERATION MILL.US$	NET BENEFIT MILL.US$	UNITARY BENEFIT US$/KW
PUWA	320.00	0.733	52.02	38.13	77.69	2.328	1.21	1.81	1.81	322.39
MAI	121.60	0.295	173.33	51.12	69.63	0.016	0.03	1.16	1.16	138.72
IKHUWA	605.00	1.467	90.10	132.21	96.40	1.704	1.54	4.23	4.23	270.27
PILUWA	107.00	0.262	93.98	24.66	100.00	0.006	0.01	1.03	1.03	381.72
UTAMOR	470.00	1.140	1741.48	1985.26	57.57	2.531	44.07	45.34	45.34	115.17
MAIWA	115.71	0.284	113.24	32.13	89.37	0.315	0.36	0.93	0.93	226.93
MTAMOR	84.00	0.195	2515.98	489.83	86.99	0.550	13.84	16.85	16.85	262.07
PHAWA	292.00	0.708	48.68	34.48	95.60	0.856	0.42	1.29	1.29	313.41
KABE-A	111.40	0.255	588.13	150.09	91.38	0.200	1.17	4.41	4.41	235.20
HEWA	212.00	0.486	176.13	85.54	94.73	0.820	1.44	2.55	2.55	246.97
UTAMAK	800.00	1.811	1177.75	2132.96	64.12	3.830	45.10	47.69	47.69	125.58
SIPRIN	150.00	0.344	123.04	42.28	95.18	0.242	0.30	0.93	0.93	183.52
DUDHK	245.38	0.595	1882.82	1120.60	47.69	2.700	50.83	66.75	66.75	248.82
KHIM-1	691.60	1.584	234.06	370.82	98.39	2.179	5.10	12.68	12.68	294.79
U-BHOT	143.20	0.309	717.49	221.52	86.18	0.510	3.66	10.02	10.02	341.43
CHAKU	124.50	0.289	42.01	12.12	93.63	0.236	0.10	0.27	0.27	179.36
BARAMC	538.20	1.247	11.15	13.90	86.39	0.784	0.09	0.31	0.31	166.70
SUNKOS	124.50	0.285	53.31	15.20	80.46	0.419	0.22	0.72	0.72	333.73
SUNKON	32.10	0.074	580.53	43.19	54.62	0.396	2.30	3.41	3.41	377.30
BALE-A	48.00	0.111	242.71	27.00	87.29	0.074	0.18	0.34	0.34	95.97
BALE-B	80.00	0.185	597.40	110.77	97.35	0.113	0.67	3.47	3.47	267.46
INDRAW	60.00	0.137	284.57	39.11	99.65	0.246	0.70	1.32	1.32	294.44
U-SANJ	156.00	0.357	176.59	63.11	54.78	0.672	1.19	1.19	1.19	90.85
L-SANJ	432.80	0.991	190.44	188.81	100.00	0.000	0.00	3.72	3.72	173.43
CHILIM	354.50	0.850	214.17	182.11	96.93	1.873	4.01	7.41	7.41	345.61
RASGAD	158.48	0.380	1761.19	669.47	99.10	0.612	10.77	21.62	21.62	280.38
TRIS3A	132.00	0.302	1483.88	448.70	100.00	0.000	0.00	21.66	21.66	456.37
TRIS2B	87.00	0.190	1460.69	277.41	100.00	0.000	0.00	13.47	13.47	478.04
TRIS	56.75	0.141	1257.28	176.91	100.00	0.000	0.00	8.79	8.79	445.72
DEVIGH	39.00	0.090	778.60	70.38	64.07	0.000	0.00	6.01	6.01	479.62
KULEK1	694.39	1.609	204.38	328.93	61.99	6.002	12.27	14.01	14.01	231.23
KULEK2	313.60	0.727	298.21	216.75	82.28	2.012	6.00	8.87	8.87	294.89
KULEK3	102.56	0.238	340.12	80.85	75.78	0.617	2.10	3.79	3.79	310.79

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BUDHIG    129.76    0.301  4505.15    1354.93      45.96   0.657    29.58     30.19    30.19     89.70

UMARSY    118.40    0.274   526.21     144.40      37.43   0.445     2.34      2.43     2.43     55.29
MMARSY     98.00    0.227  1899.43     431.43      82.68   0.748    14.20     16.57    16.57    278.17
KHUDI     105.40    0.244    93.61      22.87      90.22   0.365     0.34      0.82     0.82    281.92
LCHEPE    135.00    0.313   147.05      46.01      83.82   0.756     1.11      1.44     1.44    229.01
MARSYG     87.10    0.202  2650.46     535.05     100.00   0.305     8.08     24.81    24.81    411.58

TANA      108.13    0.262  1481.13     388.47      42.85   1.367    20.25     21.08    21.08    203.68

MODI       66.96    0.155   525.86      81.61      66.55   0.411     2.16      2.27     2.27    161.87
LMODI      17.50    0.041   190.03       7.71      55.23   0.000     0.00      0.61     0.61    381.47
KGANDA    136.80    0.317  3471.74    1100.76      90.54   1.028    35.69     43.51    43.51    313.53

WEST      829.61    2.012  3947.79    7943.77      42.99   5.748   226.92    227.58   227.58    107.89

JHIMRK    189.50    0.439   133.55      58.66      86.56   0.719     0.96      2.27     2.27    293.79

CHAMEL     94.00    0.218   574.90     125.25      62.96   0.569     3.27      3.87     3.87    170.33


SYSTEM    505.91    0.555 39852.36   22117.24      55.62   1.392   554.58    715.47   715.47    157.60
```

5.3 WASP DATABASE

5.3.1 LOADSY data file

The LOADSY data file for scenario 1, 2, 3, 5 and 6 is same. For scenario 4, the load data contains forecasted load according to the change in GDP. The data until 2020 is taken from a study made by WECS, and the data for 2020-2030 is prepared by extrapolation. LOADSY for medium term in scenario 7 is same as scenario 1. For short term in scenario 7, the load data of 2011-2020 is taken from scenario1. For long term expansion plan in scenario 7, the load data of 2011-2030 is same as scenario 1, while the load is extrapolated for 2031-2035 from the trend of 2011-2030 periods.

Table 5-6: Load (MW) due to the change in GDP

Year	GDP5.5%	GDP7.5%	GDP10%
2011	949	958	978
2012	1036	1059	1109
2013	1140	1185	1278
2014	1249	1531	1685
2015	1368	1703	2033
2016	1498	1895	2430
2017	1640	2110	2997
2018	1784	2336	3595
2019	1942	2589	4254
2020	2112	2882	4990
2021	2320	3492	5800
2022	2535	3716	6600
2023	2771	3940	7400
2024	3029	4164	8200
2025	3311	4388	9000
2026	3619	4611	9800
2027	3956	5059	11000
2028	4325	5283	12200
2029	4727	5507	13800
2030	5167	5730	15000

5.3.2 FIXSYS and VARSYS data file

The output of VWASP is opened in EXCEL and the output of each hydro plant is prepared in separate sheets. Running the program written in MATLAB, FIXSYS and VARSYS data files are prepared. For scenarios 1, 2, 4, 5, 6 and 7, twelve periods are considered, whereas for scenario3, FIXSYS and VARSYS are prepared for dry period and wet period separately.

Sample of VARSYS data for scenario5

```
BARA  HYD1    4    0  2015
 0.6  0.6  0.8  0.6  0.6  0.8  0.5  0.5  0.8
 0.6  0.5  0.8  0.5  0.4  0.8  0.5  0.4  0.8
 0.3  0.3  0.4  0.3  0.3  0.4  0.3  0.3  0.4
 0.6  0.6  0.8  0.6  0.6  0.8  0.6  0.6  0.8
 0.8  0.8  1.2  0.8  0.8  1.3  0.8  0.7  1.2
 1.1  1.1  1.7  1.3  1.2  1.8  1.3  1.3  1.9
 2.4  2.4  3.3  1.9  1.8  2.5  2.6  2.6  3.5
```

```
2.8  2.8  3.8  2.8  2.8  3.8  2.7  2.6  3.6
1.9  1.9  2.7  1.8  1.7  2.5  1.8  1.8  2.6
0.9  0.9  1.3  1.6  1.5  2.2  1.6  1.6  2.2
0.7  0.6  1.3  0.9  0.9  1.3  0.8  0.8  1.3
0.6  0.6  0.8  0.6  0.5  0.8  0.6  0.6  0.8
KUL3  HYD1    14     0  2015
3.2  3.0  4.8  5.3  5.1  7.5  5.8  5.6  8.1
3.8  3.7  6.2  5.0  4.9  7.8  4.7  4.7  7.5
6.3  6.1  8.6  7.0  6.8  9.6  7.5  7.3 10.3
7.1  7.0 10.2  8.3  8.2 11.8  8.7  8.5 12.2
6.3  6.0  8.8  6.3  6.2  9.3  8.0  7.8 11.1
6.8  6.8  9.7  8.8  8.7 12.2  7.5  7.5 10.8
9.7  9.5 13.0  9.7  9.5 13.0  9.7  9.5 13.0
9.7  9.5 13.0  9.7  9.5 13.0  9.7  9.5 13.0
4.2  4.2  5.9  3.8  3.8  5.3  3.9  3.8  5.5
4.3  4.2  6.3  5.5  5.4  7.4  5.3  5.2  7.3
4.8  4.7  7.6  3.7  3.5  6.4  5.4  5.3  8.3
7.6  7.4 10.3  6.1  6.0  8.5  6.9  6.8  9.5
```

Sample of dry period FIXSYS data

