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Small Pumped Storage Hydro Power Plant – A Feasibility Study for MIDC Dhule, Maharashtra

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GJRE-F Classification : *FOR Code: 850503, 660201*

SMALLPUMPEDSTORAGEHYDROPOWERPLANTAFEASIBILITYSTUDYFORMIDCDHULEMAHARASHTRA

Strictly as per the compliance and regulations of :

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The consumption or demand for electricity varies with time in a day. A trough and peak may be observed in demand pattern of electricity. It is not economical to build base load power plant to satisfy the peak demand. The easier way is to increase peak hydropower production by pumping up the already flown water through turbines back to the high reservoir using cheap electricity of trough periods. By development of electrical generator which can work as motor and turbines and also as pump when rotation direction is reversed, investment cost of pump storage hydropower has decreased to half and it became economically more attractive. The net effect is to store the electricity produced during the low demand period in the form of potential energy of water, which can be used during peak demand. Pumped water storage is at present the most widely used method of peak satisfaction of electric power systems.

In this paper the economic feasibility of installation of a pumped storage hydroelectric power plant is demonstrated, at MIDC area of Dhule town by taking the advantage of available water at MIDC reservoir and the Laling hills in nearby area. The preliminary survey, planning and design of pumped storage hydro electric power plant for MIDC Dhule is done along with the cost analysis.

Keywords : annual capital cost, hydro power, pumped storage power plant, sensitivity analysis.

I. Introduction

Hydroelectricity is the term referring to electricity generated by hydropower; the production of electrical power through the use of the gravitational force of falling or flowing water. The hydroelectric power is an excellent source in terms of stable supply and generation cost over the long term. It is the most widely used form of renewable energy, accounting for 16 percent of global electricity generation – 3,427 terawatt-hours of electricity production in 2010, and is expected to increase about 3.1% each year for the next 25 years.[4]

Hydropower is produced in 150 countries, with the Asia-Pacific region generating 32 percent of global hydropower in 2010. China is the largest hydroelectricity producer, with 721 terawatt-hours of production in 2010, representing around 17 percent of domestic electricity use.[9]

The cost of hydroelectricity is relatively low, making it a competitive source of renewable electricity. Hydro is also a flexible source of electricity since plants can be ramped up and down very quickly to adapt the changing energy demands. Once a hydroelectric complex is constructed, the project produces no direct waste, and has a considerably lower output level of the carbon dioxide (CO_2) than fossil fuel powered energy plants. Almost all the developing and developed nations are facing the crisis of electrical power and environmental problems due to burning of coal in thermal power plants; hence most of them have used nearly all potential sites for constructing large-scale hydroelectric facilities, and currently focusing on development of smaller scale.

The list of the first ten largest producers of hydro electric power is given in Table - 1.[6]

a) Pumped Storage Hydro Electric Power

The pumped storage hydropower plant produces the electricity to supply high peak demands by moving water between reservoirs at different elevations. At times of low demand of electricity, the excess electricity is used to pump the water into the higher reservoir, which is released back into the lower reservoir through turbine at the time of higher demand. The pumped storage schemes improve the daily load factor of the generation system. The small hydro power generation units in the range 1 MW to about 30 MW are available from multiple manufacturers using standardized packages; in which all the major mechanical and electrical equipment (turbine, generator, controls, switchgear), selecting from several standard designs to fit the site conditions are available.[4]

As the gap in demand between daytime and nighttime continues to widen, the electric power companies are developing pumped-storage power

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generation plants to meet peak demand. The share of pumped-storage generation facilities of the total hydroelectric power capacity is growing year by year in many of the developed and developing nations [12]. As electricity is nearly impossible to store in large quantities, electric power companies generate electricity by combining various power sources, considering optimal operational and economic performance, to ensure the fluctuating demand. The thermal, major hydroelectric, liquefied natural gas and nuclear power provides base load supply whereas, the oil and pumped-storage hydroelectric power respond to peak demand fluctuation and contribute to consistent stable supply of electricity.[8]

II. Background

Dhule is the district place of Maharashtra India, and is located at the junction of NH-3, NH-6 and NH-211. The industrial zone in Dhule is located in south of the town on left side of NH-3, near village Awadhan. The various industries are located in the area and all the necessary infrastructures for their smooth functioning are provided by Maharashtra Industrial Development Corporation (MIDC). The MIDC own a dam on the Moti Nalla (a local stream), which flows on west side of the area and is the tributary of river Panzara. The capacity of the MIDC reservoir is much more than the water demand of Industries. The electricity to the various industries is supplied by the Maharashtra State Electricity Distribution Company Limited (MSEDCL).

