M.Sc. THESIS

MAXIMIZING THE ENERGY OF OUTPUT OF HIGH HEAD SCHEME: A CASE STUDY OF NASIRABAD HYDRO POWER PROJECT

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Dedicated to

My Beloved Parents

ABSTRACT

Pakistan is facing severe electricity crisis over a decade. Electricity demand is being met through expensive energy resources like thermal energy instead of renewable resources like hydropower. Every year sufficient amount of water is flowing into sea without being effectively utilized. Along with this, a lot of potential sites are available where flows are available in abundance. Need of time is that to harness more and more hydropower sites. Special measures should be taken for conserving water which will be helpful not only for electricity generation but for other purposes also. By utilizing all available water resources in an optimized manner, electricity crisis can be managed to some extent at low price as compared to electricity produced by other expensive energy resources.

WAPDA has identified a lot of hydropower projects in northern areas. Nasirabad hydropower project is one of them. It has been identified in Gilgit Baltistan. WAPDA has identified this project as a run of river project with installed capacity of 15 MW utilizing two number of turbines. This study was carried out to make Nasirabad hydropower project most feasible in terms of power and energy as well as cost effective generating more revenue. For this purpose, two alternatives of peaking and continuous operation were selected. Nasirabad Hydropower Project was assumed to run as a peaking (for 4 peak hours operation and 20 off-peak hours operation) as well as a continuous (for 24 hours operation) run of river plant to get optimum results. Energy output was found out by SIMAHPP and by developing spreadsheet model for both alternatives.

Annual energy output 235.15 GWh for peaking and continuous operation was same using SIMAHPP. But revenue generated for peaking operation is 1120.91 Million rupees which is more than the revenue generated for continuous operation i.e. 1034.69 Million rupees. Revenue was computed by introducing cost per KWh for peak and off-peak hours. SIMAHPP simulates only for one turbine. Project working as a continuous operation dropped off on the basis of less revenue generated.

Computation of energy using spreadsheet model for one turbine was also carried out. Annual energy computed for both alternatives is almost same. But breakdown of total annual energy into peak and off-peak energy showed that peak energy produced in peaking operation is more than the peak energy produced in continuous operation (by providing some storage upstream to store flows to be utilized in peak hours). On this basis, annual revenue computed is 1106 Million rupees for peaking operation which is more than the revenue computed for continuous operation i.e. 1086.20 Million rupees. In this method, continuous operation was dropped off due to less revenue generated as compared to revenue generated in peaking operation.

Comparison of both studies considering only the peaking plant operation was carried out which showed same results for both studies. To increase the output of project, it was decided to increase design discharge with increased number of turbines. The purpose behind this was to utilize sufficient available flows throughout the year. SIMAHPP gives results for only one turbine. But in spreadsheet model, computations can be made for number of turbines.

Finally, project was optimized with increased design discharge working as a peaking plant for 4 peak hours operation in combination with continuous plant working for 20 off-peak hours. In this case, energy output was 645.80 GWh with installed capacity of 119 MW generating additional 117.50 Million rupees revenue than continuous system operation with same number of turbines. For peaking system, 2.84 million m^3 amount of storage was required to store extra flows which will be utilized in peak hours. Required storage of reservoir was calculated using the area-elevation-volume relationship at elevation 2046 meters. Plan and sections of proposed reservoir area were drawn with the help of contour map of Nasirabad Hydropower Project by using Auto-Cad.

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LIST OF ABBREVIATIONS

a.m.s.l	Above Mean Sea Level
GWh	Giga Watt Hour
GWh/year	Giga Watt Hour per Year
Hec-m	Hectares Meter
HEPO	Hydro Electric Planning Organization
HPP	Hydro Power Project
Km	Kilometers
Km^2	Square Kilometers
KWh	Kilo Watt Hour
m	Meters
m^2	Square Meters
m^3	Cubic Meters
m^3/sec	Cubic Meters per Second
Mm^3	Million Cubic Meters
MW	Mega Watts
WAPDA	Water and Power Development Authority

Chapter I
INTRODUCTION

1.1 GENERAL

Power can be produced by exploiting different natural resources. Out of these, hydropower is economical source of energy. Hydropower is generated by converting potential and kinetic energy of water by electromechanical means. Hydropower plays very important role in country's development as it is renewable, non-polluting, reliable, flexible and oldest source of energy. It can be key to self-reliance because of being completely national resources. It also helps to reduce dependence on imported fuel (WAPDA, 2000).

Keeping in view the present scenario of energy crisis, it is highly desirable to exploit water resources judiciously. Efforts should be made to maximize energy output of existing hydropower projects as well as installing new hydel schemes. Energy demand increases in summer as compared to winter season. However, demand criteria for northern areas are quite different from rest of Pakistan. In these areas, demand increases in winter season. Also, variation of demand occurs in peak hours daily in morning and evening. Power demand may be classified as peak and off-peak hours.

- The peak demand may occur in morning or evening for four hours.
- The off-peak demand consists of remaining twenty hours.

WAPDA supplies its peak demand by combination of thermal and hydropower energy in peak hours. If this demand is met through hydropower, it will give not only cheap energy and also hydro generators can be brought on line rapidly in well-organized manner (Hussain, 2005).

The demand for electricity is increasing day by day. Independent Power Producers (IPP's) has played an important role in country's development however power cost has also been increased significantly that is going to beyond the common man capacity. For cheap energy production, hydropower is a feasible option by storage of water. There are abundant water resources in Pakistan but during last 21 years, the share of hydropower production has come down from 60 % to 34 % of total power generation (WAPDA, 2004).

The best utilization of available water resources in Pakistan can lead to a self-sufficient country in power sector development. Hydropower is a non-polluting renewable source of energy. Pakistan's power shortages are being met with thermal energy as an alternative of hydropower. To meet energy crisis, our dependence on thermal energy has caused an extreme increase in tariff. Therefore, hydropower is an optimal choice to meet this severe energy demand (WAPDA, 2004).

1.2 PROJECT DESCRIPTION

It is great blessing for any country to have abundant water and power resources. Pakistan is one of these blessed countries and have great potential to utilize these resources. These resources are largely available in the northern areas of Pakistan. In Gilgit Baltistan, almost 278 project locations have been identified having total capacity of 21125 MW with varying heads i.e. high, medium and small heads. Nasirabad HPP is one of these projects. It is located on Hunza river and considers short-cutting various turns made by the river between its confluence with Hassanabad nullah and Nasirabad village. The project comprises of weir, head race tunnel, surge tank, penstock, power house, and tail race. (WAPDA, 2000). This study is carried out to maximize the energy output by operating the units as a peaking plant in combination with continuous operation for supplying the energy during peak hours at cheap rate. Also, to provide the storage upstream of the weir to store abundant flows available throughout the year for maximum utilization of available flows.

1.2.1 Location

The project area is located on Hunza River and considers short cutting various turns made by the river between its confluence with Hassanabad nullah and Nasirabad village. Latitude and longitude of weir site are 36°-17'-34" and 74°-37'-15" respectively. Power house site is located 36° 15'-20" N and 74°-33'00" E.

1.2.2 Accessibility

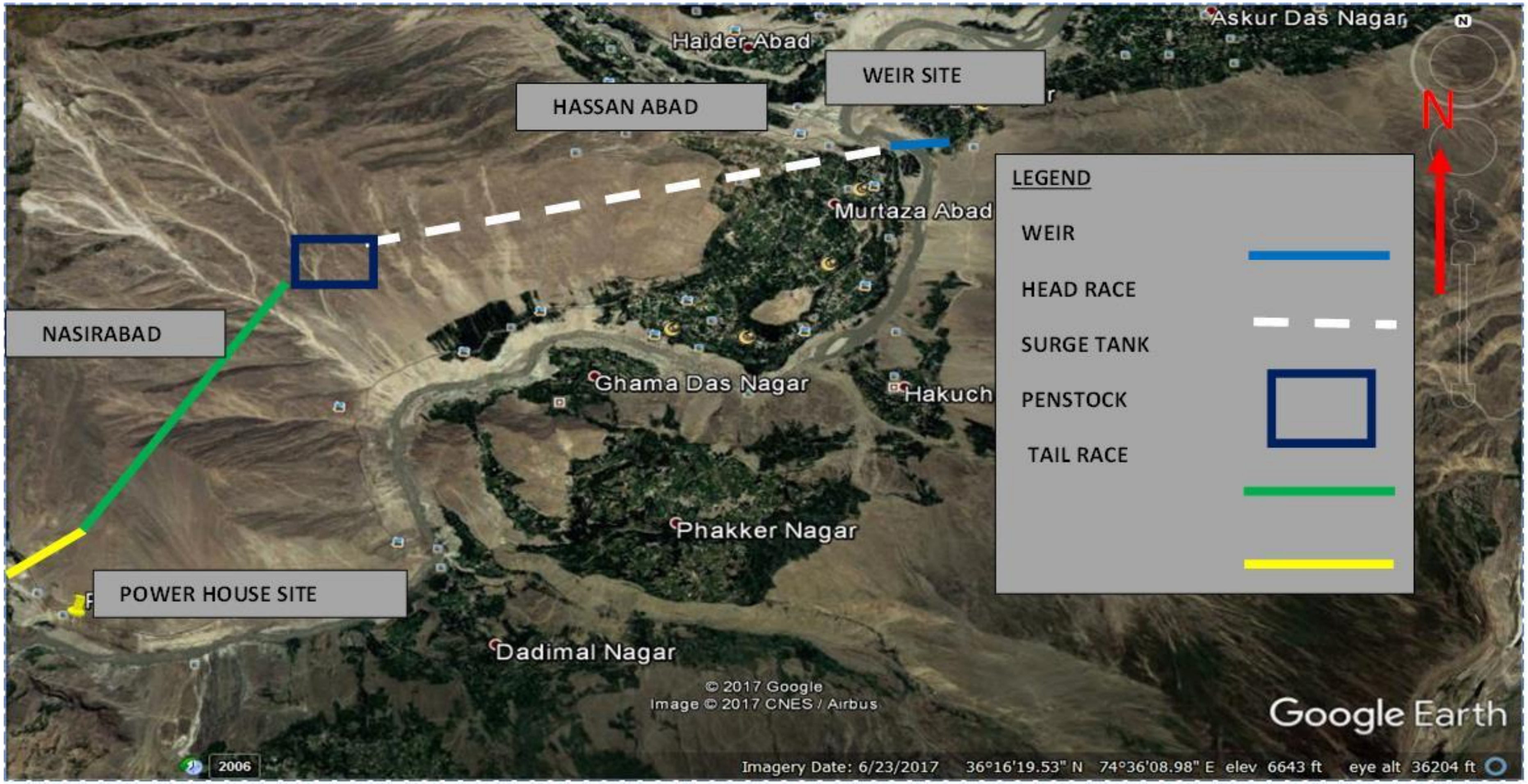
The project area is accessible from Gilgit by Karakoram Highways. The weir intake and power house site are located along K.K.H.

1.2.3 Hydrology

The catchment area of Hunza River up to the intake site is estimated to be about 11656 km^2. Mean annual minimum flow is 26.46m^3/s. Flow availability 90% of year 28.26 m^3/s. Return period of 100year flood is 4367 m^3/s.

1.2.4 Multi-Purpose Use of Water

There are no irrigation canals off-taking in the proposed project area.



Source: Google Earth

Figure 1.1 Proposed Layout of Site

1.2.5 Geology of Proposed Structures

The geological conditions seem to be favorable for the proposed hydel scheme. However, some problem like seepage and rock out breaks are expected during the excavation of tunnel hence extensive protective measures are required.

1.2.6 Description of Project Components

A brief description about main components of the scheme is given below (WAPDA, 2000):

1.2.6.1 Weir and Intake

The intake site is located just downstream of Hassanabad nullah with Hunza River, where a bridge of the road to Sumayar village crosses Hunza River. River width at the site is approximately 100 meters, for which a weir with lateral intake is being proposed.

1.2.6.2 Gravel Spill and Sand trap

Due to space limitations, gravel spill structure and sand trap will have to be constructed underground. Keeping in view the sediment load of Hunza river in this area, the size and associated cost of these structures may play an important role in the determination of the design discharge for this project.

1.2.6.3 Head Race Tunnel

The head race tunnel is proposed on right bank of the river, having about 7000-meter length. The tunnel alignment can be made in such a way that various adits are possible to allow the construction of the tunnel. The tunnel will be below the level of KKH throughout, which may simplify investigation and construction works.

1.2.6.4 Surge Tank

A surge tank is proposed near a turn made by KKH near village Nasirabad.

1.2.6.5 Penstock

Two number supported steel pipe of 1940 mm diameter, with 150 m total length of each is proposed in about 30° terrain slopes.

1.2.6.6 Power House

An external type power house at elevation 2120 m.a.s.l is proposed on a terrace on right bank of Hunza river. Two Francis type turbine generator equipped are recommended.

1.2.6.7 Tail Race

A rectangular tail race canal of 30 m length is proposed. The canal should discharge the flows into Hunza River.

1.2.6.8 Salient Features

Following are salient features as shown in Table 1.1.

Table 1.1 Salient Features

Sr. No.	Design Feature	Design Data
1	Design Capacity (P)	15 MW
2	Design Discharge (Q)	26 m^3/s
3	Gross Head (H)	80 m
4	Head Race Length	7000 m
5	Tail Race Length	30 m
6	Type of Project	High Head, Run-Of River

1.3 PROBLEM STATEMENT

Hunza region is in the grip of severe climate where temperature varies between -20 to 45ºC. the area is completely black out during winter season due to low flow in the streams. The demand of electricity during winter is high as opposed to down country. The demand during morning and evening is very high. The area is abundant of hydropower potential. The GB Govt. has planned number of hydropower projects in Hunza valley and surroundings. One of these projects, Nasirabad hydropower project of 15 MW have been identified on Hunza river as a run of river scheme. In this study, a research will be undertaken to use of hydropower potential at optimized level. By designing the project for peaking mode, the demand at peak can be met and potential could be used otherwise there is huge loss of power, if not exploited.

The present scarcity of fuel oil and its highly increasing prices has made it difficult to use the fuel oil for power generation purposes. The cheapest renewable natural resource is the hydel energy. This natural source is in abundance in Pakistan and needs to be exploited. The exploitation of natural resources will help to meet the growing power demand of Gilgit-Baltistan. The contribution of hydel power generation into Regional Grid being cheap energy resource will help to reduce the tariff.

Electricity demand varies throughout the day which can be divided into peak hours and off-peak hours. Usually, peak hours are considered two hours in the morning i.e. from 07:00 am to 09:00 am and two hours in the evening i.e. from 07:00 pm to 09:00 pm or total four hours in the evening from 07:00 pm to 11:00 pm. During peak hours the thermal energy is used. If this demand is met through hydropower, the cost can be reduced. Tarbela, Mangla and Ghazi Barotha are operating as peaking hydropower plants in Pakistan and thus reducing the cost of electricity.

1.4 OBJECTIVES

Followings are the objectives of the study:

- To determine the energy output of project under peaking and continuous flow conditions using software SIMAHPP.
- To develop a methodology to compute power production considering the power house functioning as peaking system as well as continuous system.
- Computation of reservoir volume for the storage of extra flows to be used in peak hours i.e. peak flows.

1.5 SIMAHPP

SIMAHPP (Simulation and Assessment of Feasibility of Hydropower Projects) is windows based software. It is designed to model the project and to evaluate that either the hydropower projects are economically feasible or not. It is designed to work out a lot of challenges including determination of design discharges and selection of appropriate water turbines. Simulation can be carried out for small hydropower projects to mega hydropower projects as well as for single site to multiple sites. Results can be obtained in the form of detailed project characteristics. Results are presented in tabular and graphical form on the basis of three main input parameters including hydraulic, financial and environmental (Environmental-expert, 2010).

It gives multi criteria project evaluation which is described below:

1.5.1 Hydraulic Evaluation

Technically, it helps to calculate:

- Design discharge
- Power for the effectiveness of a system
- Optimized Power Production by utilizing optimal system operation period.
- Suitable selection of unit for the modeled hydropower system.

1.5.2 Financial Evaluation

Feasibility of any project on the basis of simulation results can be determined using SIMAHPP

- Investment costs
- Annually or monthly Amortization rate
- Payback period
- Investment costs according to system volume.
- Carbon market turnover.

1.5.3 Environmental Evaluation

With the increase of global warming, hydropower projects are helpful in reduction of carbon dioxide quantity being a renewable energy source. In generation of same quantity of energy, hydropower projects release less amount of carbon dioxide as compared to other non-renewable sources such as coal and natural gas. Keeping in view the environmental factors, this software will be helpful to see that what is the role of planned hydropower projects in the global warming reduction (HYDRO XPERT, 2010)

1.6 UTILIZATION OF RESEARCH

In this research, it will be demonstrated that peak hour plants are need of the time both for economical point of view and meeting demand during peak hours. As the cost per unit during peak time is high. So, more revenue can be generated which can be based for further development of HPP’s in the region. Further, cheap energy utilization during peak hours will also replace expensive thermal energy production. Later on, at any stage these power projects can be connected to National grid which will give additional benefit.

Chapter II
LITERATURE REVIEW

Pakistan is facing intense energy crisis at present. All possible efforts should be made in order to improve the capacity of energy production. This could only be possible by identifying and exploring more sites and more water and power resources. The installation of peaking facility in any project is the need of time to supply secure, dependable, continuous and cheap hydropower energy.

In Pakistan, during peak hours energy is supplied from thermal generation which is expensive. Hydel power stations do not provide continuous supply throughout the year depending upon the availability of flows. It ultimately leads to demand for thermal energy in peak hours. Although hydropower projects take time in development but they produce energy at a very low rate (WAPDA, 2012).

Keeping in view these requirements projects are being planned to work as peak hour plants by increasing the stored capacity at fore bay or reservoir. Furthermore, projects are being optimized to get most efficient system in hand. By optimization, enhanced energy output can be obtained at optimum cost.

2.1 PEAKING PLANTS

Peaking power plants generally run only when there is a high demand, known as peak demand for electricity. Because they supply power only for short period. The power supplied in this period at a much higher price per kilowatt hour than continuous power. Peak load power plants are used in combination with continuous power plant, which supply a reliable and constant amount of electricity, meeting the minimum demand (Wikipedia.org/peaking power plant).