```
PUWA  HYD1     6     0
2.8  2.6  5.2  3.4  3.3  5.6  3.3  3.1  5.5
2.0  1.8  4.5  2.8  2.7  5.2  2.5  2.3  4.9
2.2  1.9  4.3  3.1  2.9  5.0  2.6  2.2  4.6
2.6  2.4  4.9  3.5  3.4  5.6  3.0  2.9  5.2
 2
 MAI  HYD1    19     0
2.3  2.2  3.0  2.3  2.2  3.0  2.3  2.2  3.0
1.7  1.6  2.5  1.7  1.6  2.5  1.7  1.6  2.5
1.8  1.8  2.4  1.8  1.8  2.4  1.8  1.8  2.4
2.0  1.9  2.7  2.0  1.9  2.7  2.0  1.9  2.7
```

Sample of wet period FIXSYS data

```
 PUWA  HYD1     6     0
 3.8  3.6  5.7  4.1  4.0  5.8  4.3  4.2  6.0
 4.5  4.5  6.3  4.5  4.5  6.3  4.5  4.4  6.3
 4.7  4.6  6.3  4.7  4.6  6.3  4.7  4.6  6.3
 4.7  4.6  6.3  4.7  4.6  6.3  4.7  4.6  6.3
 2.7  2.7  3.8  2.7  2.7  3.8  1.9  1.5  3.8
 2.8  2.8  3.8  2.8  2.8  3.8  2.8  2.8  3.8
 4.4  4.4  6.3  4.5  4.5  6.3  4.4  4.4  6.3
 4.1  3.9  6.2  3.7  3.5  5.8  3.7  3.5  5.8
  2
  MAI  HYD1    19     0
 3.3  3.3  4.5  3.3  3.1  4.5  3.3  3.2  4.5
 9.7  9.1 15.3 10.9 10.7 16.1 10.6 10.4 15.5
12.0 11.8 16.1 12.0 11.8 16.1 12.0 11.8 16.1
12.0 11.8 16.1 12.0 11.8 16.1 12.0 11.8 16.1
11.6 11.6 16.1 11.6 11.6 16.1 11.6 11.6 16.1
11.1 10.3 16.1 12.0 11.8 16.1 11.5 11.1 15.9
 4.4  4.3  6.0  4.4  4.3  6.0  4.4  4.3  6.0
 2.7  2.6  3.6  2.7  2.6  3.6  2.7  2.6  3.6
```

Database for optimization

CONGEN, DYNPRO and MERSIM database are same for all scenarios except scenario 5, 6 and 7 (short and long term).

CONGEN data for scenario5

```
     Demonstration Case (Variable Expansion)            0
 4
    -30       30
 8
 1
 2
 0   0   0   0   0
```

```
3
0  0  0  0  0
1        (END OF YEAR  2011)
2
0  0  0  0  0
3
0  0  0  0  0
1        (END OF YEAR  2012)
2
0  0  0  0  0
3
0  0  0  0  0
1        (END OF YEAR  2013)
2
0  0  0  0  0
3
0  0  0  0  0
1        (END OF YEAR  2014)
2
0  0  0  4  0
3
1  1  1  2  0
1        (END OF YEAR  2015)
2
0  0  0  0  0
3
1  1  1  6  1
1        (END OF YEAR  2016)
2
1  1  1  8  2
3
1  1  1  2  1
1        (END OF YEAR  2017)
2
1  1  1 11   3
3
1  1  1  2  1
1        (END OF YEAR  2018)
2
1  1  1 13   4
3
1  1  1  1  1
1        (END OF YEAR  2019)
2
1  1  1 15   6
3
1  1  1  0  0
1        (END OF YEAR  2020)
2
1  1  1 15   6
3
1  1  1  0  0
1        (END OF YEAR  2021)
2
1  1  1 15   7
3
1  1  1  0  0
1        (END OF YEAR  2022)
2
1  1  1 15   7
3
1  1  1  0  0
1        (END OF YEAR  2023)
2
1  1  1 15   7
3
1  1  1  0  0
1        (END OF YEAR  2024)
2
1  1  1 15   8
3
1  1  1  0  0
1        (END OF YEAR  2025)
2
1  1  1 15   8
```