2.2 OPTIMIZATION

It can be defined as, "taking decision or to design a plant most efficient as possible". In case of hydropower, optimization is carried out to obtain desired results by utilizing minimum water consumption (Curtiss et al, 2012). Maximum benefits can be obtained from a project in terms of cost and power generation using different optimization techniques. Optimum design of hydropower project by increasing power output and reducing cost by making it economical is known for a long time. But due to complexity of hydropower project and its optimization model, it is difficult to carry out its complete utilization. Various studies have been carried out for the optimization of high head (run of river) hydropower projects. Different alternatives may be adopted for optimization. Best suited components of hydropower plant can be obtained by applying optimization technique. Similarly, best layout of plant is achieved. Optimization is carried out to solve complex problem in hydropower. It can be done by analytically, graphically or mathematically. Software may also be used for this purpose.

2.3 BENEFITS OF OPTIMIZATION

By using different optimization techniques, following benefits can be obtained:

- Most economical hydropower plant/project
- Maximization of energy output
- Improved performance of units/components of plant

- Enhanced / augmented service life of components / equipment
- Optimum design of a plant
- Reducing power losses
- To maximize the value of water resources

2.4 TYPES OF OPTIMIZATION

Chief of Engineers, U.S. Army or (USACE) and other American federal agencies defined following types of optimization related to hydropower in the 1980s.

1. Improved system of a single unit regarding energy generation for available flow with same head.
2. Synchronization of turbines to obtain a powerhouse production set point utilizing the minimum discharge. The enhanced performance of the system at this phase is attained by selection of the most excellent feasible turbine and load sharing.
3. Synchronization of all the storage reservoirs and powerhouses in a catchment area/water basin.
4. Synchronization of several catchment areas in a specific terrain or locality.
5. Synchronization of several renewable resources in an area. (Curtiss et al, 2012)

2.5 OPTIMIZATION TECHNIQUES

To carry out optimization, a large no. of techniques and software are available. These techniques can be applied to hydropower generation, flood control, water supply and irrigation. Some techniques are described below:

2.5.1 Decision Support System

It suggests rapidly how to exploit hydropower benefits while interacting non-energy features of water management e.g. special effects on the river downstream and on the fore bay upstream. The components of decision support systems Depend on how quickly specific judgment must be made. Figure 2.1 shows the components of a comprehensive decision support system developed by Charles Howard & Associates Ltd. for operations and for planning.

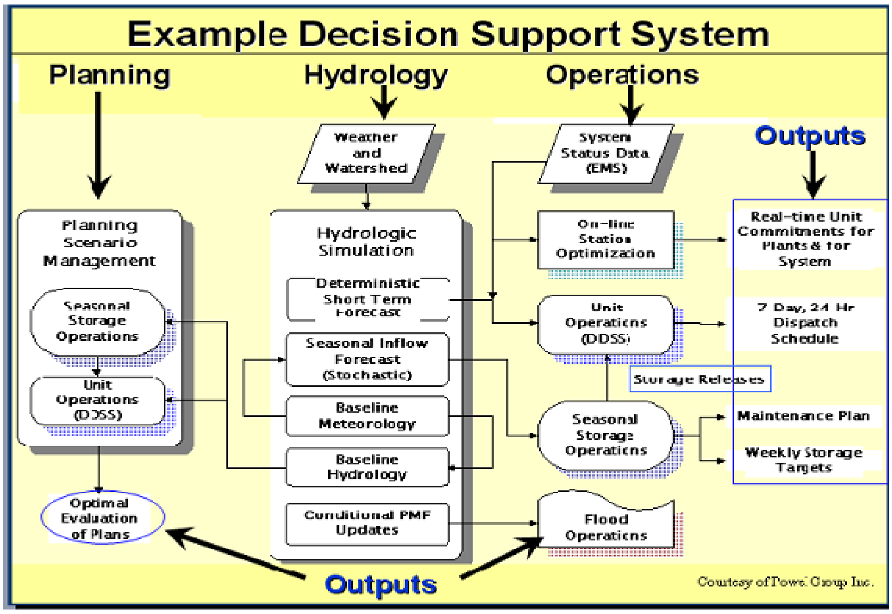


Figure 2.1 Components of a Comprehensive Hydroelectric DSS

While carrying out the investigation/research of a hydropower plant/ facility, DSS gives guarantee of utilizing the finest available information (facts and figures) that confines the most benefits. With a well-designed decision support system, this objective can be accomplished. Guidance for new trainer can be obtained from software even when some changes occur in operating settings. Decision support systems presently in operation comprise single generating stations, cascades of dams, and difficult river networks.

The components of decision support system are different for each hydropower system showing different priorities and forecasted benefits and costs. Decision support systems are unique for one specific site (Howard, 2006).

2.5.2 Particle Swarm Optimization

Nowadays, this method is very popular in research fields. Application of this method is somewhat a new technique. Best design in terms of benefit and cost ratio is obtained for hydropower plants by using this method. Benefit cost ratio was determined by taking into consideration multiple cost parameters and turnover production of HPP. The result was greater than one making it economically feasible for hydropower projects. This is required criteria for making any hydropower project feasible that benefit cost ratio should be greater than one. Direct costs and turnover obtained were the basis in analyzing the benefit cost ratio. Nevertheless, attention was not paid to other advantages (Rahi et al, 2011).

Selection of several turbines is carried out randomly among the total available turbines for specific purpose. Further, detailed selection of units is made arbitrarily. The load sharing algorithm can be executed only in the case, if the available power is greater than or equivalent to the required power. The algorithm reiterates again and again. As a result of this iteration, the optimum turbine is chosen and load sharing output is selected. To get the most reliable results, a number of iterations has to be performed. Moreover, with this method, choice of units can be improved which ultimately leads to the best output (Curtiss et al, 2012).

2.5.3 Stochastic Dynamic Programming (SDP)

Two steps are performed in this method:

1. Discretized the Inflow and Reservoir Storage: for same time frame, influx have been divided into number of non-continuous intervals starting from minimum to maximum. An observation was made for this influx series. The probability of inflow interval i (during time period t) to inflow j (during time period t + 1) is computed.
2. To Investigate the best proposal: By using Equation

   F(Si,Ii,Ii+1…..Ii+n) = max Bi(Si,Ri)+Ei+1(f(Si+1,Ii+1,Ii+2…….Ii+n))

   The best proposal is determined by utilizing this equation and making it best operational measures. Following are the measures used in research.

$$V_t + 1 = D(V_t, I_t)$$

Where t is the reservoir volume required to choose, and V_t and I_t are the present reservoir volume and influx. This model is used for hydropower generation (Mythili et al, 2013).

2.5.4 Lowest Peak Efficiency Dropping for Unit Selection

In this process, peak efficiency is the basic criterion in selecting the turbines. Units having lowest peak efficiency are dropped off. Load sharing is find out and evaluated to the former findings. Similarly, units having low efficiency are being dozed off, unless the power requirement is not obtained by utilizing the producing units and units having high efficiency are selected as a result of this method. To find an optimum approach, the computer algorithm takes no time for any given setpoint in a 10- turbine powerhouse, with an accuracy margin of 0.5% (Curtiss et al, 2012).

2.6 RELATED WORK

By using an alternative layout of a project and optimization technique, Robertson (2009) enhanced the power generation of Aberfeldie Hydropower project up to 25 MW. This project was constructed in 1922 with generating capacity of 5 MW. The project was optimized for 20, 25 and 30 MW. The optimization technique was implemented for selection of optimized diameter of low pressure tunnels in the waterways of project for each capacity. The objective was to get the pipe diameter with maximum benefit to cost ratio. Optimization for high pressure tunnels was also performed. The results showed that the most economical diameter found for high pressure tunnels was 1m. This economical diameter for high pressure tunnels was less as compared to diameter for low pressure tunnels. Later, optimization for number of turbine units was carried out. Several combinations of turbine units were taken. Two identical turbines, three identical turbines, four identical turbines, and two identical turbines having same capacity with one different unit having less capacity and two turbine units having different capacities were selected for evaluation. Conclusion was that the optimization of project can be carried out with varying potential energy from 20 megawatts to 30 megawatts. For improved and enhanced system of project up to 25 megawatts, three numbers of turbine units having same capacity were chosen. Type of turbine was horizontal Francis. Its enhanced mean annual energy was 105 Giga Watt hours which was previously 34 Giga Watt hours. After improving the system, Plant Factor reached up to 48%.

Leon (2014) performed Dimensionless analysis for hydropower projects. In this analysis, optimum flow and diameter of penstock was determined for two types of turbines i.e. impulse and reaction turbines. The aim was to produce hydropower energy by minimizing water consumption. Various relationships were established among power, energy, discharge and losses to develop number of dimensionless equations. Further, by combining these equations optimal discharge and penstock diameter were determined. The conclusion was made to reduce water utilization as minimum as possible, gross head and net head ratio must not be greater than 15%.

For a specific flow rate, increase in energy losses and water velocity occurs with the decrease in diameter of pipe. This happens because friction is a function of velocity. With the increase in velocity, friction also increases. Yet, increase in diameter of pipe would result a drop-in velocity as well as a decrease in friction (head loss). But there is a significant increase in the price of pipe with the increase in diameter of pipe. The method adopted for penstock design and penstock sizing will be helpful to maintain equilibrium between energy loss and diameter of pipe, material of pipe, and thickness of wall. For the preliminary design of penstock, proposal of 4 ft/sec velocity is presented (McKinney et al, 1983).

Mays (1999) determined the economically suitable penstock size. The most optimum diameter of penstock can be obtained by determining the total cost of construction and energy loss cost. By increasing the penstock diameter, the energy loss cost decreases but penstock cost will increase. Best penstock size can be decided by using the hit and trial method.

Number of factors e.g. flows, head, and plant capacity involve in the turbine selection of hydropower projects. In the process of selecting type of turbines, focusing on the appropriate number of units, setting of center line, specific speed, size of runner and elevation of center line of turbine is the primary purpose of this process. Two fundamental methods are usually used for selection of turbines (1) By discharge and head (2) On the basis of specific speed. For turbine selection, standard graphical charts are followed. While selecting the turbines, not only technical but economic and socio environmental factors must be taken into account (Sangal et al, 2013).

Using the least number of turbines for any project is economical. It is expedient to use several units when flows are available in abundance. Normally, preference is given to same capacity turbines when several units are being utilized. While choosing optimal units, different options are considered for one unit, two or more than two units of same capacity and multiple units of different capacities. Suitable number of turbines can also be selected by analyzing the flow duration curve. Different methods are adopted for turbine selection (WARNICK et al, 1984).

In the demonstration of Monograph No.20 of USBR (1976), it is recommended that while selecting turbines, care should be taken in this regard that units can be operated efficiently when there is a varying flow. The turbines should be manufacture in this way to comply varying discharge series. During process of selecting turbines, precise investigation of necessary data is carried out. Necessary data consists of availability of flow data, how reservoir is operated and field data. The cost of hydropower plant is dependent on the number of units. Efficiency of turbines can be increased by using several turbines.

A dynamic programming model was developed for Itaipu hydroelectric project. Its planning and designing was carried out in such a manner that generation by generating units can be optimized in the highly lucrative way. The location of this project is in south of America on Parana River. Its generation capacity is 12.6 Giga Watt Hours. 18 number of turbines are installed with same capacity of 700 megawatt each. The total plant efficiency is affected to a great extent by utilizing several turbines and generator units. By optimal generation of turbine units, millions of dollars can be obtained every year in terms of direct cost benefits (Arce et al, 2002).

Tuhtan (2007) carried out cost optimization of small hydropower projects for the case study of Neumuhle, Southern Germany. The electricity demand increases as world economy increases. Keeping in view the future possible energy sources, hydropower has multiple advantages. It is most efficient, low annual maintenance cost and its life span is long. Developed countries have exploited large scale hydropower potential whereas in developing countries a large-scale hydropower development is still required. However, small hydropower development is still required in developed as well as developing countries. In construction of small hydropower project, its high initial investment cost is the biggest economic challenge in comparison of fossil fuel sources. By providing limited set of site specific data, best suited design components of small hydropower can be obtained at initial stage. After this optimization, to set the boundaries of the cost uncertainty of four costing groups and the calculated net present value of the project, stochastic simulation is used. RETScreen formulae-based costing method for four cost categories was used. In the first step, the assessment of suitability of adopting this method was carried out. After this, the NPV was figured out for a 30-year design life and making it efficient by utilizing a continuous Genetic Algorithm. Stochastic simulations were performed using the Monte Carlo method. In this simulation, comparison was carried out between the anticipated prefeasibility cost accuracy and the results of research. While analyzing the cost, it was determined that the early accuracy of the costing equation had the greatest effect on the results. Moreover, a comparison was carried out between efficient optimal design and initial evaluation in finding out the initial values of flow rate and operating head. As a result of this comparison, performance of optimal design was very well.

Hermida (2013) carried out research by using an optimization technique to determine the best operation of a reservoir with both regulated and non-regulated hydro power plants. The proposal for computing the best energy bids of a set of hydropower plants in a reservoir was presented as an optimization problem. The operation was planned for the short duration i.e. 24-Hour, the application of model was applied to a real Spanish reservoir. The requirements of environmental flows and social uses for the real operation were considered by the algorithm. By considering both of these requirements, the assessment of economic weight of these requirements was performed by this program in the management of resources. Without direct control abilities, out of these, one hydro plant was run of river. Along with this, the operation of hydro power plants was modified. It was observed in the results that the run of river plant can be effectively regulated by utilizing the storages of the other plants which are not fluent. Social consumption costs were found more significant in simulations as compared to the environmental conditions. An estimation was carried out for the charges to be incurred for provision of water for social use. The generation of maximum profitable electricity in the daily power market was calculated by this method keeping in view the environmental restrictions and provision of water for community. The algorithm proposed can easily be stretched to account for different operative limitations on the hydro systems.

Due to high price of electricity during peak hours i.e. from 1900 hrs. to 2200 hrs., industrial customers try to find other optimum solutions such as independent power supplies. Customers don’t rely only on the power supplied by the grid. An optimum solution was found out for a mill where paper recycling was carried out. This mill aimed to carry out its working even during peak hours. The location of mill is in Rio Grande do Sul, in southern Brazil. In this mill, PV module, a set of diesel generator and a micro hydropower plant are considered to be used. Study was carried out for two number micro hydropower plants. One plant had to be rehabilitated and other one had to be completely equipped with tools. Homer software was executed to find out the highly appropriate set of components. The result was excessive sale of electricity to the grid. It looked significant to the feasibility of these alternate options that were not built exclusively on diesel generator. The optimum product comprises of a set of diesel generators and micro hydropower plants as a first alternative. While as another alternative, only one hydropower plant was considered. By a considerable penetration of PV modules, specific condition was that if there is 12% reduction in its present value, selling a total electricity equivalent to one that was purchased. As annual sufficient water is not available, first site demands to make up for this deficiency. However, in second alternative, this supplement is not required as annual water availability is abundant (Beluco et al, 2013).

Fuzzy MCDM (Multi Criteria Decision Making) was used for selection of small optimal hydropower project. It is a multi-criteria optimization technique which offers a consistent procedure to categorize other options of natural energy sources by considering the various purposes and restrictions (Adhikary et al, 2015).

Turkey's energy demand and its dependence on imported energy resources is mounting rapidly. In order to combat this energy challenge, efforts are being made to utilize the domestic renewable sources. Turkey has significant water resources. The main aim is to assess the hydropower capacity of the Zab River reservoir by using Geographic Information Systems and Remote Sensing methods which will be utilized ultimately for the development of country. SIMAHPP software was used to calculate the annual energy generation, installed capacity and estimated costs. Suitable locations for 12 dams in the basin were also determined with the help of SIMAHPP (Cabuk et al, 2013).

Cine Dam will be constructed as a multipurpose dam. Electricity generation, to control floods and to fulfill irrigation requirements are its main purposes. It will be built on Cine stream. This stream is located at Buyuk Menderes River in Turkey. This stream has significant importance being an important bay of Buyuk Menderes River. The results of this research were compared by authors with other researches carried out by other organizations. Hydroelectric energy potential of the project was determined using the SIMAHPP 4 (Simulate and Assess the Feasibility of Hydropower Project). It is a professional software. The comparison of calculated hydroelectric potential by using SIMAHPP and power production worked out by other departments was carried out. The results of this comparison were same. The observed values of unit power, installed power, rated design discharge of units and energy production per annum were very close to the compared values. The power plant was planned using the data collected from the tributaries of last 43 years. This plant was planned with energy generation potential of 210.87 GWh/year. Its capacity was 48.14 MW. Its observed design discharge was 35 m^3/sec. The water structures have high costs as they will have to be operational for many years. So, for the safe operation during the service life of any project, analyzing the planning and design of any project should be carried out by using different computational methods. It will be helpful for the planning of the project (Koc et al, 2016).

2.7 REVIEW OF PREVIOUS STUDIES

2.7.1 GTZ Studies

Location of Lawi Hydropower Project is approximately 40 km away from Chitral in the Khyber Pakhtunkhwa. Initially, Lawi HPP was harnessed and designed by German consultants in 2001 as a run-off- river project. On the upstream of dam, a little live storage was suggested which would be utilized for daily peaking. The total head 405 meter was determined from the intake structure to the site where powerhouse is located. In addition, an estimation was made that using this total head and chosen layout, potential energy of the powerhouse would be 65 megawatts.

2.7.2 Feasibility Studies by HEPO (WAPDA)

Hydroelectric Power Organization performed feasibility studies in 2007. A critical evaluation was done by this organization. They analyzed the project with power potential of 67.63 megawatts on Shishi River which is a stream of Chitral river on left bank. A total head of 413 meter was exploited and energy generation per annum was estimated approximately 295 Giga Watt Hours against 20 m^3/sec flow.

A proposal for concrete weir was given on Shishi river which is near Lao Nassar village. This weir will divert 20 m^3/sec water to a headrace tunnel. Headrace tunnel will transport this flow to Lawi village. From here, flows can be carried down to powerhouse through penstock. The water from powerhouse will be released to Chitral river through tailrace tunnel which will be concrete lined.

"An analysis to find out best scheme layout, design flow, economical conduit size, size of surge shaft, Number and specifications of turbines for increasing the plant efficiency and energy against lowest possible cost for the final scheme layout can be carried out by feasibility study. Cost and economic parameters are basis of this study. To determine the dimensions of surge tank, Hydraulic Transient analysis was performed too. Installed capacity optimization criteria was critically evaluated for the progress of high head hydropower projects. During this evaluation, data of Lawi hydropower project was utilized performing the precise optimization with the help of worksheets, hydropower dimensioning and costing software (HPC) and AFT impulse (for optimal sizing of surge tank). An optimized potential of 69 megawatts, average energy of 297.90 Giga Watt hours per year, Plant factor of 49.33% with three numbers of vertical Pelton turbine units were recommended" (Haroon et al, 2005).