```
3
1   1   1   0   0
1         (END OF YEAR  2026)
2
2   2   2  15   9
3
0   0   0   0   0
1         (END OF YEAR  2027)
2
2   2   2  15  10
3
0   0   0   0   0
1         (END OF YEAR  2028)
2
2   2   2  15  10
3
0   0   0   0   0
1         (END OF YEAR  2029)
2
2   2   2  15  10
3
0   0   0   0   0
1         (END OF YEAR  2030)
```

5.4 LRMC COMPUTATION FROM WASP OUTPUT

The output of DYNPRO optimization module provides the optimized costs for each year. An increase of load by 50MW is applied in each scenario for computing LRMC.

E1: Generated energy for base case
E2: Generated energy for perturbation case
NPV1: Net present value for base case
NPV2: Net present value for perturbation case

Table 5-7: LRMC computation for scenario2

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2030	22270.6	22538.6	143953	150584
2029	20970.4	21238.3	148784	155906
2028	19716.9	19984.8	133646	139582
2027	18322.4	18590.4	155892	149454
2026	17024.4	17292.4	119191	135811
2025	15815.4	16083.4	107041	111793
2024	14690	14957.9	98830	102938
2023	13641.2	13909.2	665682	669581
2022	12663.7	12931.6	96485	101259
2021	11822.3	12090.3	91043	95636
2020	10997	11264.9	219447	225135
2019	10219.4	10487.3	119669	125931
2018	9486.8	9754.7	242407	248426
2017	8793.3	9061.3	622508	629321
2016	8092.3	8360.3	149422	162874
2015	7434.2	7702.2	283048	296491
2014	6815.2	7083.2	188213	221132
2013	6233.8	6501.7	143954	170699
2012	5664.1	5932.1	108682	130072
2011	5182.8	5450.8	86919	103561
			LRMC	**3.8Cts/KWh**

Table 5-8: LRMC computation for scenario3 (dry period)

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2030	22727	23000.5	586341	608097
2029	21400.2	21673.6	540886	563002
2028	20121	20394.4	489011	510518
2027	18697.9	18971.4	437521	457576
2026	17373.3	17646.8	378077	396811
2025	16139.5	16413	333236	350116

2024	14991.1	15264.5	298140	313049
2023	13920.8	14194.2	863165	875957
2022	12923.2	13196.7	278598	289877
2021	12064.6	12338	356202	366428
2020	11222.4	11495.8	387914	398515
2019	10428.8	10702.3	303804	315872
2018	9681.2	9954.7	428925	440122
2017	8973.5	9247	644307	655522
2016	8258.2	8531.6	391332	413592
2015	7586.6	7860	603148	623501
2014	6954.9	7228.4	896313	999986
2013	6361.5	6635	748426	855041
2012	5780.2	6053.6	613676	705151
2011	5289.1	5562.5	522367	603642
			LRMC	**11.7 Cts/KWh**

Table 5-9: LRMC computation for scenario3 (wet period)

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2030	21780.1	22042.1	163493	169908
2029	20508.5	20770.5	172461	179778
2028	19282.6	19544.6	156628	163069
2027	17918.8	18180.9	167436	172760
2026	16649.4	16911.5	154146	160073
2025	15467.1	15729.1	130147	135751
2024	14366.4	14628.5	119785	124928
2023	13340.7	13602.8	683380	688735
2022	12384.8	12646.8	123783	129858
2021	11561.9	11824	115748	122174
2020	10754.8	11016.8	239410	247387
2019	9994.3	10256.3	139790	148270
2018	9277.8	9539.9	228088	146888
2017	8599.6	8861.7	674677	768613
2016	7914.1	8176.1	196495	211340
2015	7270.5	7532.5	332567	346752
2014	6665.1	6927.2	299151	343945
2013	6096.5	6358.5	235812	276378
2012	5539.3	5801.4	181980	215145
2011	5068.7	5330.7	151513	176341
			LRMC	**5.0 Cts/KWh**

Table 5-10: LRMC computation for scenario4 (5.5% GDP)

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2030	27690.8	27958.7	335113	347672
2029	25332.7	25600.7	306133	318768
2028	23178.4	23446.3	239407	250110
2027	21200.8	21468.8	199689	208677
2026	19394.8	19662.8	178793	171003
2025	17744.2	18012.1	167815	188973
2024	16232.9	16500.8	125852	131739
2023	14850.2	15118.2	683934	688584
2022	13585.5	13853.4	114007	119924
2021	12433.2	12701.2	146349	151415
2020	11318.5	11586.5	175336	180297
2019	10407.5	10675.4	123711	124283
2018	9560.7	9828.7	243814	249870
2017	8789	9057	622169	628931
2016	8028	8296	152418	165877
2015	7331.3	7599.3	284385	297770
2014	6693.6	6961.5	185546	218147
2013	6109.4	6377.4	142087	168098
2012	5552.1	5820	108064	129570
2011	5085.8	5353.8	86155	103645
			LRMC	**4.2 Cts/KWh**

Table 5-11:LRMC computation for scenario4 (7.5% GDP)

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2030	30708	30975.9	488743	503554
2029	29512.9	29780.8	540578	558083
2028	28312.4	28580.4	512180	530028
2027	27112	27379.9	491326	509333
2026	24711.1	24979	392375	408852
2025	23516	23783.9	357226	373006
2024	22315.5	22583.5	322579	337333
2023	21115.1	21383	861967	875724
2022	19914.6	20182.6	317809	331925
2021	18714.2	18982.1	379736	353233
2020	15445.1	15713	277347	326507
2019	13874.9	14142.8	260169	269631
2018	12519	12787	223615	201855
2017	11307.8	11575.8	613635	652135

2016	10155.6	10423.6	351682	367778
2015	9126.6	9394.6	463119	480355
2014	8204.9	8472.8	424610	483514
2013	6350.6	6618.6	165323	194952
2012	5675.3	5943.3	117557	140509
2011	5134.1	5402	89096	107155
			LRMC	**6.6 Cts/KWh**

Table 5-12: LRMC computation for scenario4 (10% GDP)

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2030	80387.4	80655.3	4588104	4611080
2029	73956.4	74224.3	4624146	4649420
2028	65381.7	65649.7	4196886	4224686
2027	58950.7	59218.7	3894178	3924764
2026	52519.7	52787.7	3524456	3558088
2025	48232.4	48500.4	3284856	3321868
2024	43945.1	44213.1	2962145	3002847
2023	39657.8	39925.7	2541998	2586749
2022	35370.4	35638.4	2697662	2744961
2021	31083.1	31351.1	1664521	1713044
2020	26742.2	27010.2	1161738	1201328
2019	22797.9	23065.8	796118	826986
2018	19266.2	19534.1	534560	555872
2017	16061.4	16329.4	917058	930923
2016	13022.8	13290.7	569630	603905
2015	10895.2	11163.1	683172	704938
2014	9030.2	9298.1	622128	696669
2013	6849	7117	224304	262757
2012	5943.3	6211.3	140509	166648
2011	5241.3	5509.2	95964	115404
			LRMC	**12.7 Cts/KWh**

Table 5-13: LRMC computation for scenario5

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2030	22270.6	22538.6	72144	73888
2029	20970.4	21238.3	62321	64267
2028	19716.9	19984.8	67173	69158
2027	18322.4	18590.4	83265	85373
2026	17024.4	17292.4	269164	271388

2025	15815.4	16083.4	178362	182992
2024	14690	14957.9	102680	107642
2023	13641.2	13909.2	667281	671665
2022	12663.7	12931.6	241521	247024
2021	11822.3	12090.3	99763	105354
2020	10997	11264.9	186913	192159
2019	10219.4	10487.3	160235	160207
2018	9486.8	9754.7	232063	239077
2017	8793.3	9061.3	655156	662341
2016	8092.3	8360.3	166617	181305
2015	7434.2	7702.2	267524	281733
2014	6815.2	7083.2	211457	246068
2013	6233.8	6501.7	163610	193261
2012	5664.1	5932.1	123511	148127
2011	5182.8	5450.8	96844	117039
			LRMC	**3.6 Cts/KWh**

Table 5-14: LRMC computation for scenario6

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2030	22270.6	22538.6	56895	58686
2029	20970.4	21238.3	48896	50785
2028	19716.9	19984.8	41293	43126
2027	18322.4	18590.4	35473	37323
2026	17024.4	17292.4	28885	30488
2025	15815.4	16083.4	387787	388554
2024	14690	14957.9	198328	204985
2023	13641.2	13909.2	798926	806549
2022	12663.7	12931.6	119565	128994
2021	11822.3	12090.3	128037	136181
2020	10997	11264.9	197944	205269
2019	10219.4	10487.3	195170	202535
2018	9486.8	9754.7	160299	167819
2017	8793.3	9061.3	560235	567592
2016	8092.3	8360.3	224769	244248
2015	7434.2	7702.2	276481	293999
2014	6815.2	7083.2	214689	249760
2013	6233.8	6501.7	166207	196271
2012	5664.1	5932.1	126051	150701
2011	5182.8	5450.8	99191	119706
			LRMC	**4.1 Cts/KWh**

Table 5-15: LRMC computation for scenario7 (short term)

E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
10997	11264.9	146860	151077
10219.4	10487.3	103798	110535
9486.8	9754.7	145074	120105
8793.3	9061.3	325729	364496
8092.3	8360.3	174565	188213
7434.2	7702.2	222442	236202
6815.2	7083.2	203109	236990
6233.8	6501.7	156958	185234
5664.1	5932.1	119607	142657
5182.8	5450.8	94836	113968
		LRMC	**5.84 Cts/KWh**

Table 5-16: LRMC computation for scenario7 (long term)

Year	E1(Gwh)	E2(Gwh)	NPV1 (K$)	NPV2 (K$)
2035	29475.4	29743.3	24693	25674
2034	28403.5	28671.5	23661	24408
2033	26527.8	26795.8	21645	22156
2032	25188	25456	21410	21850
2031	23580.5	23848.3	134747	134977
2030	22270.6	22538.6	90228	90903
2029	20970.4	21238.3	38584	39271
2028	19716.9	19984.8	279404	279976
2027	18322.4	18590.4	56712	60280
2026	17024.4	17292.4	45649	48408
2025	15815.4	16083.4	39189	41339
2024	14690	14957.9	321785	323392
2023	13641.2	13909.2	1134758	1138749
2022	12663.7	12931.6	122145	131801
2021	11822.3	12090.3	105949	114222
2020	10997	11264.9	206321	213302
2019	10219.4	10487.3	261614	268927
2018	9486.8	9754.7	167879	175605
2017	8793.3	9061.3	610721	618082
2016	8092.3	8360.3	230148	249581
2015	7434.2	7702.2	288908	306333
2014	6815.2	7083.2	213299	248242
2013	6233.8	6501.7	165132	195016
2012	5664.1	5932.1	125281	149671
2011	5182.8	5450.8	98780	119076

			LRMC	**3.17 Cts/KWh**

Table 5-17: LRMC comparison

Scenario	**Case**	**LRMC (Cts/Kwh)**
1	Basic	3.9
2	Export	3.8
3	Dry	11.7
	Wet	5.0
4	5.5%GDP	4.2
	7.5%GDP	6.6
	10%GDP	12.7
5	Additional Storage projects to scenario1	3.6
6	Major projects (without thermal addition)	4.1
7	Time horizon	
	Long	3.2
	Medium	3.9
	Short	5.8

Table 5-18: Average LOLP comparison

Scenario	Case	LOLP (%)
1	Basic	4.28
2	Export	4.20
3	Dry	33.53
	Wet	5.63
4	5.5%GDP	9.00
	7.5%GDP	20.0
	10%GDP	60.1
5	Additional Storage projects to scenario1	2.91
6	Major projects (no thermal addition)	4.65
7	Time horizon	
	Long	3.5
	Medium	4.3
	Short	4.4

VALORAGUA-WASP models simulate combined hydro-thermal system. Therefore, the model cannot be executed without thermal component. In hydro system, ROR, PROR and storage plants are considered. All scenarios except scenario 5 and 6 include 2 storage plants. Scenario 5 includes 5 storage plants and scenario 6 includes 6 storage plants.

The following is the result of comparative analysis of various scenarios.
LRMC for export option is slightly less than basic case. In this case, there should be excess energy for export. LRMC for dry season is higher than wet season due to the low generation of power. LRMC increases with the increase of GDP due to increment of load. LRMC with more storage projects and long time horizon is less. The result of LOLP is also in agreement with the result of LRMC. The result shows that hydro system with the combination of simple run off river, peaking run off river, and storage hydropower plants will be the best option for Nepalese context.

Appendix -6

Sensitivity Analysis

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6. SENSITIVITY ANALYSIS

Sensitivity analysis refers to the change in the output of model due to change in parameter. In power optimization study using VALORAGUA-WASP, some parameters are estimated using available data whereas some parameters are assigned from the prevailing conditions. In this study, following case studies are performed as a part of sensitivity analysis:

1. Hydro plants with Thermal and without export, design flow for existing plant and Q25 for expansion candidates
2. Hydro plants with Thermal and without export, design flow for existing plant and Q30 for expansion candidates
3. Hydro plants with Thermal and without export, design flow for existing plant and Q40 for expansion candidates
4. Hydro plants with Thermal and without export, design flow for existing plant and Q50 for expansion candidates
5. Hydro plants with Thermal and without export, design flow for existing plant and Q60 for expansion candidates
6. Hydro plants with Thermal and without export, design flow for all plants, unserved energy cost: 30 cents/kwh, 55 cents/kwh, 80 cents/kwh and 1 USD/Kwh

6.1 VALORAGUA database

Table 6-1:Cases 1-5, nominal discharge data to be used in CADIR

Existing plants	Design discharge (m^3/s)	Under construction/to be constructed plants	Q25 (m^3/s)	Q30 (m^3/s)	Q40 (m^3/s)	Q50 (m^3/s)	Q60 (m^3/s)
PUWA	2.5	KHANI	4.95	3.75	2.56	1.39	1.12
MAI	16	BARAMCHI	0.77	0.63	0.45	0.29	0.23
PILUWA	3.5	KULEKHANI-3	15.94	10.65	6.88	5.11	3.84
SIPRIN	7.5	LOWER MODI	58.45	44.65	29.48	17.94	15.13
KHIMTI-1	10.8	CHAMELIYA	49.59	36.69	28.53	20.49	16.67
UPPER BHOTEKOSHI	36.8	HEWA	18.82	16.78	13.42	9.38	7.12
CHAKU	2.7	PHAWA	8.42	6.76	4.46	2.80	2.02
SUNKOSHI SMALL	2.7	BALEPHI-A	11.94	9.13	7.14	3.83	3.20
SUNKOSHI	40	UPPER SANJEN	12.96	10.17	6.71	4.20	3.07
INDRAWATI	15	IKHUWA	12.07	10.17	7.27	4.63	3.31
CHILIME	8.3	KABELI-A	74.23	59.61	39.28	24.64	37.73
TRISHULI	45.3	LOWER CHEPE	23.47	17.64	13.76	7.82	6.26
DEVIGHAT	45.3	MAIWA	14.86	11.94	7.87	4.93	3.57
KULEKHANI-1	12.1	LOWER SANJEN	14.69	11.53	7.61	4.77	3.48
KULEKHANI-2	13.5	BALEPHI-B	65.89	50.42	39.39	21.15	17.66
MIDDLE MARSYANGDI	80	TRISHULI3B	329.5	258.71	170.72	106.92	78.12
KHUDI	4.6	UPPER MARSYANGDI	30.48	22.91	17.87	10.15	8.13
MARSYANGDI	91.5	UPPER TAMAKOSHI	113.69	86.07	58.87	31.93	25.80
BIJAYPUR	8.3	RASUWAGADHI	237.59	186.53	123.09	77.09	56.32

MODI	27.5	UPPER TAMOR	158.93	127.64	84.11	52.77	38.20
KALI GANDAKI	134	MIDDLE TAMOR	177.83	142.82	94.11	59.05	42.73
ANDHI	4.9	TRISHULI2A	327	256.73	169.41	106.11	77.52
JHIMRUK	36	BUDHI GANDAKI	372.23	300.20	197.60	130.02	91.65

For cases 1-5, change is made in hydropower plants data part of CADIR file for expansion candidate (second last column of first part of data for nominal flow and monthly maximum flow of respective stations in second part).

<u>Sample of hydropower plant data of CADIR file for case 1</u>

```
                    ********** HYDRO POWER PLANTS *********
46
  PUWA   1    2  0 116.00 0.01   0.85   0.05   0.00 320.00   2.50 480.00
   MAI   2    0  0 1 8.89 0.01   0.90   0.05   0.00 121.60  16.00 195.00
IKHUWA   3    0  0 110.00 0.01   0.90   0.05   0.00 605.00  10.17 900.00
PILUWA   4    0  0 1 5.50 0.01   0.91   0.05   0.00 107.00   3.50 650.00
UTAMOR   5    7  0 120.00 0.01   0.90   0.05   0.00 470.00 127.64 700.00
 MAIWA   6    7  0 110.81 0.01   0.91   0.05   0.00 190.09  11.94 609.62
MTAMOR   7    0  0 1 7.50 0.01   0.86   0.05   0.00  84.00 142.82 600.00
 PHAWA   8    9  0 114.00 0.01   0.90   0.05   0.00 292.00   6.76 600.00
KABE-A   9    0  0 1 5.40 0.01   0.85   0.05   0.00 111.40  59.61 445.00
HEWA  10    0  0 1 5.50 0.01   0.85   0.05   0.00 212.00  16.78 650.00
UTAMAK  11    0  0 122.00 0.01   0.91   0.05   0.00 800.00  86.071206.50
SIPRIN  12    0  0 110.00 0.01   0.85   0.05   0.00 150.00   7.50 900.00
KHANI  13    0  0 123.00 0.01   0.85   0.05   0.00 940.00   3.751136.00
KHIM-1  14    0  0 134.60 0.01   0.87   0.05   0.00 691.60  10.75 579.00
U-BHOT  15   19  0 1 7.20 0.01   0.80   0.05   0.00 143.20  36.80 700.00
CHAKU  16   19  0 1 7.50 0.01   0.86   0.05   0.00 124.50   2.70 650.00
BARAMC  17   19  0 125.00 0.01   0.86   0.05   0.00 545.00   0.63 525.30
SUNKOS  18   19  0 1 9.50 0.01   0.85   0.05   0.00 124.50   2.70 601.00
SUNKON  19    0  0 1 1.60 0.01   0.86   0.05   0.00  32.10  40.00 500.00
BALE-A  20   21  0 1 2.00 0.01   0.86   0.05   0.00  48.00   9.13 460.00
BALE-B  21    0  0 1 5.00 0.01   0.86   0.05   0.00  80.00  50.42 350.00
INDRAW  22    0  0 1 5.00 0.01   0.89   0.05   0.00  60.00  15.00 900.00
U-SANJ  23   24  0 1 5.30 0.01   0.85   0.05   0.00 156.00  10.172180.00
L-SANJ  24   25  0 1 9.20 0.01   0.85   0.05   0.00 432.80  11.531730.00
CHILIM  25   27  0 117.70 0.01   0.82   0.05   0.00 354.50   8.251136.00
RASGAD  26   27  0 1 9.42 0.01   0.91   0.05   0.00 158.48 186.531130.00
TRIS3A  27   28  0 112.50 0.01   0.85   0.05   0.00 132.00 256.73 720.00
TRIS2B  28   29  0 113.24 0.01   0.81   0.05   0.00  87.00 258.71 454.00
TRIS  29   30  0 1 2.80 0.01   0.85   0.05   0.00  56.75  45.30 147.05
DEVIGH  30    0  0 1 1.50 0.01   0.80   0.05   0.00  41.10  45.30 105.20
KULEK1  31   32  0 129.00 0.01   0.91   0.05   0.00 589.00  12.10 916.00
KULEK2  32   33  0 115.60 0.01   0.82   0.05   0.00 313.60  13.50 601.00
KULEK3  33    0  0 1 7.24 0.01   0.92   0.05   0.00 102.56  10.65 475.00
BUDHIG  34    0  0 112.00 0.01   0.84   0.05   0.00 185.00 430.00 312.00
UMARSY  35   36  0 1 4.80 0.01   0.85   0.05   0.00 118.40  22.91 650.00
MMARSY  36   39  0 1 4.50 0.01   0.79   0.05   0.00 120.00  80.00 525.30
KHUDI  37   39  0 110.00 0.01   0.86   0.05   0.00 105.40   4.55 550.00
LCHEPE  38   39  0 110.00 0.01   0.86   0.05   0.00 140.00  17.64 735.00
MARSYG  39    0  0 1 4.40 0.01   0.91   0.05   0.00  90.50  91.50 242.50
BIJAYP  40    0  0 1 2.60 0.01   0.86   0.05   0.00  65.40   8.30 890.00
MODI  41   42  0 1 3.04 0.01   0.86   0.05   0.00  66.96  27.50 800.00
LMODI  42   43  0 1 3.70 0.01   0.86   0.05   0.00  84.30  44.65 600.00
KGANDA  43    0  0 1 6.80 0.01   0.85   0.05   0.00 136.80 134.00 530.00
ANDHI  44    0  0 112.50 0.01   0.86   0.05   0.00 242.60   4.90 843.00
JHIMRK  45    0  0 1 9.50 0.01   0.86   0.05   0.00 189.50   8.00 550.00
CHAMEL  46    0  0 1 9.70 0.01   0.92   0.05   0.00  94.00  36.69 784.30
```

```
  PUWA  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5  2.5
  PUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
MAI  3.0  2.5  2.4  2.7  4.5 16.0 16.0 16.0 16.0 16.0  6.0  3.6
   MAI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
IKHUWA  2.0  1.7  1.5  2.0  4.0  4.0 10.2 10.2 10.2 10.2  4.0  2.6
IKHUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
PILUWA  2.8  2.1  1.9  2.8  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
PILUWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
UTAMOR127.6127.6127.6127.6127.6127.6127.6127.6127.6127.6127.6127.6
UTAMOR  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MAIWA  2.2  1.8  1.9  2.6  5.2 11.9 11.9 11.9 11.9 11.9  4.5  2.9
 MAIWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MTAMOR142.8142.8142.8142.8142.8142.8142.8142.8142.8142.8142.8142.8
MTAMOR  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 PHAWA  1.2  1.0  1.1  1.5  2.1  2.1  6.8  6.8  6.8  6.8  2.1  1.6
 PHAWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KABE-A 11.0  9.2  9.3 13.2 26.0 59.6 59.6 59.6 59.6 59.6 22.4 14.2
KABE-A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
HEWA  3.8  3.0  2.6  4.0  8.1  8.1 16.8 16.8 16.8 16.8  8.1  5.6
  HEWA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
UTAMAK 86.1 86.1 86.1 86.1 86.1 86.1 86.1 86.1 86.1 86.1 86.1 86.1
UTAMAK  0.1  0.1  0.1  0.1  0.0  0.0  0.0  0.0  0.0  0.0  0.1  0.1
SIPRIN  1.8  1.6  1.5  1.8  3.2  7.5  7.5  7.5  7.5  7.5  4.0  2.6
SIPRIN  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 KHANI  0.7  0.6  0.6  0.7  1.2  3.7  3.7  3.7  3.7  3.7  2.0  1.0
 KHANI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KHIM-1  6.1  5.1  5.0  5.3  9.0 10.8 10.8 10.8 10.8 10.8 10.8  8.3
KHIM-1  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.1  0.1  0.1  0.1  0.1
U-BHOT 23.0 21.0 21.0 24.0 36.8 36.8 36.8 36.8 36.8 36.8 36.8 27.0
U-BHOT  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
 CHAKU  0.6  0.6  0.6  0.7  1.2  2.2  2.7  2.7  2.7  2.7  1.1  0.8
 CHAKU  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BARAMC  0.2  0.2  0.1  0.2  0.3  0.5  0.6  0.6  0.6  0.6  0.3  0.2
BARAMC  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
SUNKOS  1.8  1.6  1.7  1.9  2.7  2.7  2.7  2.7  2.7  2.7  2.7  2.2
SUNKOS  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
SUNKON 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0 40.0
SUNKON  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
BALE-A  2.3  2.0  2.0  2.2  3.2  9.1  9.1  9.1  9.1  9.1  5.0  3.0
BALE-A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BALE-B 12.7 11.1 10.7 12.1 18.0 50.4 50.4 50.4 50.4 50.4 24.0 17.0
BALE-B  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
INDRAW  7.0  6.0  6.0  6.6 10.0 15.0 15.0 15.0 15.0 15.0 13.1  9.1
INDRAW  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
U-SANJ 10.2 10.2 10.2 10.2 10.2 10.2 10.2 10.2 10.2 10.2 10.2 10.2
U-SANJ  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
L-SANJ  2.3  2.0  2.0  2.6  5.1 11.5 11.5 11.5 11.5  9.0  4.2  3.0
L-SANJ  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
CHILIM  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3  8.3
CHILIM  0.0  0.0  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
RASGAD 37.0 33.0 33.0 42.0 80.0186.5186.5186.5186.5186.5 69.0 47.0
RASGAD  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
TRIS3A 51.0 45.0 45.0 51.0 51.0256.7256.7256.7256.7256.7 51.0 51.0
TRIS3A  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
TRIS2B 51.0 45.0 45.0 51.0 51.0258.7258.7258.7258.7258.7 51.0 51.0
TRIS2B  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  TRIS 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3
  TRIS  0.1  0.1  0.0  0.0  0.0  0.0  0.0  0.1  0.1  0.1  0.1  0.1
DEVIGH 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3 45.3
DEVIGH  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
KULEK1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1 12.1
KULEK1  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KULEK2 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5 13.5
KULEK2  0.4  0.4  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KULEK3 10.6 10.6 10.6 10.6 10.6 10.6 10.6 10.6 10.6 10.6 10.6 10.6
```