2.8 EXAMPLES OF PEAKING OPERATION

2.8.1 Duber Khwar HPP

The Project is located in the District Kohistan of Khyber Pakhtunkhwa (KPK) of Pakistan on the river Duber Khwar, a right bank stream of Indus river. Access road is available to the project area Pattan. It is located 270 kilometers away from Rawalpindi and 300 kilometers from Peshawar.

The enhanced power plant production is 130 megawatts. Its design flow is 29 m^3/sec at an average total head of 535 m attained from a channel which is 4873-meter long. The annual production of electricity is estimated as 595 GWh/annum will be the peak energy. The firm capacity is 105 MW peak energy and firm capacity refers to the 4-hour daily peak at 90% availability.

2.8.2 Ghazi Barotha

Ghazi Barotha may be referred to as a model for peaking hydropower plant. The 16.2 Mm^3 storage at head pond allows storing extra water during off-peak hours thus increasing the head about 10-15 ft. The power demand is usually low during off-peak hours, which is met with opening 2-3 units. Whereas the incoming discharges to the channel are more than the released discharges. So, the additional water coming in gets stored at the forebay. At peak demand hours, all the units are operated at their full capacity. At the end of peak, the forebay volume gets used and 2-3 units are shutdown with 2-3 operating. This way another cycle of filling of forebay starts and until next day peak hours it gets filled. Almost all the water gets stored at chashma reservoir from where irrigation water releases are regulated.

2.8.3 Khan Khwar HPP

The high-head hydropower development at Khan Khwar will provide cheaper hydropower. The project having an installed capacity of 72 MW corresponding to a designed maximum discharge of 35 m^3/sec at 20% availability of flow. Optimized annual energy generation will be 306 GWh out of which 105 GWh will be the peak energy. The firm capacity is 70.7 MW. This is a hydel scheme with a smaller reservoir. It will store water in the low discharge period for daily peaking operation. Storage volume for four daily peak operation will be 400,000 m^3.

2.8.4 Mangla Dam

Mangla Dam is also being used to supply peak power. All the units are run in peak hours to meet the demand. Whereas in off-peak hours, only 3-4 units are run accordingly with the discharge available. The extra water released during peak hours is collected and stored at Rasul Barrage.

2.8.5 Tarbela Dam

Tarbela Dam is being used to supply peak power with off-peak power generation as well. If provision of a large reservoir like Kalabagh is there downstream of Tarbela, then Tarbela can be run only in peak hours. Currently, the extra water released during peak hours is collected and stored at Ghazi Barrage.

2.8.6 Allai Khawar HPP

The optimized maximum power output is 121 MW with designed discharge of 21 m^3/sec at 20% availability of flow throughout the year to utilize maximum available flows. The optimized project will produce 463 GWh annually. Out of which, 160 GWh will be available during 4 hours/day during peak hours. The firm peak power available during these four hours is 81 MW annually.

Chapter III
METHODOLOGY

3.1 DATA COLLECTION

The required hydrological and topographic data for optimization of Nasirabad hydropower project was collected from Hydro Planning Department of WAPDA (HEPO-WAPDA) and surface water hydrology project of WAPDA (SWHP-WAPDA). Contour map of the site Nasirabad was also collected from Survey of Pakistan.

3.2 DATA SYNTHESIS

As there is no gauging station installed on Nasirabad to measure daily flows, no records of flows were available on site. To estimate the flows at site, daily flow data was obtained from the gauging station installed at Danyor bridge 46 kilometers downstream of the weir site. Historic daily flow records were available at Danyor bridge from year 1966 to 2004. After 2004, there was no flow data available due to earthquake of 2005 up to year 2013.

To utilize this flow data, a relationship was developed for two sites i.e. Danyor bridge and Nasirabad site considering the catchment areas. The catchment area at Danyor was 13157 Km^2 and the catchment area of Hunza river up to the intake site was estimated to be about 11656 Km^2. Ratio of both areas was taken to develop the suitable relationship of discharge for both sites which is given below.

Catchment Area at Danyor = 13157 Km^2

Catchment Area at Nasirabad = 11656 Km^2

Ratio of catchment areas $= \frac{11656}{13157}$

$$= 0.89$$

$$Q\ (\text{Site}) = 0.89Q\ (\text{at Danyor})$$

By using the above relation, daily discharge data at site of Nasirabad was computed from the available daily flow data of gauging station at Danyor bridge downstream of the project for the period of 39 years from 1966 to 2004. A graph was drawn to show the comparison of daily flows at both sites which is shown in following figure.

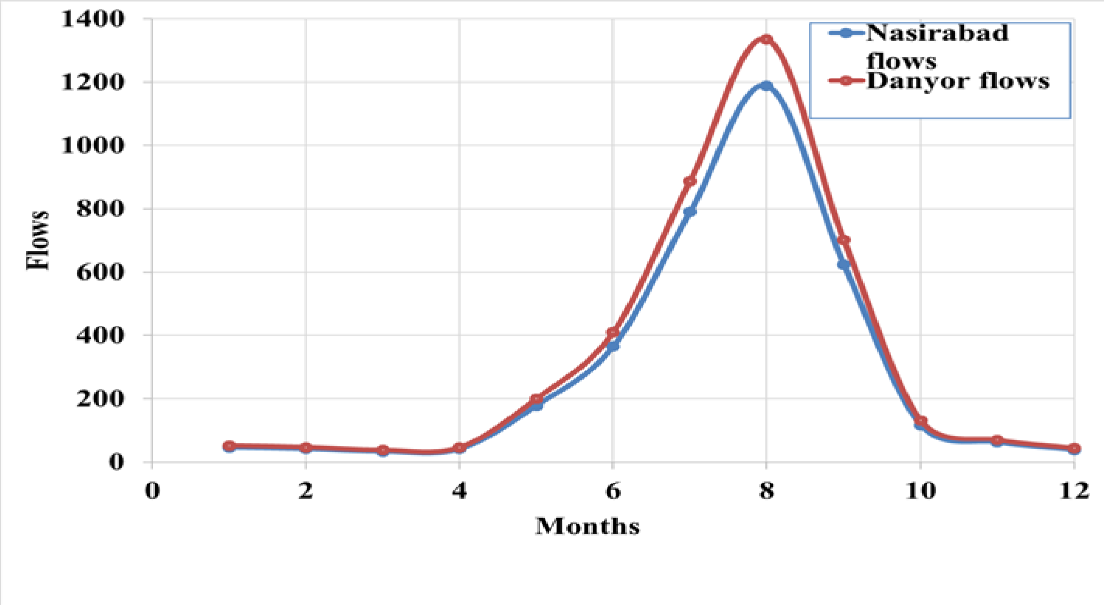


Figure 3.1 Comparison of flows (1966-2004)

This daily discharge data was further processed to determine river inflow volumes on 10-daily, monthly and annual basis. Daily discharge data of each year was converted to mean 10-daily flows, mean monthly flows and mean annual flows. Daily discharge data for one average year was computed by computing the average monthly flows for each year considering the historic record of 39 years flow data. (Table 2 in Appendix A). Mean annual flows for available flow data were 293.68 m3/sec. Flow duration curve was drawn to get the idea about the availability of flows throughout the year for an average year. (Figure 3.2).

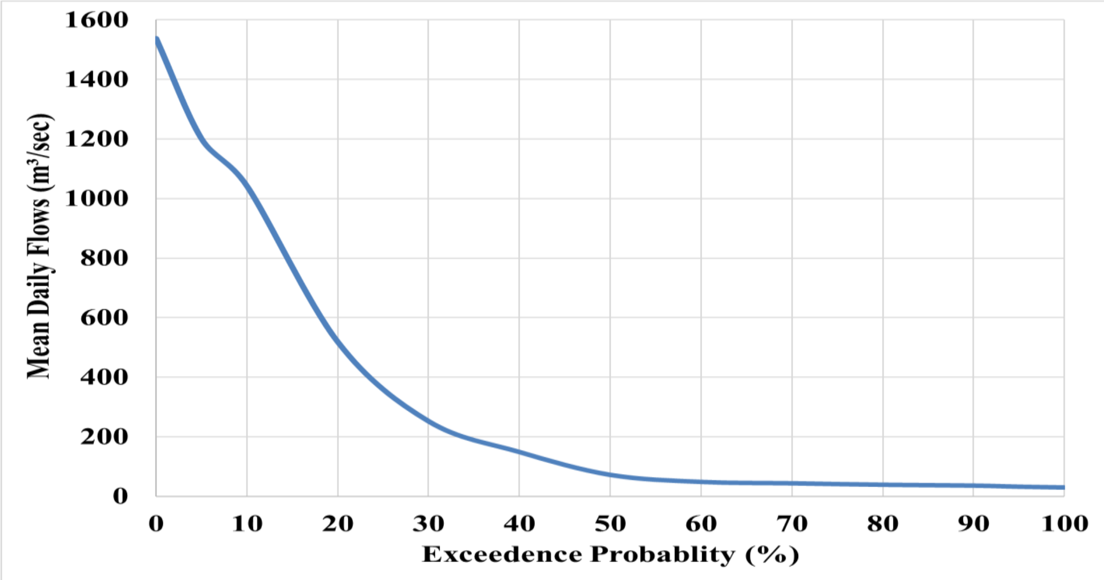


Figure 3.2 Flow Duration Curve (Mean Daily Flows 1966-2004)

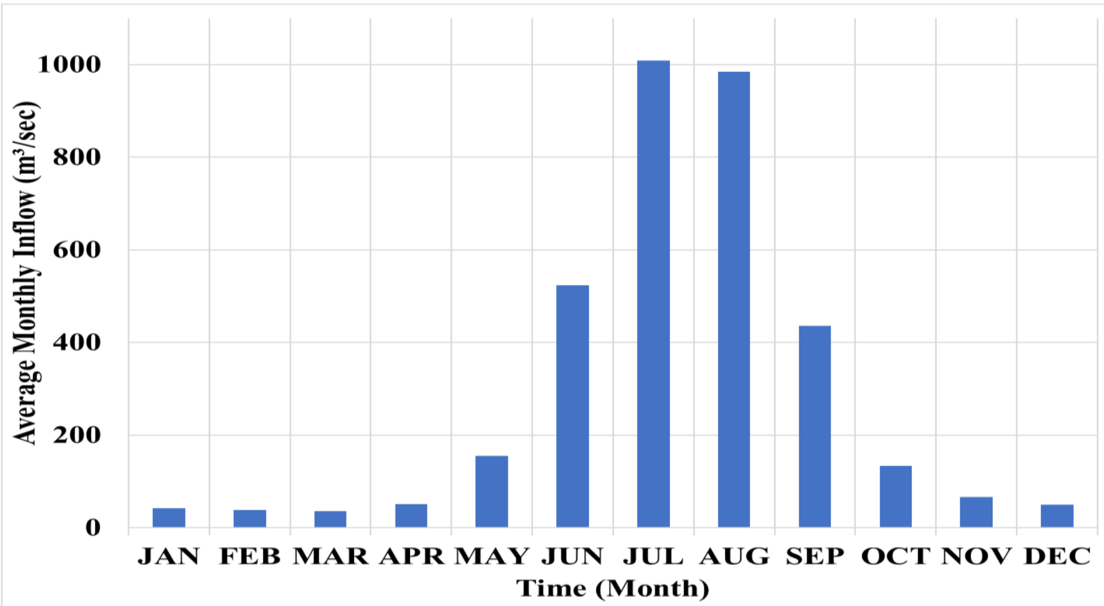


Figure 3.3 Average Monthly Synthesized Inflow (1966-2004)

Average monthly inflows at Nasirabad site were shown in figure 3.3 which showed the information that from May to September sufficient flows were available. Refer to mean monthly flows table 1 in Appendix A.

3.3 OPTIMIZATION OF PROJECT

Optimization of Nasirabad HPP was carried out to maximize the energy output of project using software SIMAHPP. In this software, simulation was carried out by entering the 12 entries of synthesized average monthly flow data for an average year of 39 years flow data. Refer to average monthly flows in appendix A. This flow data of 39 years at Danyor bridge was estimated for Nasirabad project using specific relationship. Average monthly flow data was entered as an input data. Gross head of Nasirabad site was 80 meters. Taking 2 meters as tail water head, net head of site was taken 78 meters. For financial information of Nasirabad HPP, assumed rate of electricity Rs.6/KWh for peak hours and Rs.4/KWh for off-peak hours was entered. Different rates for peak and off-peak hours were assumed because power supplied in peak hours commands a much higher price per kilo watt hour than power supplied during off-peak hours.

All required design and cost parameters including gross head, tail water head, cost of electricity per kwh, operation per day depending on the availability of flow per day, inflation rate, VAT and other taxes values were also entered as an input data in software. All investment cost and other designed values are mainly dependent on head and flow data. All this process is shown in flow chart in Figure 3.4. Data entry screens and procedure can be seen in Appendix A. SIMAHPP was simulated considering the different alternatives depending upon design time of operation which is as follows. Refer to Tables 4.1, 4.2 & 4.3.

1. For 4-hours design time of operation to be operated as peaking plant in combination with 20 hours off-peaking continuous operation.
2. For 24 hours design time of operation to be operated as continuous system.

3.4 SIMAHPP DESCRIPTION

SIMAHPP software designed to model and to determine the feasibility of hydropower projects. It is designed to work out a lot of challenges including determination of design discharge and selection of right water turbines. It is flexible in its operation. It can be executed for small to large hydropower projects. In addition to this, operation can be carried out not only for single site but for many sites. Flow chart for SIMAHPP is shown in figure 3.4. Technically, SIMAHPP computes power and energy with the help of following formulas on the basis of Flow Duration Curve and Hydrograph of available flows for given period of time.

3.4.1 Power

The power and energy were estimated on the basis of available average monthly flows data. The design capacity computed with following formula.

$$P = \frac{\eta \times g \times Q \times H}{1000} \qquad (3.1)$$

Where

P = Power in megawatts (MW) estimated from mean monthly discharge and corresponding head

Q = Mean monthly discharge data Q_d (m^3/s)

H = Net head (meters)

η = Combined efficiencies of turbine, generator, transformer

g = Gravity acceleration i.e. 9.81 m/s^2

3.4.2 Mean Annual Energy

The mean annual energy estimated on the basis of available mean monthly flows by using the following formula.

$$E = \frac{\eta \times g \times Q \times H \times t}{1000} \qquad (3.2)$$

Where

E = mean annual energy in GWh/annum

Q = average design discharge (m^3/s) and

t = time in hour

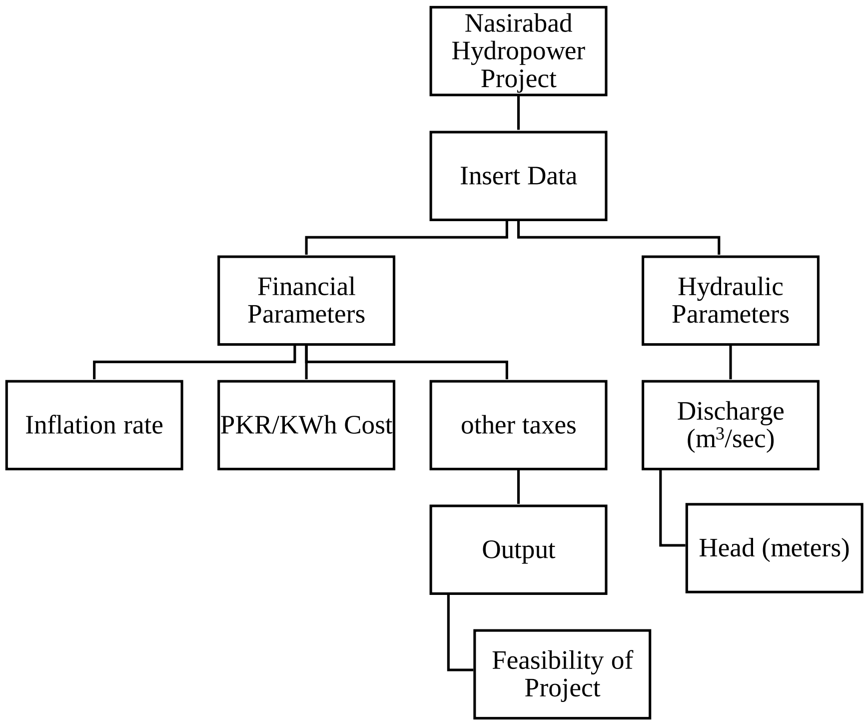


Figure 3.4 Flow Chart of SIMAHPP

3.5 COMPUTATION OF ENERGY OUTPUT

A methodology was developed to compute installed power and energy generation using Microsoft Excel. Computation for energy output was carried out by considering the two alternatives.

- Project working as peaking system in combination with continuous system.
- Project working as continuous system.

3.5.1 Peaking System

Following steps were taken for computation of energy assuming Nasirabad hydropower project working for fixed peaking duration i.e. for 4 hours in combination with 20 hours off-peaking operation. Refer to Tables 4.4 & 4.7.

1. Average monthly flows were used for computation
2. Average monthly flow values were converted to volume available in 24 hours as:

$$\mathrm{V} = \mathrm{Q} \times 24 \times 60 \times 60\ m^3$$

3. All selected units were assumed to run in peak hours according to the design capacity
4. Volume required in peak hours was found out as

$$\mathrm{V_p} = \mathrm{Qd} \times 4 \times 60 \times 60\ m^3$$

5. Volume available for operation during off-peak hours was found out as,

$$\mathrm{V_{op}} = \mathrm{V} - \mathrm{V_p}$$

6. V_{op} was converted to discharge available in off-peak hours as,

$$\mathrm{Q_{op}} = \mathrm{V_{op}} /\ (20 \times 60 \times 60)$$

7. Computed power produced for both peak hours and off-peak hours as

$$\mathrm{P_p} = \frac{\eta \times \mathrm{g} \times \mathrm{Q} \times \mathrm{H}}{1000}\ \mathrm{MW}$$

$$\mathrm{P_{op}} = \frac{\eta \times \mathrm{g} \times \mathrm{Q} \times \mathrm{H}}{1000}\ \mathrm{MW}$$

Where

P_p= Peak Power

P_{op}= Off-peak Power

Q = Average monthly available flow data (m^3/s)

H = Net head (meters)

η = Combined efficiencies of turbine, generator, transformer = 0.925

g = Acceleration due to gravity i.e. 9.81 m/s^2

8. Determined peak energy and off-peak energy generation as,

$$\text{Peak Energy} = \left(P_p \text{ in MW } \times \text{no. of days } \times 4\right) / 1000$$

$$\text{OffPeak Energy} = \left(P_{op} \text{ in MW } \times \text{no. of days } \times 20\right) / 1000$$

Where energy is in GWh

9. Annual energy was computed as the sum of average monthly peak and off-peak energy

10. Plant factor was computed as

$$\text{P.F} = (\text{Annual Energy } \times 100) / (8.76 \times \text{Installed Capacity})$$

3.5.2 Continuous System

Following steps were taken for computation of energy assuming Nasirabad hydropower project working for 24 hours operation as a continuous system. Refer to Tables 4.5 & 4.8.