```
KULEK3  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BUDHIG430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0430.0
BUDHIG  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
UMARSY 22.9 22.9 22.9 22.9 22.9 22.9 22.9 22.9 22.9 22.9 22.9 22.9
UMARSY  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MMARSY 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0 80.0
MMARSY  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 KHUDI  3.0  2.0  2.0  3.0  4.5  4.5  4.5  4.5  4.5  4.5  4.5  3.0
 KHUDI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
LCHEPE  5.0  4.0  4.0  4.0  6.0 17.6 17.6 17.6 17.6  7.5  7.5  6.0
LCHEPE  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
MARSYG 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5
MARSYG  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BIJAYP  1.0  1.0  1.0  1.0  2.0  4.0  8.3  8.3  8.3  8.3  5.0  2.0
BIJAYP  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
  MODI 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5 27.5
  MODI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 LMODI 10.0  8.0  8.0 11.0 18.0 29.0 44.7 44.7 44.7 44.7 18.0 13.0
 LMODI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
KGANDA134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0134.0
KGANDA  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
 ANDHI  3.0  3.0  2.0  2.0  4.0  4.9  4.9  4.9  4.9  4.9  4.9  4.0
 ANDHI  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
JHIMRK  4.0  4.0  3.0  3.0  3.0  8.0  8.0  8.0  8.0  8.0  8.0  5.0
JHIMRK  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.4  0.4  0.0  0.0
CHAMEL 36.7 36.7 36.7 36.7 36.7 36.7 36.7 36.7 36.7 36.7 36.7 36.7
CHAMEL  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.3  0.3  0.3  0.0  0.0
```

For case 6, change is made in CADIR in only the cost value of unserved energy for id REST.

Part of CADIR file (shown by underline) where change is made for Case 5.

```
          ********* THERMAL POWER PLANTS AND IMPORTS ********
 5
DUHABI   1  6  6  1    6.5 40.0000 0.0100000    00.2000.100
     1.0 1.0 1.0 1.0 1.0
HETAUD   1  4  4  2    2.5 40.0000 0.0100000    00.2000.100
     1.0 1.0 1.0 1.0 1.0
  ADD   1  1  1  3 300.0  40.0000 0.0100000    00.0000.000
     1.0 1.0 1.0 1.0 1.0
  IMP   1  0  0  3 1000.0  10.0000 0.0100000    00.0000.000
     1.0 1.0 1.0 1.0 1.0
 REST   1  4  8  2 1000.0  80.0000 0.0100000    00.2000.060
     1.0 1.0 1.0 1.0 1.0
```

6.1 WASP DATABASE

The data of LOADSY is same as basic scenario for all cases. From the output of VWASP of each case, FIXSYS and VARSYS files are prepared. The year by year configuration in CONGEN and the data in MERSIM file is also kept same for all cases. The basic data of DYNPRO is also same except for case 6.

Part of DYNPRO file (shown by underline) where change is made for Case 5.

```
         Demonstration Case (Variable Expansion)          0  2
 2011 2011 2011   20
     10.      10.
   2
    100.   900.    25.     0.     0.    10.     3.           THRM
    100.  1400.    25.     0.     0.    10.     3.           MULT
      0.     0.    25.     0.     0.    10.     2.           PRCH
             50.
    500.  1500.                         10.     5.           KHAN
    630.  1890.                         10.     5.           BARA
    720.  2170.                         10.     5.           KUL3
    450.  1800.                         10.     5.           LMOD
    900.  2800.                         10.     5.           CHAM
    280.   830.                         10.     5.           HEWA
    500.  1500.                         10.     5.           PHAW
    600.  1900.                         10.     5.           BALA
    750.  2250.                         10.     5.           USAN
    500.  1500.                         10.     5.           IKHU
    550.  1650.                         10.     5.           KABA
    940.  2820.                         10.     5.           LCHE
    690.  2060.                         10.     5.           MAIW
    750.  2250.                         10.     5.           LSAN
    640.  1930.                         10.     5.           BALB
    690.  2070.                         10.     5.           TRIB
             50.
    930.  2780.                         10.     5.           UMSY
    360.  1090.                         10.     5.           UTAK
    550.  1650.                         10.     5.           RASG
    780.  2350.                         10.     5.           TRIA
   1390.  4180.                         10.     7.           BUDG
    550.  1650.                         10.     5.           MTMR
    550.  1660.                         10.     6.           UTAM
  13
  10
  16
   1
  11
0.80     0     0
  12
    25
   1                            (End of year 2011)
   1                            (End of year 2012)
   1                            (End of year 2013)
   1                            (End of year 2014)
   1                            (End of year 2015)
   1                            (End of year 2016)
   1                            (End of year 2017)
   1                            (End of year 2018)
   1                            (End of year 2019)
   1                            (End of year 2020)
```

1	(End of year 2021)
1	(End of year 2022)
1	(End of year 2023)
1	(End of year 2024)
1	(End of year 2025)
1	(End of year 2026)
1	(End of year 2027)
1	(End of year 2028)
1	(End of year 2029)
1	(End of year 2030)

6.2 OUTPUTS

6.2.1 LRMC

Similar to the case of different scenarios, the load of base case is increased by 50MW for the determination of LRMC.

Table 6-2: LRMC for case 1: Q25 and Qdesign

Year	**E1(GWh)**	**E2(GWh)**	**NPV1 (K$)**	**NPV2 (K$)**
2030	22270.6	22538.6	148739	154922
2029	20970.4	21238.3	136543	142641
2028	19716.9	19984.8	151459	156474
2027	18322.4	18590.4	128482	133295
2026	17024.4	17292.4	129870	134281
2025	15815.4	16083.4	104937	109490
2024	14690	14957.9	96783	100896
2023	13641.2	13909.2	227028	230884
2022	12663.7	12931.6	89423	93339
2021	11822.3	12090.3	309906	313890
2020	10997	11264.9	181467	185662
2019	10219.4	10487.3	186682	193245
2018	9486.8	9754.7	248528	255105
2017	8793.3	9061.3	387072	394658
2016	8092.3	8360.3	157965	171980
2015	7434.2	7702.2	299944	313840
2014	6815.2	7083.2	208046	242616
2013	6233.8	6501.7	160445	189716
2012	5664.1	5932.1	121804	145352
2011	5182.8	5450.8	96888	116096
			LRMC	**3.9Cts/KWh**

Table 6-3: LRMC for case 2: Q30 and Qdesign

Year	E1(GWh)	E2(GWh)	NPV1 (K$)	NPV2 (K$)
2030	22270.6	22538.6	126444	132437
2029	20970.4	21238.3	137110	143489
2028	19716.9	19984.8	138972	144284
2027	18322.4	18590.4	142414	135631
2026	17024.4	17292.4	112815	128871
2025	15815.4	16083.4	102557	106861
2024	14690	14957.9	95431	99266
2023	13641.2	13909.2	376436	380103
2022	12663.7	12931.6	94193	98419
2021	11822.3	12090.3	312851	317062
2020	10997	11264.9	295215	301212
2019	10219.4	10487.3	178179	184149
2018	9486.8	9754.7	240182	246219
2017	8793.3	9061.3	376654	383458
2016	8092.3	8360.3	152671	166191
2015	7434.2	7702.2	295114	308633
2014	6815.2	7083.2	190850	223722
2013	6233.8	6501.7	146239	173205
2012	5664.1	5932.1	110351	132226
2011	5182.8	5450.8	87666	104960
			LRMC	**3.7Cts/KWh**

Table 6-4: LRMC for case 3: Q40 and Qdesign

Year	E1(GWh)	E2(GWh)	NPV1 (K$)	NPV2 (K$)
2030	22270.6	22538.6	125979	132479
2029	20970.4	21238.3	137516	144586
2028	19716.9	19984.8	122381	127948
2027	18322.4	18590.4	148870	141888
2026	17024.4	17292.4	108828	125119
2025	15815.4	16083.4	98950	103043
2024	14690	14957.9	92015	95775
2023	13641.2	13909.2	292501	296170
2022	12663.7	12931.6	92605	96952
2021	11822.3	12090.3	215650	219998
2020	10997	11264.9	220209	226057
2019	10219.4	10487.3	122135	128195
2018	9486.8	9754.7	216810	222746
2017	8793.3	9061.3	340443	347161
2016	8092.3	8360.3	154790	168273

2015	7434.2	7702.2	251104	264592
2014	6815.2	7083.2	187828	220956
2013	6233.8	6501.7	144050	170350
2012	5664.1	5932.1	108926	130454
2011	5182.8	5450.8	86526	103813
			LRMC	**3.70Cts/KWh**

Table 6-5: LRMC for case 4: Q50 and Qdesign

Year	**E1(GWh)**	**E2(GWh)**	**NPV1 (K$)**	**NPV2 (K$)**
2030	22270.6	22538.6	174446	183022
2029	20970.4	21238.3	151940	159308
2028	19716.9	19984.8	136386	142148
2027	18322.4	18590.4	157165	150630
2026	17024.4	17292.4	119457	136643
2025	15815.4	16083.4	106433	111534
2024	14690	14957.9	103500	108221
2023	13641.2	13909.2	212635	217009
2022	12663.7	12931.6	102328	108421
2021	11822.3	12090.3	173133	179037
2020	10997	11264.9	177333	184776
2019	10219.4	10487.3	117923	125981
2018	9486.8	9754.7	174156	119659
2017	8793.3	9061.3	295731	358078
2016	8092.3	8360.3	168864	182149
2015	7434.2	7702.2	213246	226620
2014	6815.2	7083.2	177566	209788
2013	6233.8	6501.7	135498	160485
2012	5664.1	5932.1	103791	123128
2011	5182.8	5450.8	83536	99448
			LRMC	**3.8Cts/KWh**

Table 6-6: LRMC for case 5: Q60 and Qdesign

Year	**E1(GWh)**	**E2(GWh)**	**NPV1 (K$)**	**NPV2 (K$)**
2030	22270.6	22538.6	156913	164667
2029	20970.4	21238.3	162093	170029
2028	19716.9	19984.8	145815	151961
2027	18322.4	18590.4	164514	169490
2026	17024.4	17292.4	128538	134422
2025	15815.4	16083.4	116193	121443
2024	14690	14957.9	105338	110462
2023	13641.2	13909.2	95126	100210

2022	12663.7	12931.6	193086	195221
2021	11822.3	12090.3	111674	110737
2020	10997	11264.9	225086	232850
2019	10219.4	10487.3	125376	134046
2018	9486.8	9754.7	186691	150029
2017	8793.3	9061.3	295786	339114
2016	8092.3	8360.3	167599	180958
2015	7434.2	7702.2	200891	214312
2014	6815.2	7083.2	175633	206742
2013	6233.8	6501.7	134643	159231
2012	5664.1	5932.1	103509	122766
2011	5182.8	5450.8	83425	99243
			LRMC	**3.5Cts/KWh**

Table 6-7: LRMC for case 6: cost of unserved energy as 30Cts/Kwh

Year	**E1(GWh)**	**E2(GWh)**	**NPV1 (K$)**	**NPV2 (K$)**
2030	22270.6	22538.6	133268	137586
2029	20970.4	21238.3	136599	141494
2028	19716.9	19984.8	127160	131865
2027	18322.4	18590.4	153238	157669
2026	17024.4	17292.4	115198	120185
2025	15815.4	16083.4	104863	109275
2024	14690	14957.9	97544	101440
2023	13641.2	13909.2	664941	668708
2022	12663.7	12931.6	94863	99384
2021	11822.3	12090.3	134746	163568
2020	10997	11264.9	172029	149507
2019	10219.4	10487.3	117209	122875
2018	9486.8	9754.7	240932	246510
2017	8793.3	9061.3	621048	627483
2016	8092.3	8360.3	145634	157520
2015	7434.2	7702.2	281966	294335
2014	6815.2	7083.2	161311	183349
2013	6233.8	6501.7	131434	151599
2012	5664.1	5932.1	103419	121761
2011	5182.8	5450.8	83603	99393
			LRMC	**3.1Cts/KWh**

Table 6-8: LRMC for case 6: cost of unserved energy as 80Cts/Kwh

Year	E1(GWh)	E2(GWh)	NPV1 (K$)	NPV2 (K$)
2030	22270.6	22538.6	159686	168525
2029	20970.4	21238.3	165483	174895
2028	19716.9	19984.8	143873	151201
2027	18322.4	18590.4	145914	140363
2026	17024.4	17292.4	139204	156121
2025	15815.4	16083.4	110526	115995
2024	14690	14957.9	100606	105070
2023	13641.2	13909.2	666675	670751
2022	12663.7	12931.6	97606	102665
2021	11822.3	12090.3	91692	96404
2020	10997	11264.9	222281	228570
2019	10219.4	10487.3	122410	129249
2018	9486.8	9754.7	244320	250653
2017	8793.3	9061.3	624118	562522
2016	8092.3	8360.3	158704	242450
2015	7434.2	7702.2	289759	304427
2014	6815.2	7083.2	222716	266834
2013	6233.8	6501.7	163508	197320
2012	5664.1	5932.1	118960	145033
2011	5182.8	5450.8	92255	111692
			LRMC	**4.5Cts/KWh**

Table 6-9: LRMC for case 6: cost of unserved energy as 1USD/Kwh

Year	E1(GWh)	E2(GWh)	NPV1 (K$)	NPV2 (K$)
2030	22270.6	22538.6	171344	181876
2029	20970.4	21238.3	177876	189017
2028	19716.9	19984.8	151409	159818
2027	18322.4	18590.4	138316	144801
2026	17024.4	17292.4	153146	143705
2025	15815.4	16083.4	113328	133964
2024	14690	14957.9	102018	106786
2023	13641.2	13909.2	667345	671591
2022	12663.7	12931.6	98512	103801
2021	11822.3	12090.3	92161	97004
2020	10997	11264.9	224185	230972
2019	10219.4	10487.3	124245	131577
2018	9486.8	9754.7	245358	252008
2017	8793.3	9061.3	556293	563709
2016	8092.3	8360.3	232098	246759

2015	7434.2	7702.2	292881	308510
2014	6815.2	7083.2	247808	300586
2013	6233.8	6501.7	176912	216254
2012	5664.1	5932.1	125491	154798
2011	5182.8	5450.8	95747	116841
			LRMC	**5.0Cts/KWh**

Table 6-10: LRMC comparison

Case	**Case**	**LRMC (Cts/Kwh)**
1	Reference case	3.9
2	Q25, Qdesign	3.9
3	Q30, Qdesign	3.7
4	Q40, Qdesign	3.7
5	Q50, Qdesign	3.8
6	Q60, Qdesign	3.5
7	ENS 30 Cent	3.1
	ENS 55 Cent	3.9
	ENS 80 Cent	4.5
	ENS 1USD	5.0

Table 6-11: Average LOLP comparison

Case	**Case**	**LOLP (%)**
1	Reference case	4.28
2	Q25, Qdesign	5.1
3	Q30, Qdesign	4.33
4	Q40, Qdesign	4.01
5	Q50, Qdesign	4.00
6	Q60, Qdesign	4.03
7	ENS 30 Cent	4.98
	ENS 55 Cent	4.28
	ENS 80 Cent	4.17
	ENS 1USD	4.1

Comparing cases 1-4, LRMC for case 3 and case 1 is the highest; case 2 is in the same range; and it is minimum for case4. Average LOLP for case 3 is minimum among cases 1-4. Although there is no fixed trend of LRMC from case 1 to 4, the average LOLP for cases 2-4 is in the same range. This shows that adopting the design flow in the range of Q40-Q60 for the expansion plants is ok.

In case 5, LRMC increases with the increase in cost of unserved energy. If the cost is higher, LRMC will also become higher. The average LOLP shows the reverse trend of LRMC. If the cost is higher, the loss of load will be lower.

Appendix -7

MATLAB Programme Code

Table of Contents

7. MATLAB PROGRAMME CODE

7.1 MATLAB PROGRAMME CODE FOR PREPARATION OF CADIR.DAT FILE

```
%To write data for CADIR
fid=fopen('CADIR.dat','wt');
IDENT ='********* STUDY IDENTIFICATION ********';
fprintf(fid,'%72s\n',IDENT);
ENPID='DEPT. OF ELECTRICITY DEVELOPMENT'
fprintf(fid,'%48s\n',ENPID);
EST ='OPTMQ20';
IANI =2030;
IRGIN =1980;
IRGEIN =2009;
IPROB=0;
NHS=5;
INPDIR=1;
IMPAFL=1;
fprintf(fid,'%18s
%5i%5i%5i%5i%5i%5i%5i',EST,IANI,IRGIN,IRGEIN,IPROB,NHS,INPDIR,IMPAFL);
fprintf(fid,'\n',EST,IANI,IRGIN,IRGEIN,IPROB,NHS,INPDIR,IMPAFL);
DUR=[0.050.120.180.400.25];
fprintf(fid,'%10.5f',DUR);
fprintf(fid,'\n',DUR);
IDENT1 ='********* ELECTRIC NODE IDENTIFICATION ********';
fprintf(fid,'%72s\n',IDENT1);
NEN=01;
NENM='NEPAL'
fprintf(fid,'%2i\n',NEN);
fprintf(fid,'%6s\n',NENM);
MPD=xlsread('electric nodes.xls','Sheet1');
forjjj=1:size(MPD,1);
forjkj=1:size(MPD,2);
fprintf(fid,'%6.3f',MPD(jjj,jkj));
end
fprintf(fid,'\n',MPD(jjj,jkj));
end

IDENT2 ='********* SYSTEM DEMAND DEFINITION ********';
fprintf(fid,'%72s\n',IDENT2);
NFD=01;
NFDM='DEM.1';
NENA=1;
fprintf(fid,'%2i\n',NFD);
fprintf(fid,'%6s%4i\n',NFDM,NENA);
AED=[18000];
fprintf(fid,'%6.2f',AED(:));
fprintf(fid,'\n',AED(:));
IDENT3 ='********* SECONDARY DEMAND DEFINITION ********';
fprintf(fid,'%72s\n',IDENT3);
NSD=01;
fprintf(fid,'%2i\n',NSD);
SNSDM='S.DEM1';
SNENA=1;
fprintf(fid,'%6s%4i\n',SNSDM,SNENA);
SNSDM='S.DEM1';
ASP=[9.00.01];
MPS=[46
0];
fprintf(fid,'%6s%7.2f%7.2f\n',SNSDM,ASP);
```