1. Average monthly flows were selected for computation of energy
2. Determined net head
3. Average monthly discharge values were used as available flows (Q_a)
4. Selected number of turbines (N) depending upon available flows and design discharge for each unit according to the following criteria

$$\text{If } \frac{Q_a}{N} \geq Q_{unit} \text{ then provide } Q_{unit} \text{ otherwise } \frac{Q_a}{N}$$

$$\text{If } Q_a \leq Q_{unit} \text{ then provide } Q_a \text{ otherwise } \frac{Q_a}{N}$$

$$\text{If } \frac{Q_a}{2} \leq Q_{unit} \text{ then provide } \frac{Q_a}{2} \text{ otherwise } \frac{Q_a}{N}$$

$$\text{If } \frac{Q_a}{3} \leq Q_{unit} \text{ then provide } \frac{Q_a}{3} \text{ otherwise } \frac{Q_a}{N}$$

$$\text{If } \frac{Q_a}{4} \leq Q_{unit} \text{ then provide } \frac{Q_a}{4} \text{ otherwise } \frac{Q_a}{N}$$

Where

Q_a= Available flows

N= Number of Turbines

Q_{unit}= Design discharge for one unit i.e.42 m^3/sec

5. Determined monthly energy generation as under,

$$E = \sum \left(\frac{\eta \times g \times Q_i \times H \times \text{no. of days} \times 24}{1000} \right)$$

Where

i = 1 to N

E = Monthly Energy (GWh)

η = Combined efficiency of turbine, generator and transformer

g = Acceleration due to gravity (9.81m^2/sec)

Q = Available discharge (m^3/sec)

H = Net head (meters)

6. Annual energy was computed as the sum of monthly energy generation values

7. Determined Peak energy and off-peak energy generation as,

$$\text{Peak Energy} = \frac{(\text{Energy in GWh} \times 4)}{24}$$

$$\mathrm{Off - Peak\ Energy} = \frac{(\mathrm{Energy\ in\ GWh} \times 20)}{24}$$

8. Plant factor was computed as,

$$\mathrm{P.F} = (\mathrm{Annual\ Energy}\ \times 100)/(8.76 \times \mathrm{Installed\ Capacity})$$

3.6 STORAGE COMPUTATION FOR PEAKING OPERATION

The elevation-volume-area relationship for a reservoir indicates the variations of volume and surface area with elevation. From the contour map of the reservoir area, this relationship can be obtained. The elevation can be found out by topographic survey at haphazard positions. Larger intervals of contours depict a gently sloping flat valley area and closely spaced contours show steeply sloping cliff sides (Tariq, 2008).

In this study, Capacity required for storing the flows for peaking hours operation with respect to elevations was computed from Elevation-Area-Volume relationship. Refer to Table 4.9. To compute the required storage for peaking operation, surface area was measured for each contour. The volume between two successive contours was determined as:

$$\Delta \mathrm{V} = \frac{(\mathrm{A}_1 + \mathrm{A}_2)}{2} \times \Delta \mathrm{h} \tag{3.3}$$

Where

Δh = contour interval

Total volume at any elevation is obtained by adding successive incremental volume as

$$\mathrm{V} = \Sigma \Delta \mathrm{V} \tag{3.4}$$

The data points were plotted with volume or area on x-axis and elevation on y-axis, and area on secondary x-axis to draw Area-Elevation capacity curve. Refer to Figure 4.10. Contours for proposed reservoir area with required capacity were drawn with the help of AutoCAD. Refer to Figure 4.11. Grid spacing was located at an interval of 50m on contour map of the reservoir area. Contour map of site Nasirabad is shown in Figure 3.5.

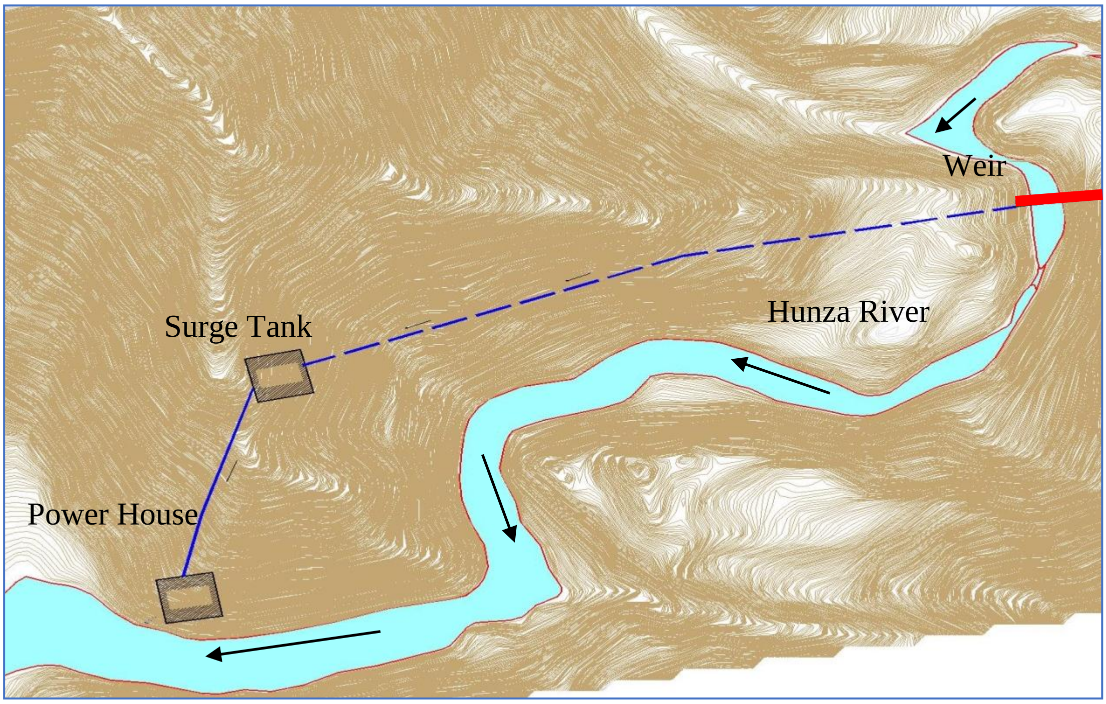


Figure 3.5 Contour Map of Site Area

After considering the bed level of the river or datum, contours were drawn at an interval of 2 meters at a suitable scale. Contours were drawn up to the maximum elevation level where required storage was achieved. Plan and sections of proposed reservoir area were also drawn for the site area. Refer to Figures 4.11, 4.12 & 4.13.

Chapter IV
RESULTS AND DISCUSSION

Nasirabad hydropower project was identified by WAPDA as a continuous run of river project. This study was carried out to maximize the energy output of project working as a peaking plant. Comparison of two studies with different alternatives was carried out on the basis of energy revenue and different number of turbines. Finally, project was optimized with increased design discharge and increased number of turbines working as a peaking plant in combination with continuous plant generating more revenue annually.

4.1 POWER AND ENERGY GENERATION

4.1.1 SIMAHPP Results

After the flow, head and economic data was entered in SIMAHPP, SIMAHPP was simulated considering the Nasirabad project as a peaking and continuous plant respectively. Results were obtained in the form of tables and graphs. Combined output annual energy for peaking and continuous operation was 235.15 GWh at 42.37 m^3/sec of flow with 92-% of turbine efficiency. For 4 hours operation, peak energy was 39.19 GWh and off-peak energy was 195.96 GW for 20 hours operation. (Tables 4.1 & 4.2). Flow 42.37 m^3/sec was selected at 90-% availability throughout the year because minimum flow conditions decide the maximum capacity of plant. Combined Annual Energy Revenue for both peak and continuous operation was 1120.91 Million Rupees on the basis of cost introduced for peak and off-peak hours. Installed power for this design discharge was 29.83 MW. SIMAHPP generated all these results considering only one unit of turbine. It did not give information about number of turbines. SIMAHPP integrated a model for sensitivity analysis. It showed how the calculated cost values were sensitive to the chosen parameters head and flow (Tables 4.1, 4.2 & 4.3).

Table 4.1 Peaking Operation (4 Hours)

Serial No.	Time (%)	Discharge (m^3/sec)	Efficiency (%)	Power (MW)	Energy Production (GWh/Year)	Energy Revenue (Million Rupees/Year)
1	10	1008.03	92	709.62	103.60	683.79
2	20	984.19	92	692.84	202.31	1335.23
3	30	523.13	92	368.27	161.30	1064.58
4	40	436.4	92	307.21	179.41	1184.11
5	50	133.48	92	93.97	68.59	452.72
6	60	66.82	92	47.04	41.21	271.96
7	70	50.81	92	35.77	36.56	241.27
8	80	49.29	92	34.70	40.53	267.48
9	90	42.37	92	29.83	39.19	258.67
10	100	36.13	92	25.43	37.13	245.08

Table 4.2 Continuous Operation (20 Hours)

Serial No.	Time (%)	Discharge (m^3/sec)	Efficiency (%)	Power (MW)	Energy Production (GWh/Year)	Energy Revenue (Million Rupees/Year)
1	10	1008.03	92	709.62	518.02	2279.29
2	20	984.19	92	692.84	1011.54	4450.78
3	30	523.13	92	368.27	806.50	3548.61
4	40	436.4	92	307.21	897.05	3947.04
5	50	133.48	92	93.97	342.97	1509.08
6	60	66.82	92	47.04	206.03	906.54
7	70	50.81	92	35.77	182.78	804.22
8	80	49.29	92	34.70	202.64	891.61
9	90	42.37	92	29.83	195.96	862.24
10	100	36.13	92	25.43	185.67	816.95

For continuous system, design time of operation was considered 24 hours. SIMAHPP was simulated again with all the same input data. (Table 4.3) In this case, annual energy generated was 235.16 GWh. A breakdown of total annual energy into annual peak energy was 39.19 GWh and off-peak energy was 195.96 GWh. Energy revenue for continuous system was 1034.69 million rupees.

Table 4.3 Continuous Operation (24 Hours)

Serial No.	Time (%)	Discharge (m^3/sec)	Efficiency (%)	Power (MW)	Energy Production (GWh/Year)	Energy Revenue (Million Rupees/Year)
1	10	1008.03	92	709.62	621.63	2735.15
2	20	984.19	92	692.84	1213.85	5340.93
3	30	523.13	92	368.27	967.80	4258.33
4	40	436.4	92	307.21	1076.47	4736.45
5	50	133.48	92	93.97	411.57	1810.90
6	60	66.82	92	47.04	247.24	1087.84
7	70	50.81	92	35.77	219.33	965.06
8	80	49.29	92	34.70	243.17	1069.93
9	90	42.37	92	29.83	235.16	1034.69
10	100	36.13	92	25.43	222.80	980.34

The results for both alternatives were almost same in terms of annual energy produced for one unit of turbine. But energy revenue for 4 hours operation in combination with 20 hours operation (peaking plant) was more than the revenue of 24 hours operation (continuous plant). In this case, additional 86.22 million rupees energy revenue can be generated. So, project was selected as a peaking plant working for 4 hours peak operation in combination with continuous system for 20 off-peak hours operation. At this point, 2nd alternative of 24 hours operation as a continuous system was dropped on the basis of revenue. Plant factor for both alternatives was 90 percent.

4.1.2 Graphs for FDC and Energy Produced

Graphs for site Nasirabad were self-generated in this software. Graphical outputs include:

- Flow hydrographs
- Flow duration curve (FDC)
- Power & Energy duration curves

Flow Duration Curve was drawn using available monthly flows for an average year. Refer Figure 4.1. The maximum and minimum flows available throughout the year can be obtained by the flow duration curve. For this project, optimum design discharge was selected at 90-% time availability of flow i.e. 42.37 m^3/sec. This curve showed that minimum available flows were 36.13 m^3/sec throughout the year.

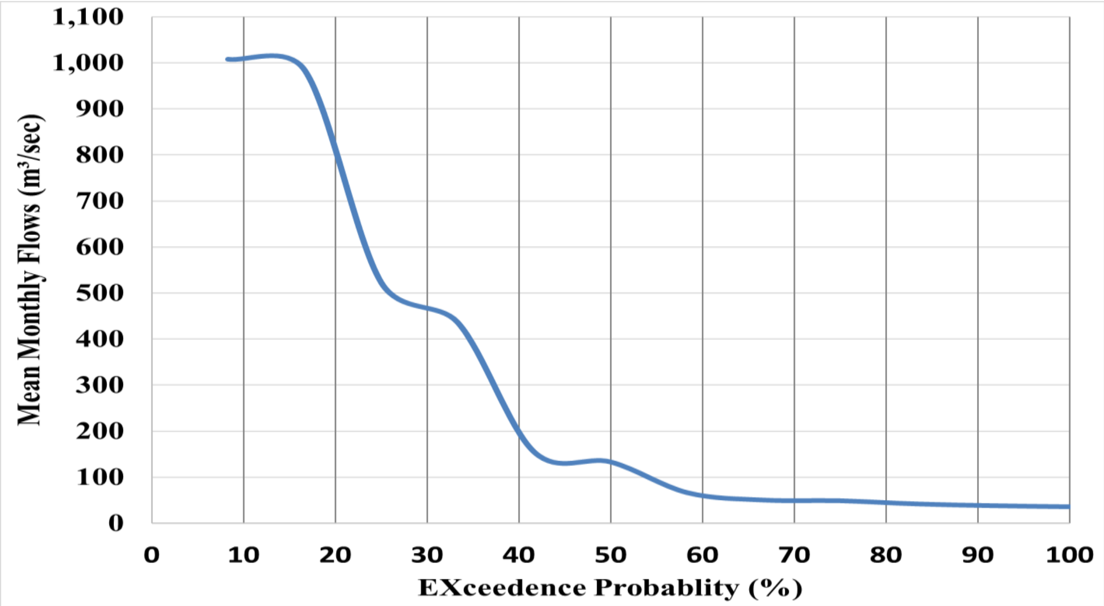


Figure 4.1 Flow Duration Curve (Mean Monthly Flows 1966-2004)

A hydrograph was drawn between mean monthly flow data of Nasirabad hydropower project for one-year time period. Refer Figure 4.2. This graph was representing the overall trend of flows throughout the year. In this graph, it can be seen that sufficient flows were available for 40-% of the time throughout the year.

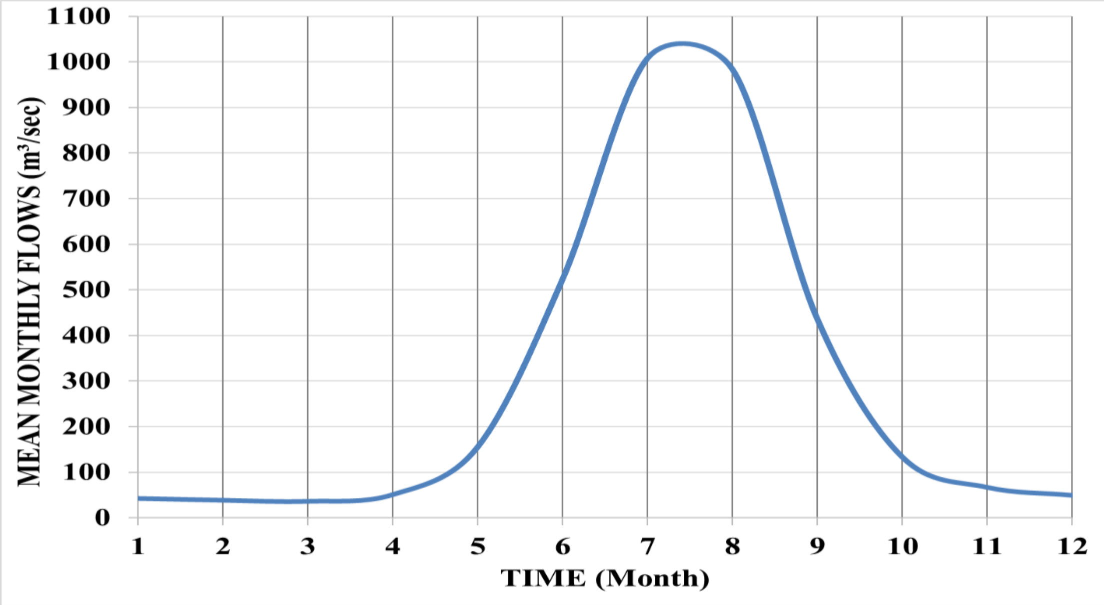


Figure 4.2 Hydrograph for Mean Monthly Flows (1966-2004)

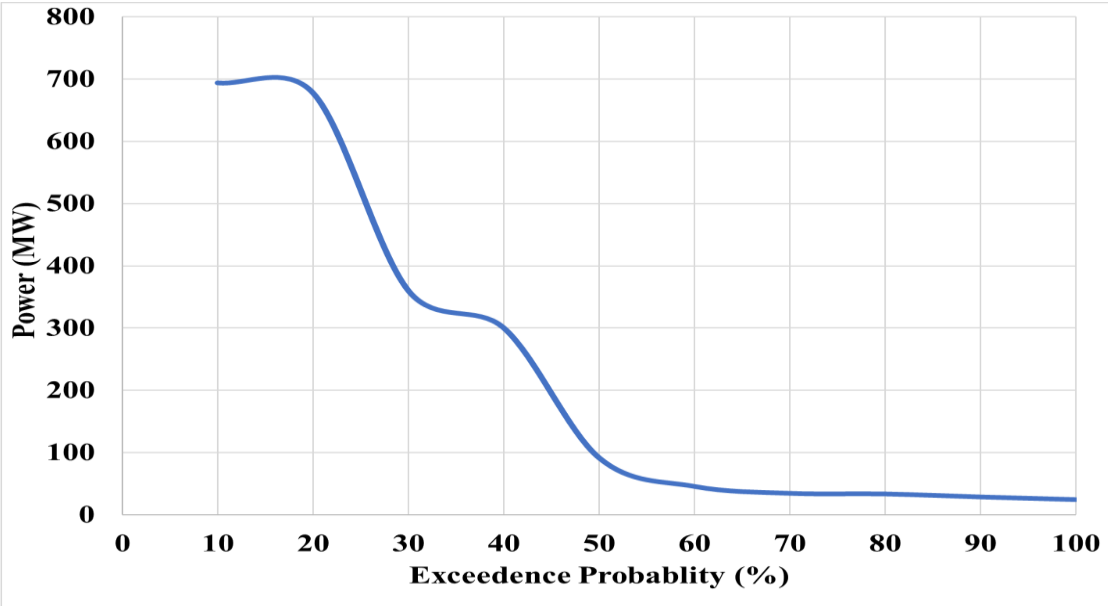


Figure 4.3 Power Produced for Peaking and Continuous system (One Unit)

Power generated curve was drawn between the percentage time of the year and energy produced throughout the year. Refer to Figures 4.3 & 4.4. Power and energy production values were selected against 90-% time of the year. The purpose for selecting the energy at 90-% availability of time was to provide energy for maximum time of the year. Power generated curve was also called Load Duration curve. This curve was demonstrating the total power available at the site. When the power-probability chart was examined, it was observed that the curve was parallel to the flow duration curve.

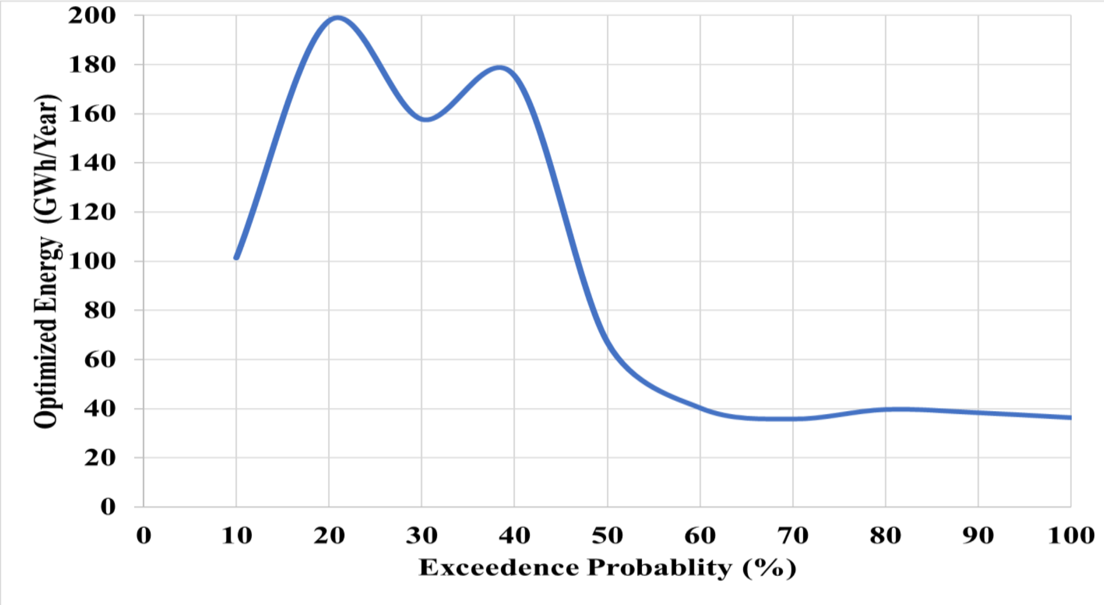


Figure 4.4 Energy Produced for Peaking and Continuous system (One Unit)

As flow rate grows, the power generation will increase. A decrease in flow, will result a reduction in power generation. Data entered to the software was the average monthly flow rates (12 number of data). Therefore, calculation results showed that the flow rates vary gradually for whole year. This was the reason that flow duration and power probability graphs were plotted as variable lines, changing throughout the year.

Graphs drawn for flow hydrograph, flow duration curve and power and energy duration curve showed the same trend for peaking as well as continuous system.

4.1.3 Energy Computation

A spreadsheet model was also prepared to compute power and energy of Nasirabad hydropower project considering the project as a peaking plant as well as continuous plant for one unit of turbine. Refer to Table 4.4 & 4.5 for peaking and continuous system respectively.

4.1.3.1 Peaking Operation

Mean monthly flows were taken for this purpose. Against each average monthly flow, peak and off-peak volume was computed. After this, daily and monthly power in MW and energy in GWh was calculated respectively. (Table 4.4). Optimum design discharge 42 m^3/sec was taken from the flow duration curve at 90-% availability of time. Refer to Figure 4.1. Total installed power was 30 megawatts. Annual energy computed through spreadsheet model was 255.74 GWh. Total peak energy computed was 43 GWh and total off-peak energy was 212 GWh. (Figure 4.5). Plant factor of project was 98.18-%. Energy revenue computed was 1106 million rupees annually on the basis of assumed cost of Rs.6/ KWh for peak hours and Rs. 4/KWh for off-peak energy.

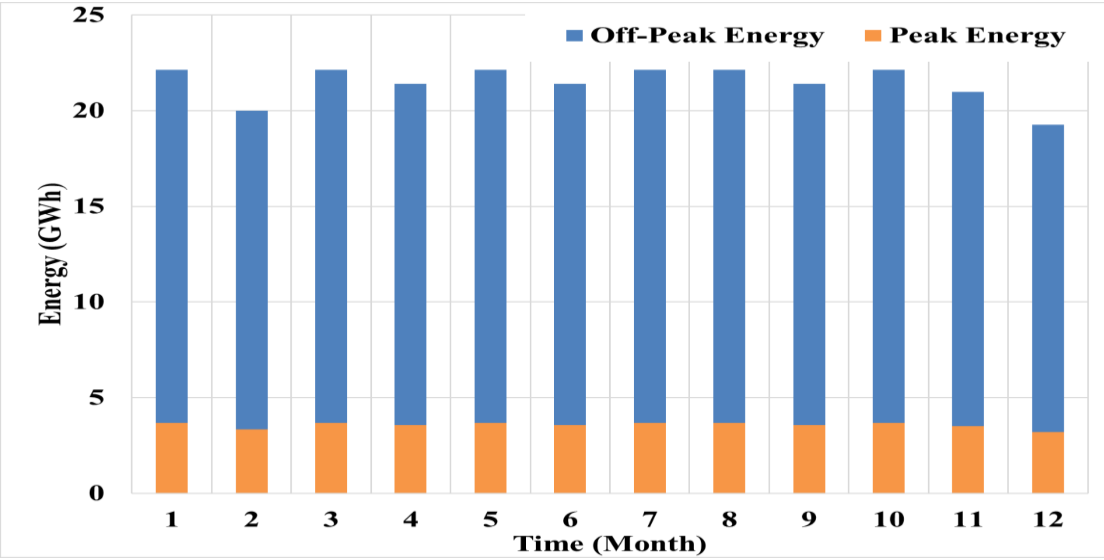


Figure 4.5 Peak and Off-Peak Energy (one-unit Peaking Operation)

4.1.3.2 Continuous Operation

Computations were carried out by considering the project as continuous plant. (Table 4.5). Installed power was 29.73 MW in this case. Annual energy generation was 250.65 GWh. Peak energy generated was 41.78 GWh and off-peak energy generation was 208.88 GWh considering one unit of turbine. (Figure 4.6). Plant factor of project was 98.76%. In this case, energy revenue computed was 1086.20 million rupees annually.

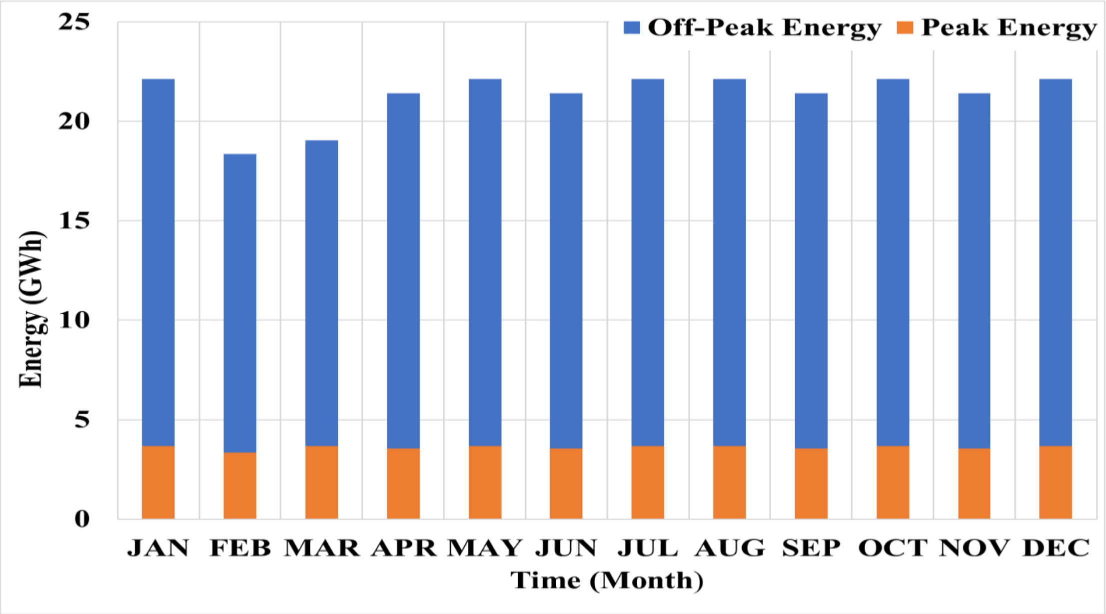


Figure 4.6 Peak and Off-Peak Energy (one-unit Continuous Operation)

Using this methodology, results of both alternatives were compared. From comparison, it was found that annual energy generation for both alternatives was almost same including peak and off-peak energy. Plant factor for both alternatives showed that sufficient flows were available throughout the year to run hydropower plant using one unit of turbine.

Table 4.4 Combined Peaking & Continuous Operation (1 Unit)

	Discharge		Volume			Time		Power		Daily Energy			Monthly Energy		
Month	Q_{inflow}	Q_{power}	Total	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Day	Peak	Off-Peak	Total
	m^3/s	m^3/s	m^3/day	m^3	m^3	hrs	hrs	MW	MW	GWh	GWh		GWh	GWh	GWh
JAN	42.37	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	31	3.69	18.44	22.12
FEB	38.56	38.56	3,331,584	604,800	2,726,784	4.00	20.00	30	27	0.12	0.54	28	3.33	15.01	18.34
MAR	36.13	36.13	3,121,632	604,800	2,516,832	4.00	20.00	30	25	0.12	0.49	31	3.69	15.34	19.03
APR	50.81	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	30	3.57	17.84	21.41
MAY	154.99	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	31	3.69	18.44	22.12
JUN	523.13	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	30	3.57	17.84	21.41
JUL	1008.03	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	31	3.69	18.44	22.12
AUG	984.19	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	31	3.69	18.44	22.12
SEP	436.40	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	30	3.57	17.84	21.41
OCT	133.48	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	31	3.69	18.44	22.12
NOV	66.82	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	30	3.57	17.84	21.41
DEC	49.29	42.00	3,628,800	604,800	3,024,000	4.00	20.00	30	30	0.12	0.59	31	3.69	18.44	22.12
													Annual Energy		255.74
													Plant Factor		98.18

Table 4.5 Continuous Operation (1 Unit)

TIME	PERIOD	AVAILABLE FLOW	NET HEAD	TURBINE - 1			MEAN MONTHLY ENERGY		
				Q_1	h_{T1}	$Energy_1$	Total Energy	Peak Energy	Off-Peak Energy
months	(days)	(m^3/s)	(m)	(m^3/s)	(%)	(GWh)	(GWh)	(GWh)	(GWh)
1	31	42.37	78.0	42.00	92.5%	21.68	21.68	3.61	18.07
2	28	38.56	78.0	38.56	92.5%	17.98	17.98	3.00	14.98
3	31	36.13	78.0	36.13	92.5%	18.65	18.65	3.11	15.54
4	30	50.81	78.0	42.00	92.5%	20.98	20.98	3.50	17.49
5	31	154.99	78.0	42.00	92.5%	21.68	21.68	3.61	18.07
6	30	523.13	78.0	42.00	92.5%	20.98	20.98	3.50	17.49
7	31	1008.03	78.0	42.00	92.5%	21.68	21.68	3.61	18.07
8	31	984.19	78.0	42.00	92.5%	21.68	21.68	3.61	18.07
9	30	436.40	78.0	42.00	92.5%	20.98	20.98	3.50	17.49
10	31	133.48	78.0	42.00	92.5%	21.68	21.68	3.61	18.07
11	30	66.82	78.0	42.00	92.5%	20.98	20.98	3.50	17.49
12	31	49.29	78.0	42.00	92.5%	21.68	21.68	3.61	18.07
MEAN ANNUAL ENERGY (GWh)						=	**250.65**	**41.78**	**208.88**
PLANT FACTOR						=	**96.23**		

But more revenue can be generated by considering the project as a peaking plant because cost per kilo watt hour is higher in peak hours as compared to low cost off-peak power produced in continuous system. So, continuous system was dropped on the basis of energy revenue.

4.2 COMPARISON OF BOTH STUDIES

Results produced by spreadsheet model were compared with results of software SIMAHPP. In this comparison, project working as a peaking plant was considered only dropping the 2nd alternative of continuous system on the basis of revenue generated. Comparison is shown in Table 4.6. This table shows that there were some minor deviations with the parameters set by spreadsheet model. The overlap rate of parameters obtained from two studies ranges from 0.99 to 1.09. These differences were of minor nature based on two different calculation methods.

Table 4.6 Comparison of Two Studies

	Parameters		
	Spreadsheet Model	SIMAHPP	Overlap Ratio
Operation	Peaking (4 Hours peaking + 20 hours continuous)	Peaking (4 Hours peaking + 20 hours continuous)	-
Installed Power	30 (MW)	29.83 (MW)	1.01
Energy production	255.74 (GWh)	235.16 (GWh)	1.09
Net Head	78 (m)	78 (m)	1.0
Design Discharge	42 (m^3/sec)	42.37 (m^3/sec)	0.99
No. of units	1	1	-

4.3 OPTIMIZATION OF NASIRABAD HYDROPOWER PROJECT

Out of two alternatives peaking and continuous operation, peaking operation was generating more revenue than continuous operation in both studies with one unit. To optimize the energy output of project, it was considered to increase the design discharge from 90% availability to 49% availability of the time throughout the year to compensate the local demand of energy during peak hours in winter season. For this purpose, spreadsheet model was utilized to optimize the energy output of project by increasing the design discharge with increased number of turbines due to availability of sufficient flows. As SIMAHPP does not give information about multiple turbines, optimized energy output was determined by spreadsheet model only. Annual energy generation of project as peaking operation was 645.80 GWh at a plant factor of 61.98% (Table 4.7).

By storing certain amount of available flows in off-peak hours to utilize it later in peak hours, energy output of Nasirabad hydropower project can be enhanced. For this purpose, design discharge of 168 m^3/sec was taken with four units considering the system working as daily peaking throughout the year (Figure 4.7).

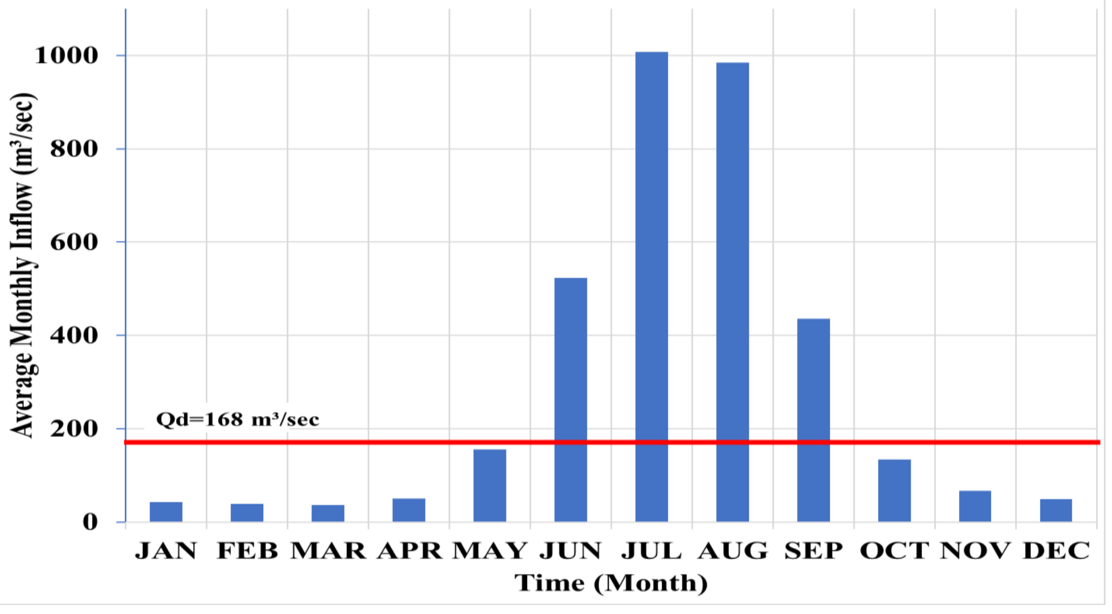


Figure 4.7 Average Monthly Inflows

The purpose was to get maximum benefits in terms of energy as well as generating more revenue. Energy output was computed for both alternatives peaking as well as continuous system with four units of turbines. The design discharge for each unit was taken 42 m^3/sec. Installed power was 119 MW. Total energy generation during peak hours was 174 GWh and total energy generation during off-peak hours was 472 GWh (Figure 4.8).