```
fprintf(fid,'%6.f\n',MPS);
 IDENT4 ='********* MAINTENANCE TEAMS ********';
fprintf(fid,'%72s\n',IDENT4);
NMK=02;
fprintf(fid,'%2i\n',NMK);
[num,txt]=xlsread('maintenance.xls','maint');
for j=1:NMK;
fprintf(fid,'%6s',txt{j,1});
for i=1:12;
fprintf(fid,'%5i',num(j,i));
end
fprintf(fid,'\n',txt{j,1},num(j,i));
end
        IDENT5 ='********* THERMAL POWER PLANTS AND IMPORTS ********';
fprintf(fid,'%72s\n',IDENT5);
NFF=02;
fprintf(fid,'%2i\n',NFF);
[type, sheets]=xlsfinfo('maintenance.xls');
[maintdata,shnames]=xlsread('maintenance.xls','maint');
[mycoeff,shenames]=xlsread('nominal capacity.xls','coeff');
forll=1:size(sheets,2)-1;
[shnames{ll,1}];
crews=xlsread('maintenance.xls',[shnames{ll,1}]);
coeffs=xlsread('nominal capacity.xls',[shenames{ll}]);
forlil=1:size(crews,1);

fprintf(fid,'%6s%4i%3i%3i%3i%7.1f%8.4f%10.7f%5.0f%5.3f%5.3f\n',shnames{ll,1
},crews(lil,:));
end
forljl=1:size(coeffs,1);
fprintf(fid,'       %4.1f%4.1f%4.1f%4.1f%4.1f',coeffs(ljl,:));
end

fprintf(fid,'\n');
end
[num,txt]=xlsread('operational data.xls','operational data');
forjj=1:2*(NMK);
fprintf(fid,'%6s',txt{jj,1});
for ii=2:13;
fprintf(fid,'%5s',txt{jj,ii});
end
fprintf(fid,'\n',txt{jj,1},txt{jj,ii});
end

         IDENT5 ='********* RESERVOIR CHARACTERISITCS ********';
fprintf(fid,'%72s\n',IDENT5);
NSS=5;
fprintf(fid,'%2i\n',NSS);
[num,txt]=xlsread('reservoirs20txt.xls','Reservoir characteristics');
forjjj=1:NSS;
for iii=1;
fprintf(fid,'%6s',txt{jjj,1});
for iii=2;
fprintf(fid,'%4s',txt{jjj,iii});
for iii=3;
fprintf(fid,'%10s',txt{jjj,iii});
for iii=4;
fprintf(fid,'%5s',txt{jjj,iii});
for iii=5;
fprintf(fid,'%5s',txt{jjj,iii});
for iii=6;
```

```
fprintf(fid,'%10s',txt{jjj,iii});
for iii=7;
fprintf(fid,'%10s',txt{jjj,iii});
for iii=8;
fprintf(fid,'%10s',txt{jjj,iii});
for iii=9;
fprintf(fid,'%10s',txt{jjj,iii});
end
end
end
end
end
end
end
end
end
fprintf(fid,'\n',txt{jjj,iii});
end
        NSSO =0000;
        NSSO1='STORAGE BOUNDS';
fprintf(fid,'%4i  %30s\n',NSSO,NSSO1);
    EVAP =0000;
    EVAP1='HEIGHT EVAPORATION (MM)';
fprintf(fid,'%4i  %30s\n',EVAP,EVAP1);
        REALEASE=00;
        REALEASE1='WATER RELEASE (HM3)'
fprintf(fid,'%4i  %30s\n',REALEASE,REALEASE1);
IDENT6 ='********* SPILLWAYS ********';
fprintf(fid,'%72s\n',IDENT6);
NQS=NSS;
fprintf(fid,'%2i\n',NQS);
[num,txt]=xlsread('reservoirs20txt.xls','Spillways');
for k=1:NQS;
fprintf(fid,'%6s',txt{k,1});
for l=1:2;
fprintf(fid,'%4i%5i',num(k,l));
end
fprintf(fid,'\n',num(k,l));
end
        IDENT7 ='********* HYDRO POWER PLANTS ********';
fprintf(fid,'%72s\n',IDENT7);
NQQ=NSS;
fprintf(fid,'%2i\n',NQQ);
[num,txt]=xlsread('reservoirs20txt.xls','Hydro Power Plants');
forkk=1:NQQ;
fprintf(fid,'%6s',txt{kk,1});
forll=1;
fprintf(fid,'%4i',num(kk,ll));
forll=2;
fprintf(fid,'%5i',num(kk,ll));
forll=3;
fprintf(fid,'%3i',num(kk,ll));
forll=4;
fprintf(fid,'%2i',num(kk,ll));
forll=5;
fprintf(fid,'%5.2f',num(kk,ll));
forll=6;
fprintf(fid,'%5.2f',num(kk,ll));
forll=7;
fprintf(fid,'%7.2f',num(kk,ll));
forll=8;
```

```
fprintf(fid,'%7.2f',num(kk,ll));
forll=9;
fprintf(fid,'%7.2f',num(kk,ll));
forll=10;
fprintf(fid,'%7.2f',num(kk,ll));
forll=11;
fprintf(fid,'%7.2f',num(kk,ll));
forll=12;
fprintf(fid,'%7.2f',num(kk,ll));
end
end
end
end
end
end
end
end
end
end
end
end

fprintf(fid,'\n',num(kk,ll));
end
[num,txt]=xlsread('reservoirs20txt.xls','hydro turbines');
forkkk=1:2*NQQ;
fprintf(fid,'%6s',txt{kkk,1});
forlll=1:12;
fprintf(fid,'%5.1f',num(kkk,lll));
end
fprintf(fid,'\n',num(kkk,lll));
end
                IDENT8 ='(MANDATORY TEC. MINIMUM - M3/S) ';
                TECMIN =000;
fprintf(fid,'%4i      %30s\n',TECMIN,IDENT8);
        IDENT9 ='********* PUMPED STORAGE PLANTS ********';
fprintf(fid,'%72s\n',IDENT9);
PUMP=000;
fprintf(fid,'%2i\n',PUMP);
IDENT10 ='********* DEFINATION OF CASCADES ********';
fprintf(fid,'%72s\n',IDENT10);
NCA=3;
fprintf(fid,'%2i\n',NCA);
[num,txt]=xlsread('reservoirs20txt.xls','hydro cascades');
forkik=1:4;
fprintf(fid,'%12s',txt{kik,1});
forlil=1:NCA;
fprintf(fid,'%3i',num(kik,lil));
end
fprintf(fid,'\n',num(kik,lil));
end
fclose(fid);
```

7.2 MATLAB PROGRAMME CODE FOR PREPARATION OF INFLOW.DAT FILE

```
function[x]=inflowrite()
listOfiles={'INFLOW.xls'}
fid=fopen('INFLOW.DAT','wt');
NSSI=1980;
NSSF=2009;
fprintf(fid,'%5i%5i\n',NSSI,NSSF);
forifile= length(listOfiles):-1:1
partialfiles(listOfiles{ifile},fid);
end
fclose(fid);
function[x]=partialfiles(filename,fid)
[x,cs]=xlsread(filename,'stats');
numberOfStations= size(x,1);
x(:,[16])
for i =1:numberOfStations
disp(['Show me:'cs{i,4}]);
if x(i,end)==1
[Inflows,css]=xlsread(filename,cs{i,4});
    Inflows =Inflows(2:end,1:13);
jN= length(Inflows(:,1));
fprintf(fid,'TRIBUTARY  INFLOWS  TO  %s at %s (%s) ( HM3 )  %i / %i\n',...
cs{i,2},cs{i,4},cs{i,5},Inflows(1,1), Inflows(end,1));
disp(['TRIBUTARY  INFLOWS  TO  'cs{i,2}' at 'cs{i,4}' ('cs{i,5}') ( HM3 )
' num2str(Inflows(1,1))' / ' num2str(Inflows(end,1))]);
for j =1:jN
for k =2:13
if Inflows(j,k)>9999.9
disp(['flows are wrong at 'cs{i,4}': flow : ' num2str(Inflows(j,k))]);
fprintf(fid,'%6.0f', Inflows(j,k));
else
fprintf(fid,'%6.1f', Inflows(j,k));
end
end
fprintf(fid,'\n');
end
end
end
```

7.3 MATLAB PROGRAMME CODE FOR PREPARATION OF LOADSYS.DAT FILE

```
%To write data for LOADSYS
fid=fopen('loadsys.dat','wt');
IDENT ='Demonstration Case (Fixed Expansion)';
fprintf(fid,'%60s\n',IDENT);
NPER =4;
NOCOF =50;
IOPT =0;
fprintf(fid,'%4i%4i%4i',NPER,NOCOF,IOPT);
fprintf(fid,'\n',NPER,NOCOF,IOPT);
PKMW=[967.11056.91163.21271.71387.215101640.81770.21906.902052220623632545.
402741.102951.103176.703418.903679.1039134155.62];
JAHR=[201120122013201420152016201720182019202020212022202320242025202620272
02820292030];
fprintf(fid,'%7.1f%14i\n',PKMW(1,1),JAHR(1,1));
INDEX=[1234];
fprintf(fid,'%4i\n',INDEX(1,2));
PUPPK=[.9.87.931.];
for i=1:length(PUPPK);
fprintf(fid,'%8.2f',PUPPK(i));
```

```
end
fprintf(fid,'\n',PUPPK(i))
% fprintf(fid,'%4i\n',INDEX(1,3))
% MYCOEF=xlsread('COEF.xls','Sheet1');
% for j=1:size(MYCOEF,1);
%     for k=1:size(MYCOEF,2);
%     fprintf(fid,'%12.1f',MYCOEF(j,k));
%     end
%  fprintf(fid,'\n',MYCOEF(j,k));
% end
% for m=2:29;
% fprintf(fid,'%4i\n',INDEX(1,1));
% fprintf(fid,'%8.2f%6i',PKMW(1,m),JAHR(1,m));
% fprintf(fid,'\n',PKMW(1,m),JAHR(1,m));
% end
% fprintf(fid,'%4i\n',INDEX(1,4));
% NP=NPER;
% fprintf(fid,'%4i\n',NP);
%
% [type, sheets]=xlsfinfo('LDDUR.xls')
%
% for jj=1:length(sheets);
%     disp(sheets{jj});
%     myload = xlsread('LDDUR.xls', [sheets{jj}]);
%     inans = find(isnan(myload(:,1)) | isnan(myload(:,2)) );
%     if ~isempty(inans)
%     myload(inans,:) =[];
%     disp([sheets{jj} ' found erroneous data']);
%     end
%     sizemn = size(myload);
%     numOfrows = sizemn(1); %size(myload,1);
%     numOfcols = sizemn(2);%;size(myload,2);
%
%     fprintf(fid,'%4i\n',numOfrows);
%             for ii=1:numOfrows;
%
%                 for kk=1:numOfcols;% number of columns
%                 fprintf(fid,'%10.4f',myload(ii,kk));
%                 end
%                   fprintf(fid,'\n');
%             end
% end
fprintf(fid,'%4i\n',INDEX(1,1));
for n=2:length(PKMW);
fprintf(fid,'%8.2f%6i',PKMW(1,n),JAHR(1,n));
fprintf(fid,'\n',PKMW(1,n),JAHR(1,n));
fprintf(fid,'%4i\n',INDEX(1,1));
end
fclose(fid);
```

7.4 MATLAB PROGRAMME CODE FOR PREPARATION OF FIXSYS.DAT FILE

```
%To write data for FIXSYS
fid=fopen('fixsys_final.dat','wt');
```

```
IDENT ='Demonstration Case (Fixed Expansion)';
NID =4;
fprintf(fid,'%60s%4i\n',IDENT,NID)
IDNUM =[0123];
IDNAM ={'HETU','MULT','PRC1','PRC2'};
IDTXT ={'HETAUDA  ','MULTIFUEL','PURCHASE1','PURCHASE2'};
[mrows,ncols]=size(IDNUM)
for m=1:ncols
fprintf(fid,'%4i%9s%20s',IDNUM(1,m),char(IDNAM(m)),char(IDTXT(m)))
fprintf(fid,'\n',IDNUM(1,m),char(IDNAM(m)),char(IDTXT(m)))
end
IDNAM ={'HYD1','HYD2'};
IDTXT ={'HYDRO PLANTS GROUP 1','HYDRO PLANTS GROUP 2'}
for n=1:2;
fprintf(fid,'%5s%20s\n',char(IDNAM(n)),char(IDTXT(n)))
end
JAHR =2011;
NPER =12;
NTHPL =5;
IHYDIS =3;
NAMH ={'HYD1','HYD2'}
HOM =[.55.55];
PROBH =[.55.25.20];
fprintf(fid,'%4i%4i%4i%4i%4s%6.2f%4s%6.2f%6.2f%6.2f%6.2f%6.2f',JAHR,NPER,NT
HPL,IHYDIS,char(NAMH(1)),HOM(1,1),char(NAMH(2)),HOM(1,2),PROBH)
fprintf(fid,'\n',JAHR,NPER,NTHPL,IHYDIS,char(NAMH(1)),HOM(1,1),char(NAMH(2)
),HOM(1,2),PROBH)
[type, sheets]=xlsfinfo('thermal plants.xls');
[plantdata,shnames]=xlsread('thermal plants.xls','plants');
[mypollutants,shenames]=xlsread('pollutants.xls','pollutdata');
forll=1:size(sheets,2)-1;
[shnames{ll,1}];
thermoplant=xlsread('thermal plants.xls',[shnames{ll,1}]);
polluts=xlsread('pollutants.xls',[shenames{ll}]);
forlil=1:size(thermoplant,1);

fprintf(fid,'%4s%3.2i%4.2f%4.2f%6.2f%6.2f%4.2f%4.2f%3.2i%2.2i%5.1f%3.2i%4.2
f%5.2f%5.1f\n',shnames{ll,1},thermoplant(lil,:));
end
forljl=1:size(polluts,1);
fprintf(fid,'%10.1f%10.1f%10.1f',polluts(ljl,:));
end

fprintf(fid,'\n');
end
NGROUPLM=4;
IPNLT=0;
PNLTLOLP=[0.0 1.0];
EMISNAME={'SO2', 'NOx'};
MEASIND = [ 1 2 3 1 0];
fprintf(fid,'%2i%2i%10.1f%10.1f %3s
%3s%2i%2i%2i%2i%2i\n',NGROUPLM,IPNLT,PNLTLOLP,EMISNAME{:},MEASIND)
EaEb = xlsread('EaEb.xls','sheet1') ;
forjjj=1:size(EaEb,1);
forjkj = 1:size(EaEb,2);
if ~isnan(EaEb(jjj,jkj));

fprintf(fid,'%4i%4i%4i%4i%9.f.%4i%4i%4i%9.f.%4i%4i%4i%4i%4i%4i%4i%9.f.%4i%4
i%9.f.%4i%4i%4i',EaEb(jjj,jkj));
end
end
```

```
fprintf(fid,'\n');
end
    [type, sheets] = xlsfinfo('hydrocondition.xls');
    [MYDAT,ShNames] = xlsread('hydrocondition.xls','DATA') ;
    [myindex,sheetnames]=xlsread('index.xls','IND');
for ii=1:size(sheets,2)-1;
        [ShNames{ii,1} '  ' ShNames{ii,2}];
hydrocon = xlsread('hydrocondition.xls', [ShNames{ii,1}]);
index = xlsread('index.xls', [sheetnames{ii}]);
fprintf(fid,'
%4s%6s%6.f%6.f\n',ShNames{ii,1},ShNames{ii,2},MYDAT(ii,1),MYDAT(ii,2));
forkik=1:NPER;
fprintf(fid,'%5.1f%5.1f%5.1f%5.1f%5.1f%5.1f%5.1f%5.1f%5.1f
\n',hydrocon(kik,:));
end
forkjk=1:size(index,1);
forkkk = 1:size(index,2);
if ~isnan(index(kjk,kkk));
fprintf(fid,'%4i',index(kjk,kkk));
end
end
fprintf(fid,'\n');
end
end
fclose(fid);
```

7.5 MATLAB PROGRAMME CODE FOR PREPARATION OF VARSYS.DAT FILE

```
%To write data for VARSYS
fid=fopen('varsys.dat','wt');
IDENT ='Demonstration Case (Fixed Expansion)';
fprintf(fid,'%60s\n',IDENT);
NPER =12;
NTHPL =5;
IHYDIS =3;
NAMH ={'HYD1'};
HOM =[.55];
PROBH =[.45.3.25];
NUH =[30];
NUPS =0;
fprintf(fid,'    %4i%4i%4i  %4s%6.2f
%6.4f%6.4i%6.4i',NPER,NTHPL,IHYDIS,char(NAMH(1)),HOM(1,1),PROBH,NUH,NUPS);
fprintf(fid,'\n',NPER,NTHPL,IHYDIS,char(NAMH(1)),HOM(1,1),PROBH, NUH,
NUPS);
[type, sheets]=xlsfinfo('extend-thermal plants.xls');
[plantdata,shnames]=xlsread('extend-thermal plants.xls','plants');
[mypollutants,shenames]=xlsread('pollutants.xls','pollutdata');
forll=1:size(sheets,2)-1;
[shnames{ll,1}];
thermoplant=xlsread('extend-thermal plants.xls',[shnames{ll,1}]);
polluts=xlsread('pollutants.xls',[shenames{ll}]);
forlil=1:size(thermoplant,1);
fprintf(fid,'%4s   %4i.%4i.%6i.%6i.%4i.%4i.%3i%2i%5.1f%3i%4i.
%5.1f%6.1f\n',shnames{ll,1},thermoplant(lil,:));
end
forljl=1:size(polluts,1);
fprintf(fid,'%10.1f%10.1f%10.1f',polluts(ljl,:));
end

fprintf(fid,'\n');
```

```
end
NGROUPLM=4;
EMISNAME={'SO2','NOx'};
MEASIND =[12310];
fprintf(fid,'%2i                       %3s
%3s%2i%2i%2i%2i%2i\n',NGROUPLM,EMISNAME{:},MEASIND);
EaEb=xlsread('EaEb.xls','sheet1');
forjjj=1:size(EaEb,1);
forjkj=1:size(EaEb,2);
if~isnan(EaEb(jjj,jkj));

fprintf(fid,'%4i%4i%4i%4i%9.f.%4i%4i%4i%9.f.%4i%4i%4i%4i%4i%4i%4i%9.f.%4i%4
i%9.f.%4i%4i%4i',EaEb(jjj,jkj));
end
end

fprintf(fid,'\n');
end
fprintf(fid,'\n');
 [type, sheets] = xlsfinfo('hydrocondition.xls');
    [MYDAT,ShNames] = xlsread('hydrocondition.xls','DATA') ;
for ii=1:size(sheets,2)-1;
        [ShNames{ii,1} '  ' ShNames{ii,2}];
hydrocon = xlsread('hydrocondition.xls', [ShNames{ii,1}]);
fprintf(fid,'
%4s%6s%6.f%6.f%6i\n',ShNames{ii,1},ShNames{ii,2},MYDAT(ii,1),MYDAT(ii,2),MY
DAT(ii,3));
forkik=1:NPER;

fprintf(fid,'%5.1f%5.1f%5.1f%5.1f%5.1f%5.1f%5.1f%5.1f%5.1f\n',hydrocon(kik,
:));
end
end
fclose(fid);
```