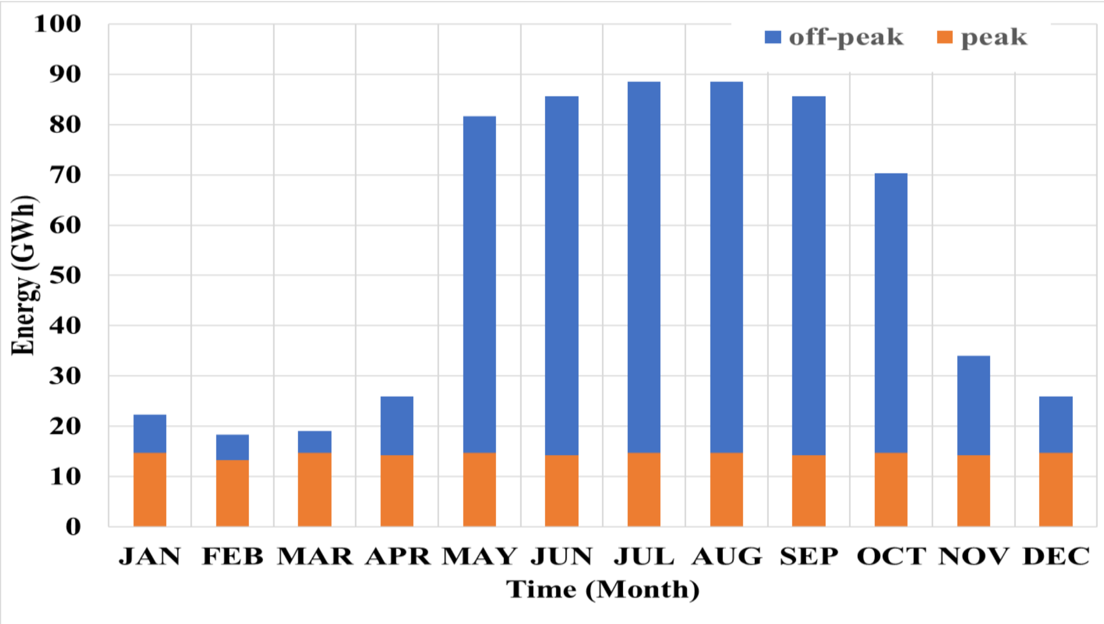


Figure 4.8 Peak and Off-Peak Energy (4 Unit Peaking Operation)

In case of continuous operation for 24 hours, power produced for 4 turbines was 118.94 MW. Annual energy output was 649.51 GWh. Peak energy produced was 108.25 GWh and off-peak energy production was 541.25 GWh. (Table 4.8 & Figure 4.9). On comparing the annual energy by considering both alternatives, it was found that total annual energy produced by both alternatives was almost same. But peak energy produced in peaking system was more than the peak energy produced during continuous system. So, continuous system as a second alternative was dropped off. Energy revenue computed in case of continuous system was 2814.50 million rupees

(108.25 X 6 + 541.25 X 4) and with peaking operation 2932 million rupees (174 X 6 + 472 X 4) giving us additional 117.50 million rupees annually. The turbine efficiencies were taken constant i.e.92.55 % and the net head was also fixed i.e. 78 meters. All units are suggested to run in peak hours throughout the year whereas in off-peak hours, 1,2 or 3 units will be operated according to the discharge available after peaking operation.

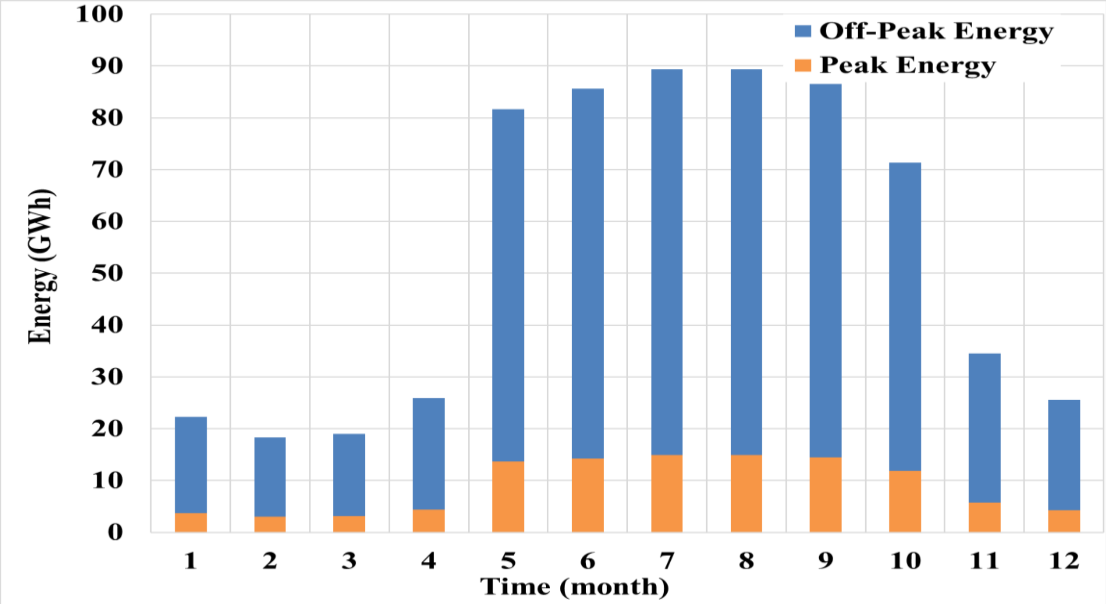


Figure 4.9 Peak and Off-Peak Energy (4 Unit Continuous Operation)

4.4 STORAGE COMPUTATION (AREA-ELEVATION RELATIONSHIP)

To run the all the turbines in 4 peak hours daily, required storage computed as follows:

No. of turbines (for peak hours)	= 4
Design discharge for one unit (Q_{unit})	= 42 m^3/sec
Total Design discharge (Q_d)	=168 m^3/sec

Design discharge of 168 m^3/sec maintained for four hours to run four turbines at a time during peaking operation. Thus, volume required to create reservoir upstream of the weir for peak operation was as follows:

$$\text{Required Peak Volume} = 168 \times 4 \times 60 \times 60$$
$$= 2419200 \text{ m}^3$$
$$= 2.42 \text{ Million m}^3$$

This required amount of water stored in 20 off-peak hours was computed with respect to elevation by using Area-Elevation relationship. (Table 4.9). Storage 2.80 million m^3 was computed at elevation 2046 meters which was almost equal to required storage. Additional storage 0.38 million m^3 greater than the required storage (=2.80-2.42=0.38 million m^3) was occupied by assumed value of free board. Elevation 2046 meters was also taken as normal conservation level determined from the elevation-volume relationship curve (Figure 4.10).

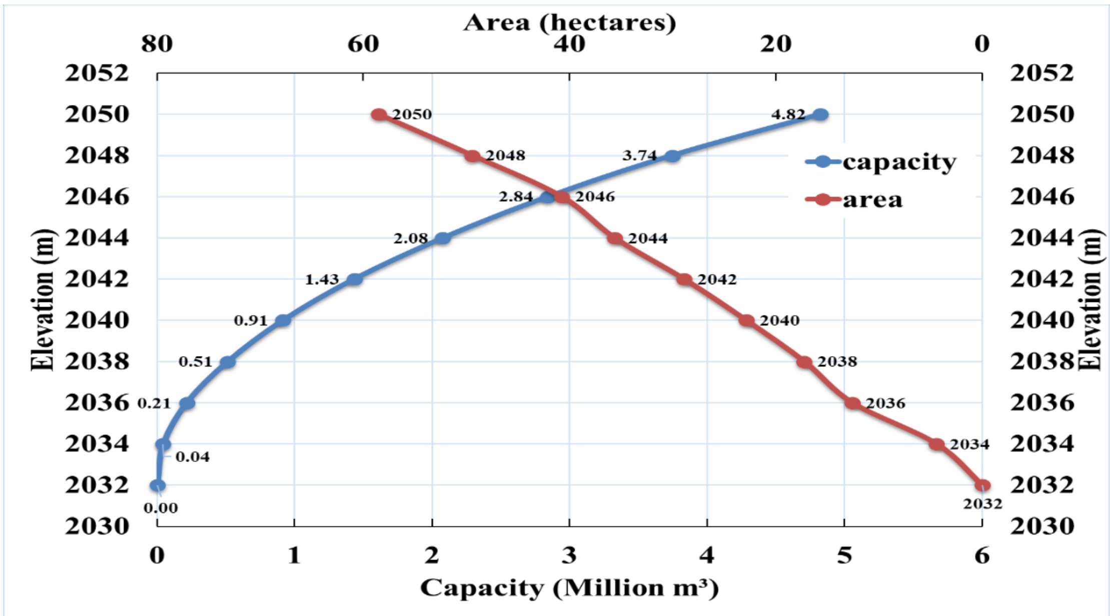


Figure 4.10 Volume-Elevation-Area Curve

The reservoir level corresponding to normal reservoir storage is called as normal conservation level (N.C.L). From Area-Volume relationship, following information was also obtained.

Table 4.7 Combined Peaking & Continuous Operation (4 units)

Month	Discharge		Volume			Time		Power		Daily Energy			Monthly Energy		
	Q_{inflow}	Q_{power}	Total	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Day	Peak	Off-Peak	Total
	m^3/s	m^3/s	m^3/day	m^3	m^3	hrs	hrs	MW	MW	GWh	GWh		GWh	GWh	GWh
JAN	42.37	42.37	3,660,768	2,419,200	1,241,568	4.00	20.00	119	12	0.48	0.24	31	14.75	7.57	22.32
FEB	38.56	38.56	3,331,584	2,419,200	912,384	4.00	20.00	119	9	0.48	0.18	28	13.32	5.02	18.34
MAR	36.13	36.13	3,121,632	2,419,200	702,432	4.00	20.00	119	7	0.48	0.14	31	14.75	4.28	19.03
APR	50.81	50.81	4,389,984	2,419,200	1,970,784	4.00	20.00	119	19	0.48	0.39	30	14.27	11.63	25.90
MAY	154.99	154.99	13,391,136	2,419,200	10,971,936	4.00	20.00	119	108	0.48	2.16	31	14.75	66.89	81.64
JUN	523.13	168.00	14,515,200	2,419,200	12,096,000	4.00	20.00	119	119	0.48	2.38	30	14.27	71.36	85.63
JUL	1008.03	168.00	14,515,200	2,419,200	12,096,000	4.00	20.00	119	119	0.48	2.38	31	14.75	73.74	88.49
AUG	984.19	168.00	14,515,200	2,419,200	12,096,000	4.00	20.00	119	119	0.48	2.38	31	14.75	73.74	88.49
SEP	436.40	168.00	14,515,200	2,419,200	12,096,000	4.00	20.00	119	119	0.48	2.38	30	14.27	71.36	85.63
OCT	133.48	133.48	11,532,672	2,419,200	9,113,472	4.00	20.00	119	90	0.48	1.79	31	14.75	55.56	70.31
NOV	66.82	66.82	5,773,248	2,419,200	3,354,048	4.00	20.00	119	33	0.48	0.66	30	14.27	19.79	34.06
DEC	49.29	49.29	4,258,656	2,419,200	1,839,456	4.00	20.00	119	18	0.48	0.36	31	14.75	11.21	25.96
													Annual Energy		645.80
													Plant Factor		62.0

Table 4.8 Continuous Operation (4 units)

TIME	PERIOD	AVAILABL E FLOW	NET HEAD	TURBINE - 1			TURBINE - 2			TURBINE - 3			TURBINE - 4			MEAN MONTHLY ENERGY		
				Q_1	h_{T1}	$Energy_1$	Q_2	h_{T2}	$Energy_2$	Q_3	h_{T3}	$Energy_3$	Q_4	h_{T4}	$Energy_4$	Total Energy	Peak Energy	Off-Peak Energy
months	(days)	(m^3/s)	(m)	(m^3/s)	(%)	(GWh)	(m^3/s)	(%)	(GWh)	(m^3/s)	(%)	(GWh)	(m^3/s)	(%)	(GWh)	(GWh)	(GWh)	(GWh)
1	31	42.37	78.0	21.19	92.5%	11.16	21.19	92.5%	11.16	0.00	92.5%	0.00	0.00	92.5%	0.00	22.32	3.72	18.60
2	28	38.56	78.0	38.56	92.5%	18.34	0.00	92.5%	0.00	0.00	92.5%	0.00	0.00	92.5%	0.00	18.34	3.06	15.29
3	31	36.13	78.0	36.13	92.5%	19.03	0.00	92.5%	0.00	0.00	92.5%	0.00	0.00	92.5%	0.00	19.03	3.17	15.86
4	30	50.81	78.0	25.41	92.5%	12.95	25.41	92.5%	12.95	0.00	92.5%	0.00	0.00	92.5%	0.00	25.90	4.32	21.58
5	31	154.99	78.0	38.75	92.5%	20.41	38.75	92.5%	20.41	38.75	92.5%	20.41	38.75	92.5%	20.41	81.64	13.61	68.03
6	30	523.13	78.0	42.00	92.5%	21.41	42.00	92.5%	21.41	42.00	92.5%	21.41	42.00	92.5%	21.41	85.63	14.27	71.36
7	31	1008.03	78.0	42.00	92.5%	22.12	42.00	92.5%	22.12	42.00	94.4%	22.57	42.00	94.4%	22.57	89.39	14.90	74.49
8	31	984.19	78.0	42.00	92.5%	22.12	42.00	92.5%	22.12	42.00	94.4%	22.57	42.00	94.4%	22.57	89.39	14.90	74.49
9	30	436.40	78.0	42.00	92.5%	21.41	42.00	92.5%	21.41	42.00	94.4%	21.84	42.00	94.4%	21.84	86.50	14.42	72.09
10	31	133.48	78.0	33.37	92.5%	17.58	33.37	92.5%	17.58	33.37	95.1%	18.07	33.37	95.1%	18.07	71.30	11.88	59.42
11	30	66.82	78.0	33.41	92.5%	17.03	33.41	95.1%	17.51	0.00	0.0%	0.00	0.00	0.0%	0.00	34.54	5.76	28.79
12	31	49.29	78.0	24.65	92.5%	12.98	24.65	89.4%	12.54	0.00	0.0%	0.00	0.00	0.0%	0.00	25.52	4.25	21.27
MEAN ANNUAL ENERGY (GWh)						=										**649.51**	**108.25**	**541.25**
PLANT FACTOR						=										**62.34**		

Suggested Reservoir Storage at Elevation 2046 m = 2842500 m^3

=2.84 Million m^3

Minimum Bed Level at Weir Site = 2030 m

Normal Conservation Level for 2.8 Mm^3 = 2046 m

Maximum Reservoir Depth = 2046 – 2030

= 16 m

Free Board (Assumption) = 4 m

Total Proposed Weir Height =16 + 4 = 20 m

Proposed Weir Crest Level =2030+20

=2050 meters

Table 4.9 Area-Volume Relationship

Elev. (m)	Ht. Above Datum (m)	Map Area (m^2)	Plan Area (Hectares)	Incr.Vol. (Hec-m)	Total Capacity (Hec-m)	Total Capacity (Million m^3)
2032	2	0	0.00	0	0	0.00
2034	4	44340	4.43	4.43	4.43	0.04
2036	6	126105	12.61	17.04	21.48	0.21
2038	8	172562	17.26	29.87	51.35	0.51
2040	10	228871	22.89	40.14	91.49	0.91
2042	12	289071	28.91	51.79	143.28	1.43
2044	14	356483	35.65	64.56	207.84	2.08
2046	16	407660	40.77	76.41	284.25	2.84
2048	18	494274	49.43	90.19	374.45	3.74
2050	20	585303	58.53	107.96	482.40	4.82

Proposed reservoir area for required storage was marked by drawing contour map of the project area with the help of AutoCAD.

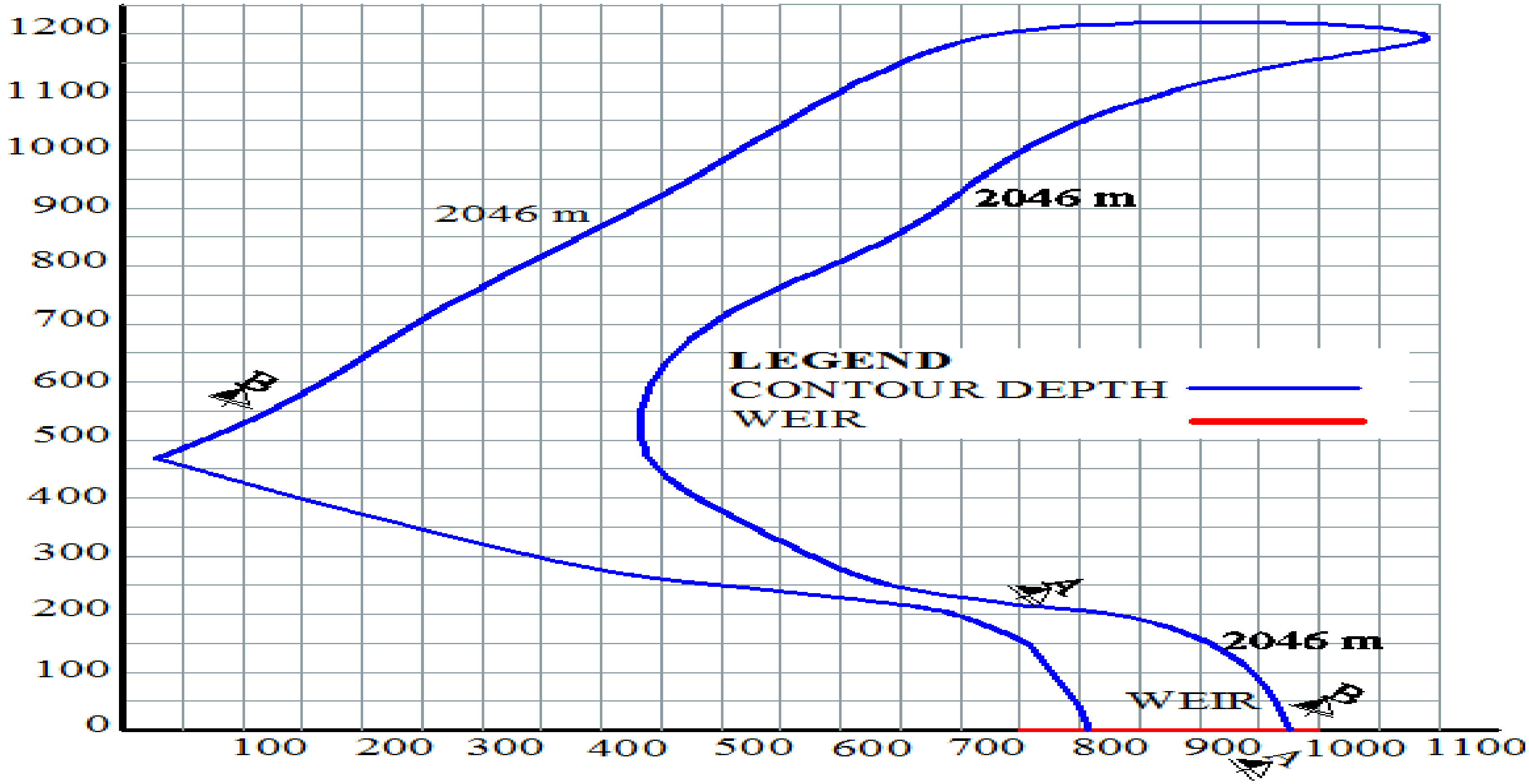


Figure 4.11 Reservoir Area (Plan)

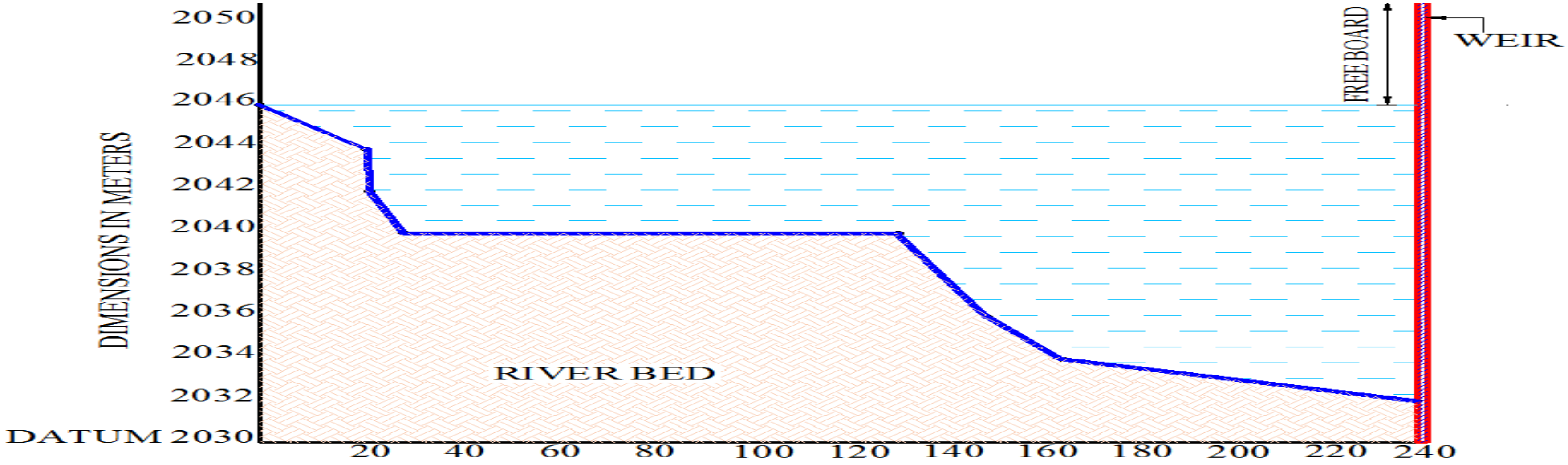


Figure 4.12 Section A-A

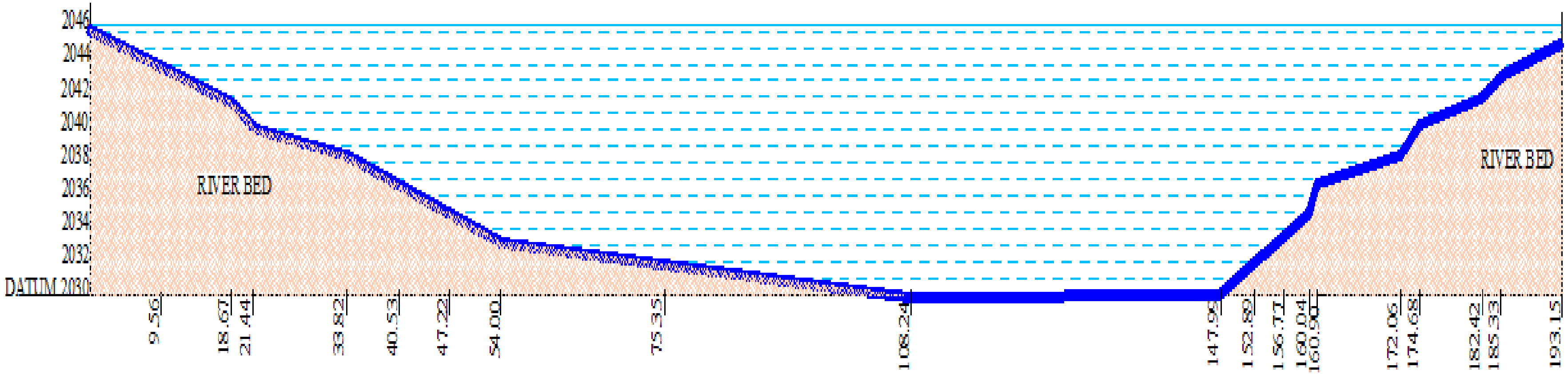


Figure 4.13 Section B-B

First of all, bed level of the river was selected i.e. 2030 meters. Contours were drawn on AutoCAD with an interval of 2 meters from the bed level. After drawing the contours, surface area for each contour was measured.

In Figure 4.11, plan of proposed reservoir area is shown. All the contours were closed lines within the reservoir area. This figure shows the possible location of a reservoir at elevation 2046 meters providing the volume almost equal to required volume i.e. 2.8 million m^3 and the area in which volume of water to be confined. Section A-A & B-B were cut to show the clear picture of reservoir area with different elevations (Figures 4.12 & 4.13).

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Chapter V
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this study, it has been decided that the proposed hydel scheme on Hunza River is technically feasible and relatively easy to construct due to available infrastructure and geological conditions in this reach of Hunza River.

From the daily discharge data, project is optimized at optimum design discharge of 168 m^3/sec for 49% time of the year. Power generated will be 119 MW with four number of turbines. Total annual energy determined in this study is 645.80 GWh in case of peaking as well as continuous operation which will be utilized to mitigate the local power demand in Nasirabad during winter season. Whereas, WAPDA identified this project at 26 m^3/sec at 95% availability of the year with two number of turbines generating 133.61 GWh energy with installed capacity of 15 MW.

For the selected optimum design discharge i.e.168 m^3/sec for four turbines, a storage reservoir of 2.84 Million m^3 is suggested to run this project on peaking as a run of river project and space is available upstream of the weir for this storage reservoir. Francis turbine is suggested for this project. Water will be stored in off-peak hours in reservoir and will be utilized in peak hours. In this way, more revenue will be generated as cheap energy will be produced in peak hours instead of thermal energy. Additional 65.75 GWh (61%) energy is produced in suggested peaking system operation generating additional revenue of 117.50 Million rupees in comparison with continuous system operation.

5.2 RECOMMENDATIONS

- Nasirabad hydropower project is recommended to be designed as a peaking power project with partial off-peak power generation as well.

- Some storage should be developed upstream of the weir to store the flows required in peak hours for energy generation

- Similar study should be done in detailed investigation and design of other hydropower projects

- New version of this software SIMAHPP 5 should be utilized for further studies. Along with other additions, it simulates for multiple units and also gives information about material and sizing of penstock

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Appendix A

A-1 DATA ENTRY STEPS

A-1.1 Open Project

To open the new project in SIMAHPP, click file from the file menu

File → Open New Project

By clicking at new project, fivesites.spr file opens. Other particulars of the project file can be viewed from the project information. Figure No.1 explains how to open the new project and also shows how to open file in SIMAHPP.

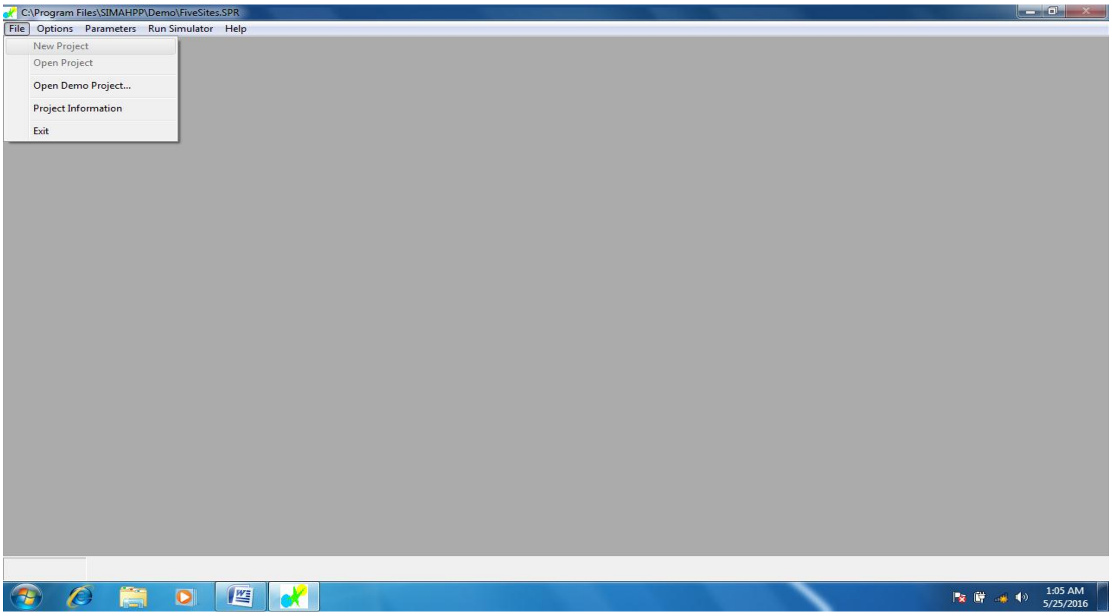

Figure No.1 Open Project

A-1.2 View Options

By clicking at 'Options' tab, another window of 'Hydropower Site Information' opens.

Click Options → Hydropower Site Information

Here the choice is given for selecting the multiple sites. By clicking at dropdown box of number of hydropower sites, one can select the required number of sites. Site names can also be changed by double clicking at given site ID. Then against each site ID, type of available flow data is entered whether it is daily mean flow, monthly mean flow or annual mean flow. After available flow data is entered, required entry for each type of flow data is also edited e.g. for daily mean flow data, required entry is 365. For mean monthly flow, required entry is 12 and for annual mean flow, required entry is only 1. Default unit system is also presented in this window. For flow and length, units are cubic meter per second (m^3/sec) and meter (m) respectively. Currency units can also be changed by clicking at drop down box in the same window. Options window screen can be seen and Hydropower Site Information screen is shown in Figure No.2 & Figure No.3

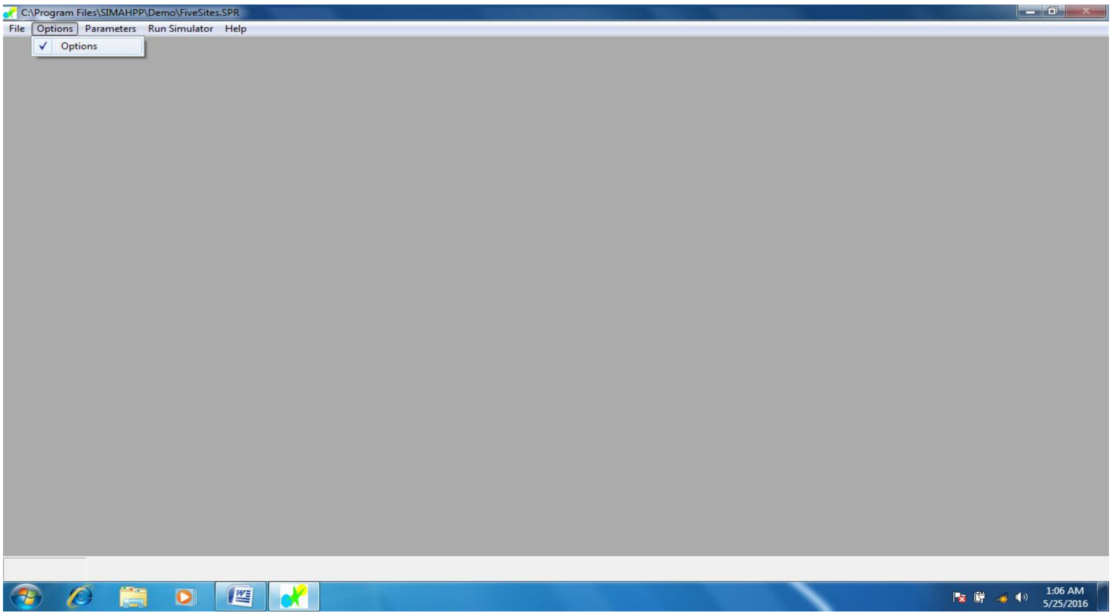

Figure No.2 Options

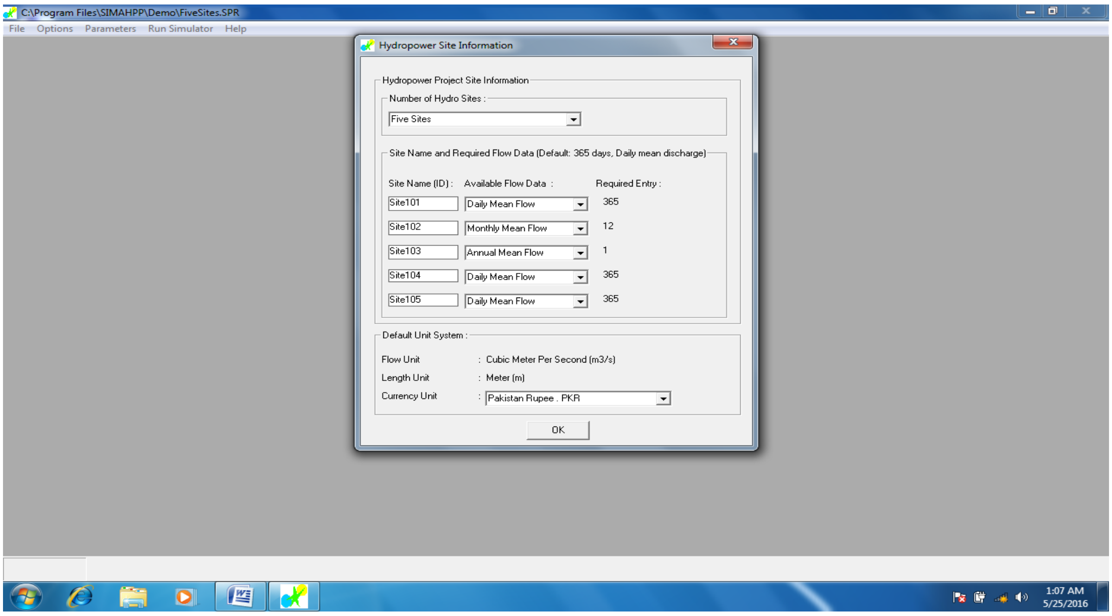

Figure No.3 Hydropower Site Information

A-1.3 Open Flow Data

By clicking at the parameters tab, submenu screen appears. At this screen, click on flow data as shown in figure No.4. Here another screen appears in which flow data is entered for required number of sites.

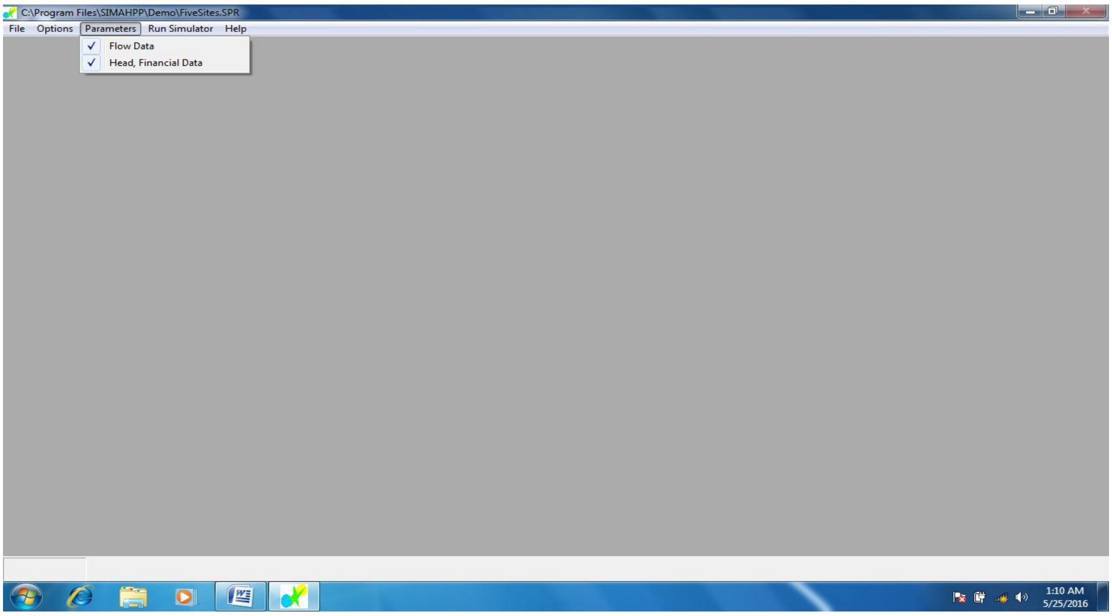

Figure No.4 Parameters

Mean monthly flow data for project site was entered at site ID Site 102 in 12 entries as shown in Figure No.5. Similarly, mean daily and mean annual flow data were entered at site ID Site 101 in 365 entries, and site 103 in only 1 entry respectively.

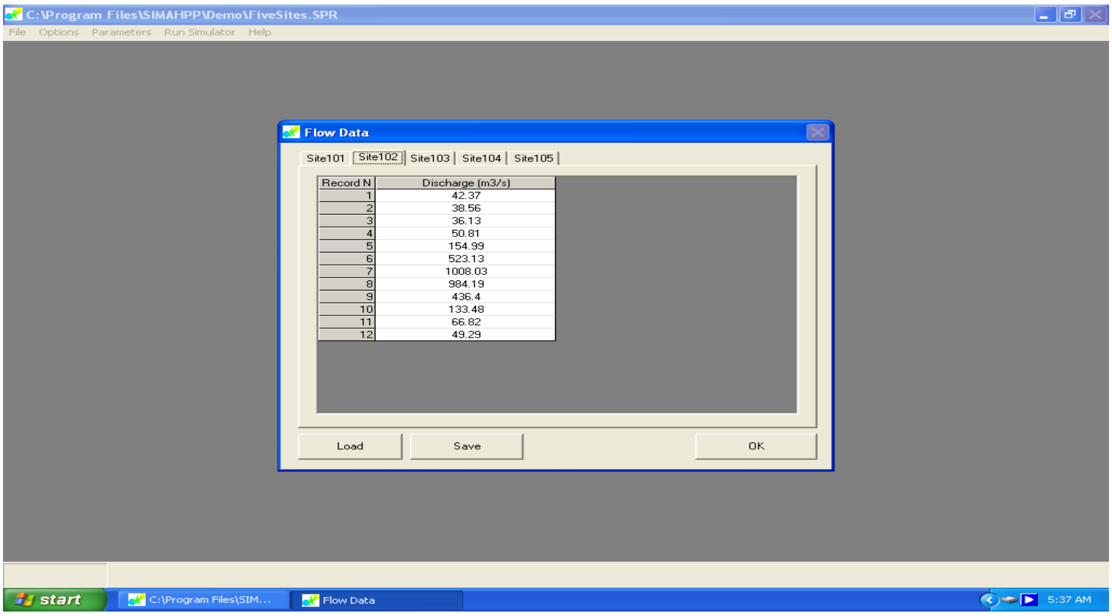

Figure No.5 Flow Data

A-1.4 Head and Financial Parameters

After entering flow data, go to the parameters tab, click head and financial data tab in submenu. Design and cost parameters including gross head, tail water level, cost of electricity per kwh, operation hours per day depending on the availability of flow per day, inflation rate, value added tax and other taxes values are entered here. All these values are entered for required number of sites. Parameters entry screen is shown in Figure No.6.

A-1.5 Run SIMAHPP

After input of all required data, click at Run Simulator tab. Simulator Windows get loaded. After this, results can be viewed. This window shows results for all sites in tabular and graphical format after simulation. Results of each site can also be viewed individually by checking at a tab where the site names are represented. Simulator window screen id displayed in Figure No.7.

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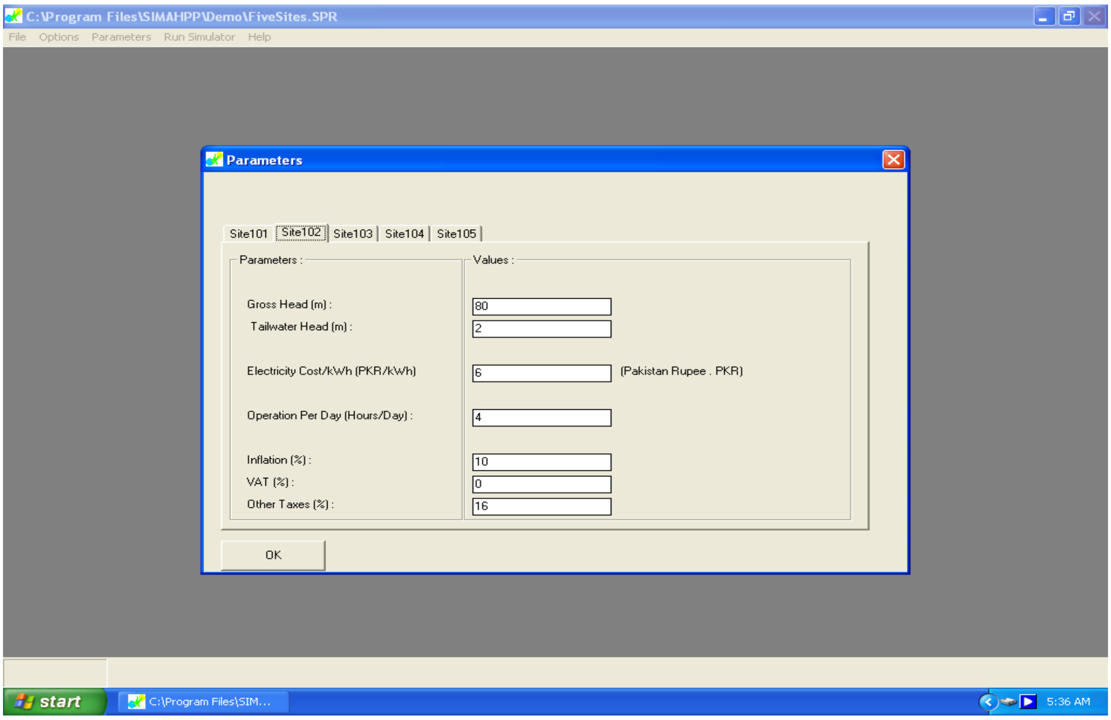

Figure No.6 Head and Financial Parameters

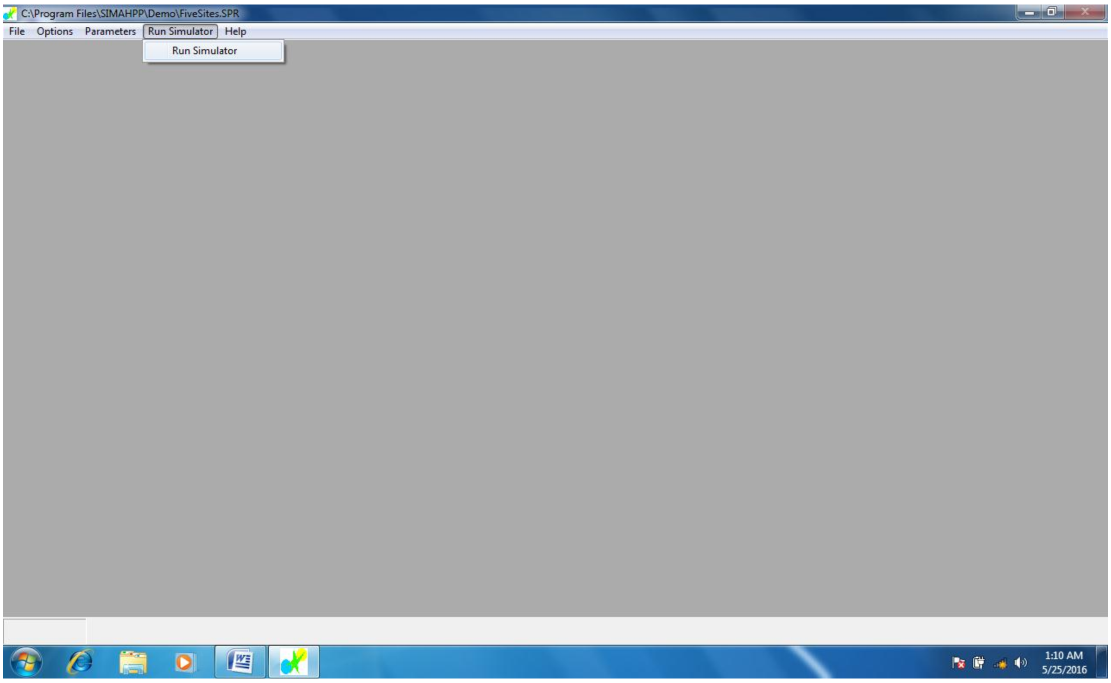

Figure No.7 Run Simulator

A-1.6 Results

By clicking at the view results tab, a table of project characteristics appears in which results of all sites is summarized.

View Results → Project Characteristics

From this tab, graphical output can also be viewed here. The names of the sites used in the simulation are also listed under the submenu of the View Results Tab.

Flow Hydrograph and FDC can be viewed as:

View Results → Flow Hydrograph and FDC → Site ID

Power duration and energy optimization curve can be viewed as:

View Results → Power and Energy Curves → Site ID

Figure No.8 represents how results can be seen in SIMAHPP.

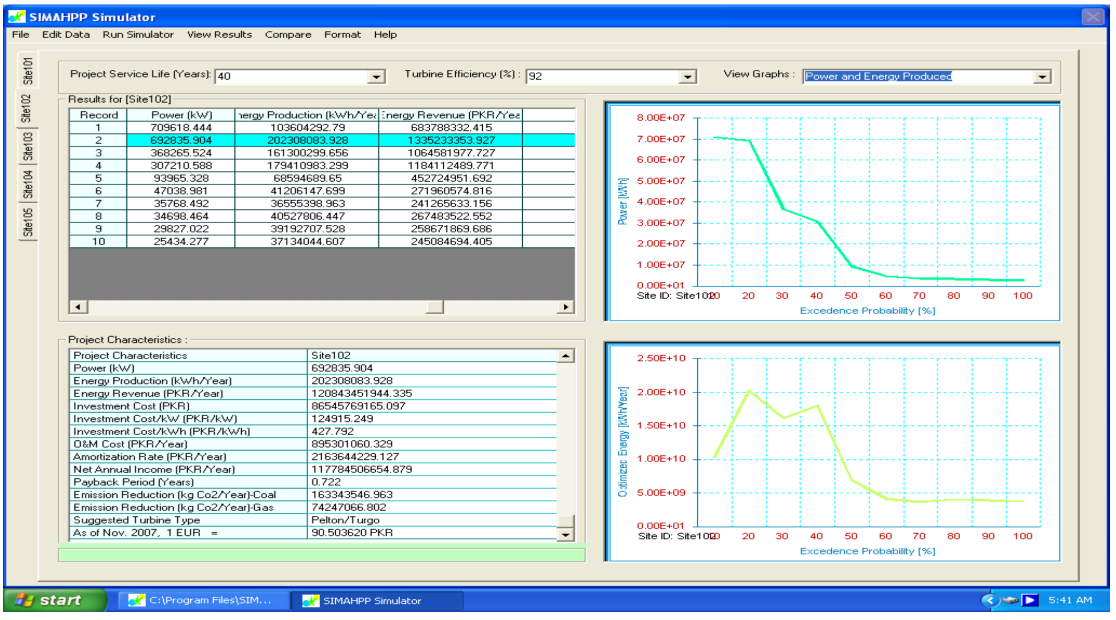

Figure No.8 View Results

A-1.7 Graphs

By clicking at the compare tab, graphical outputs are displayed. Comparison of the characteristics of individual sites is represented here in terms of graphs. Such as through the design flow and optimum operation time in a year, power and energy production, investment costs and energy revenue and other economic parameters. Correlation of all characteristics is displayed in the submenu of the compare tab. Graphical outputs in terms of comparison can be seen as shown in Figure No.9.

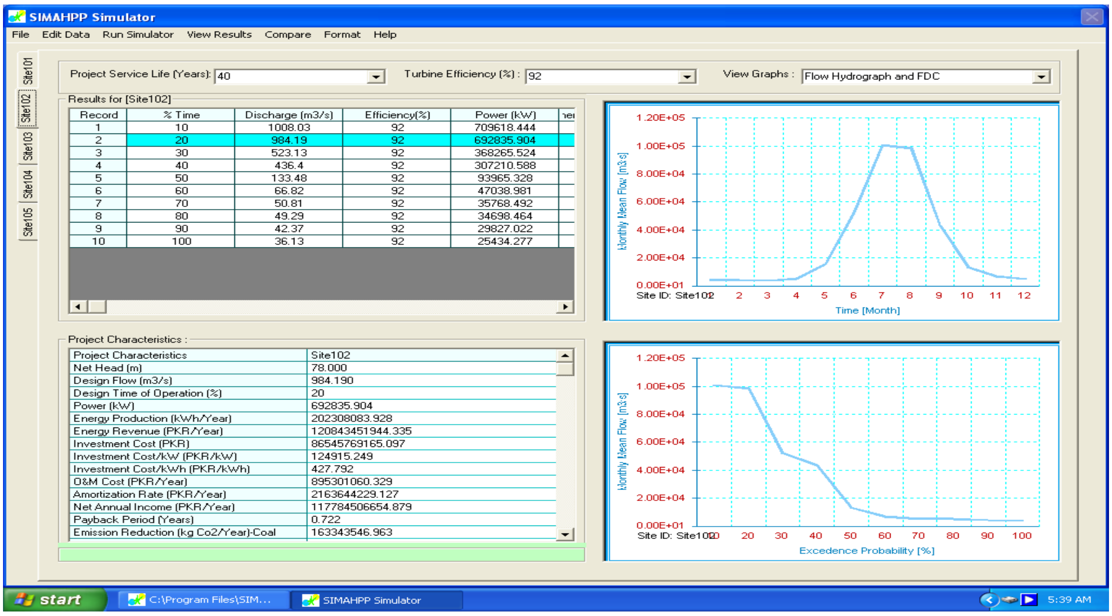

Figure No.9 View Graphs

Comparison of design flow and optimum operation time in a year can be viewed in terms of graph:

Compare → by design flow

Comparison for power and energy production:

Compare → by power generated or click at the dropdown box of view graphs at the top right of the screen

Comparison for investment costs and energy revenues:

Compare → by costs and revenues or click at the dropdown box of view graphs at the top right of the screen

Comparison for costs and capacity installed:

Compare → by costs per capacity or click at the dropdown box of view graphs at the top right of the screen

Comparison for payback periods and amortization rates:

Compare → by payback periods or click at the dropdown box of view graphs at the top right of the screen

Comparison for carbon emission reductions (kg co_2/kwh)

Compare → by emission reduction or click at the dropdown box of view graphs at the top right of the screen.

A-1.8 Format Graphical Outputs

If it is desired to change the type of chart or graph, it can be done by clicking at the format tab.

Format → Chart Type

Similarly, graph colors can also be changed by clicking at the same format tab.

Format → Chart Colors

By choosing the chart type, all the desired changes are updated automatically by program.

A-1.9 Edit Data

By editing data, more simulations can be made and results can be viewed without leaving the simulator windows. For example, service life (in years) of the planned hydropower project or the turbine efficiencies for one or more sites used in the simulation can be changed. This can be done from the first two dropdown boxes. Simulation results are automatically updated by program as these changes are made.

Main input parameters such as the flow data, head and financial data can also be changed by clicking at the edit data tab of the simulator.

The flow data can be edited:

Edit Data → Flow Data

Similarly, head and financial data can also be edited:

Edit Data → Head, Financial Data

When main input data is edited, the program will be run from the main Run Simulator tab without leaving the Simulator Windows.

A-1.10 Save Graphs

Graphical outputs can be saved into image files. By clicking at the file tab of the simulator, graphs can be saved from the submenu.

File → Save Graphs

Save Graphs dialog box opens with saving options. Graphs of the active site information as well as all graphs of all sites can be saved. Files are saved at the destination path shown on the save dialog.

A-1.11 Printing of Results

Results can be printed by clicking at the File tab.

File → Print Results Grid.

By this click, printing dialog box opens. Here are two options for one specific site i.e. printing for results table (upper) or printing for project characteristics table (lower). Results can be viewed and printed in full width by checking the option in printing dialog box. Prints for only one site can be printed. Results from all sites can also be printed from the view results tab.

View results → project characteristics

And then click at the print button. Format of the table in printed form is same as seen on the screen or print preview. Figure No.10 represents how results and project characteristics can be printed.

Record	% Time	Discharge (m3/s)	Efficiency(%)	Power (kW)	Energy Production (kWh/Year)	Energy Revenue (PKR/Year	
1	10	1008.03	92	709618.444	518021463.951	2279294441.383	
2	20	984.19	92	692835.904	1011540419.641	4450777846.422	
3	30	523.13	92	368265.524	806501498.278	3548606592.425	
4	40	436.4	92	307210.588	897054916.493	3947041632.568	
5	50	133.48	92	93965.328	342973448.251	1509083172.305	
6	60	66.82	92	47038.981	206030738.497	906535249.387	
7	70	50.81	92	35768.492	182776994.815	804218777.186	
8	80	49.29	92	34698.464	202639032.236	891611741.839	
9	90	42.37	92	29827.022	195963537.641	862239565.621	
10	100	36.13	92	25434.277	185670223.034	816948981.351	

Figure No.10 Print Results

Table 1. Mean Monthly Flows (1966-2004)

Month	Average Flows
Jan	42.37
Feb	38.56
Mar	36.13
Apr	50.81
May	154.99
Jun	523.13
Jul	1008.03
Aug	984.19
Sep	436.40
Oct	133.48
Nov	66.82
Dec	49.29

Table 2. Mean Daily Flows (1966-2004)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	47.60	43.32	37.83	29.97	65.23	266.98	871.47	1337.43	1206.46	181.35	75.31	46.34
2	47.60	43.07	37.56	29.22	63.47	221.14	914.29	1370.17	1208.98	173.79	74.55	45.34
3	47.60	43.32	37.29	29.72	62.46	202.00	954.59	1438.18	1181.27	166.23	73.29	44.83
4	48.11	43.32	37.29	29.72	63.22	175.55	765.68	1478.48	1146.01	161.20	72.54	43.83
5	47.60	43.07	37.02	29.72	64.48	187.14	743.02	1538.93	1042.74	153.64	71.78	43.32
6	47.60	43.07	36.31	30.22	65.74	173.79	624.64	1473.44	994.89	148.60	71.03	42.57
7	47.35	43.07	36.05	30.73	69.52	200.74	498.70	1410.47	909.25	143.57	70.52	42.06
8	47.60	43.07	35.78	32.49	96.97	209.81	506.26	1317.28	941.99	138.53	70.27	41.05
9	47.35	43.07	35.78	34.76	109.06	210.56	483.59	1266.91	949.55	133.49	69.52	40.80
10	47.60	42.57	35.51	37.28	139.54	213.84	483.59	1135.93	984.81	129.71	69.26	40.30
11	47.35	42.36	35.07	38.03	144.07	228.95	506.26	1047.78	838.73	125.94	68.76	40.05
12	47.35	42.36	34.53	38.54	129.21	251.11	506.26	1007.48	881.55	147.34	68.51	39.29
13	47.60	42.36	34.27	38.03	143.06	287.13	468.48	934.44	843.76	118.38	68.00	38.79
14	47.35	42.36	34.00	37.78	162.71	355.14	483.59	876.51	675.01	114.60	67.50	38.03
15	47.35	42.10	33.29	37.28	194.70	390.40	491.15	906.73	556.63	112.08	66.24	37.53
16	46.60	41.83	33.02	37.02	234.24	410.55	518.85	954.59	465.96	109.56	64.98	37.02
17	46.34	41.56	32.75	36.27	251.87	410.55	506.26	1055.34	433.22	105.79	62.72	36.52
18	46.09	40.85	32.49	36.02	289.65	372.77	533.96	1135.93	390.40	103.27	62.21	36.27
19	45.59	40.58	32.49	35.51	327.43	334.99	657.38	1211.49	355.14	100.75	59.69	36.02
20	45.34	40.58	32.04	35.01	342.54	307.28	712.79	1206.46	329.95	98.23	56.92	35.77
21	45.34	40.32	31.77	36.02	264.46	314.84	778.28	1191.35	314.84	96.97	53.90	35.51
22	44.83	40.05	31.24	37.02	245.07	352.62	926.88	1148.53	289.65	94.45	52.89	35.01
23	44.58	39.61	30.71	37.78	199.98	440.77	1163.64	1125.86	266.98	93.19	52.14	34.76
24	44.08	39.34	30.71	42.06	184.62	488.63	1017.55	1211.49	251.11	90.67	52.14	37.28
25	43.83	39.07	30.53	49.37	205.27	518.85	1264.39	1294.61	232.73	88.15	51.13	37.02
26	43.57	38.80	30.26	67.75	183.61	599.45	1135.93	1181.27	221.65	85.64	50.88	36.52
27	43.32	38.09	29.99	74.05	245.83	607.01	896.66	1201.42	214.59	83.12	49.87	36.02
28	43.32	38.09	29.73	71.78	56.91	649.82	1078.00	1042.74	204.01	82.11	49.11	35.77
29	43.57		29.46	70.52	50.36	758.13	1198.90	1055.34	196.46	80.60	48.11	35.77
30	43.32		31.77	67.75	234.24	821.10	1377.73	1105.71	188.90	77.83	46.85	35.01
31	43.07		30.73		238.27		1428.10	1166.16		76.82		35.01