The various industries in MIDC area are the small or medium scale categories, which are working maximum in two shifts i.e. from 8.00 hrs to 16.00 hrs and from 16.00 hrs to 24.00 hrs, thus there is no any demand of electricity for 8.00 hours i.e. from 00.00 hrs i.e from mid night to 8.00 hrs in the morning. However, the MSEDCL supplies the energy to MIDC for their industrial activities for 24 hours as per agreement between both. The electrical energy which is available during the slack period cannot be diverted to other users as the demand does not exist during this period. The rate of electricity during this slack period is too less, sometime less than $1/4^{th}$ of the rate during the peak hours of demand. The available electricity during the slack hours at cheap rate from 0.00 hrs to 8.00 hrs can be used for pumping operations to store the energy in terms of potential energy of water at higher elevation.

a) Suitability of Geography of Area for Pumped Storage Power Plant

The Laling Hill exists on the south of the MIDC area. It divides the two river basins i.e. Panzara and Bori, which are the tributaries of river Tapi, which is one of the main west flowing rivers of India. The local Nalla which originates from Laling hills flows towards North forms the boundary of MIDC area on west side and meet river Panzara. The MIDC dam is constructed on this Nalla, and the reservoir is the main source of water supply for MIDC area. This reservoir can be used as the main source of water for pumped storage power plant. During the pumping phase, the water from the reservoir may be lifted to the upper reservoir which may be constructed at Laling hills, in which the water can be stored with potential energy. The stored potential energy in turn can be utilized for generating the electrical energy at lower reservoir level and the water can be discharged back to main reservoir.

The pumping phase may be scheduled during the no business hours in MIDC area, when the electricity is available at cheap rates whereas the generating phase may be scheduled during the peak demand period in MIDC area thus reducing the load on the electrical energy generation system attached to supplying grid. The geography of the area showing the existing and proposed locations of reservoirs is shown in Figure -1.

Table 1 : Largest Producers of Hydro Electric Power

Country	Annual Hydroelectric production (TWh)	Installed capacity (GW)	Capacity factor	% of total Capacity
Brazil	363.8	69.08	0.56	85.56
Canada	369.5	88.974	0.59	61.12
China	652.05	196.79	0.37	22.25
India	115.6	33.6	0.43	15.8
Japan	69.2	27.229	0.37	7.21
Norway	140.5	27.528	0.49	98.25
Russia	167	45	0.42	17.64
Sweden	65.5	16.209	0.46	44.34
United States	250.6	79.511	0.42	5.74
Venezuela	85.96	14.622	0.67	69.2

III. Data Collection

a) Survey

The survey is conducted by using a total station meter. The contouring is done at the proposed site of power house and upper reservoir and contour maps are prepared. The level survey of the proposed pipe route is done, in which the RLs are taken at an interval of 30 meters, in addition to all prominent points such as peaks of levels and bottom RLs of Nallas on the route of pipe and the drawing of L-section is prepared. During the survey, the information regarding the strata classification is also collected.

b) Reservoir

The catchment area of the Moti Nala at dam site is 19.16 sq kms. The dam is planned and prepared considering 75% dependable rainfall i.e. 498.90 mm, for 65 years life. The gross storage capacity of the dam is 1698.72 Thousand Cubic meter and the live storage capacity is 1455.236 Thousand Cubic meter.

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IV. Proposal

As per outcome of the final survey and the information regarding the levels in dam, the planning for the pumped storage power plant is done. The schematic diagram with the different components of proposed pumped storage hydro electric power plant is shown in Figure - 2.

The salient features of the proposed pumped storage power plant are as under;

[a] In the proposal, the MIDC reservoir is considered as lower reservoir and is the primary source of water. The upper reservoir is proposed at the top of Laling hills.

[b] A three unit pumped storage installation is proposed. It consist of the three units i.e. Pumping Unit, Generation Unit and Common Rising Main and Penstock

[c] The existing jack well and the pump house constructed above it can be used for installation of pumps. Hence, the same is proposed to accommodate the pumping unit.

[d] The site for the proposed power house, which will accommodate the turbine is selected 210 m away from the submergence of reservoir with sufficient free board above the high flood level on plain ground. An area of 100 m x 100 m is available, which is quite enough to house the power station.

[e] The Pelton turbine is proposed along with the other necessary installation for which 30 x 30 m constructed area is enough.

[f] The length of proposed route of pipe from jack well to the upper reservoir is 4933 m, which is along the left bank of Moti Nala from MIDC reservoir to Laling Hills. The ground RLs are steadily rising with moderate gradient towards the foot of Laling hill and thereafter with steep gradient up to the top of Laling hill.

[g] The site for upper reservoir ground is plain and an area of 200 m x 200 m is available which is quite enough than required.

[h] The obligatory levels for the planning and designing of the power plants are taken as under;

- Minimum water level in the lower reservoir = 94.325 m.
- Ground level at power house = 100.167 m\
- Ground level at upper reservoir level = 401.110 m

The following assumptions are made for in the planning and designing of hydro electric power system.

[a] The Pre-stressed Concrete Cylinder Pipes is selected as penstock/rising main.

[b] The Darcy Weisbach Equation is used for calculation of head loss through rising main/penstock. The value of f in which is considered as 0.012.

$$H_f = \frac{f.L.Q^2}{12.10\, d^5}$$

Where; f = Darcy Weishbach Friction Factor =□(in ner surface condition of pipe, pipe material), Q = Discharge m^3/s, H_f = Friction Loss in m, L = Length of Rising Main / Penstock in m, d = Internal Diameter of Rising Main/Penstock in m

[a] The capacity of the upper reservoir is taken as the 5% of the live storage capacity of reservoir. Another constraint for fixing the capacity of reservoir is the availability of land for construction of reservoir at Laling hills. The plain land of size 200 m x 200 m is hardly available over here.

[b] The unit rate of electricity during off peak hours is taken as Rs.2.50 per kWh.

[c] The unit rate of electricity during peak hours is taken as Rs.9.00 per kWh.

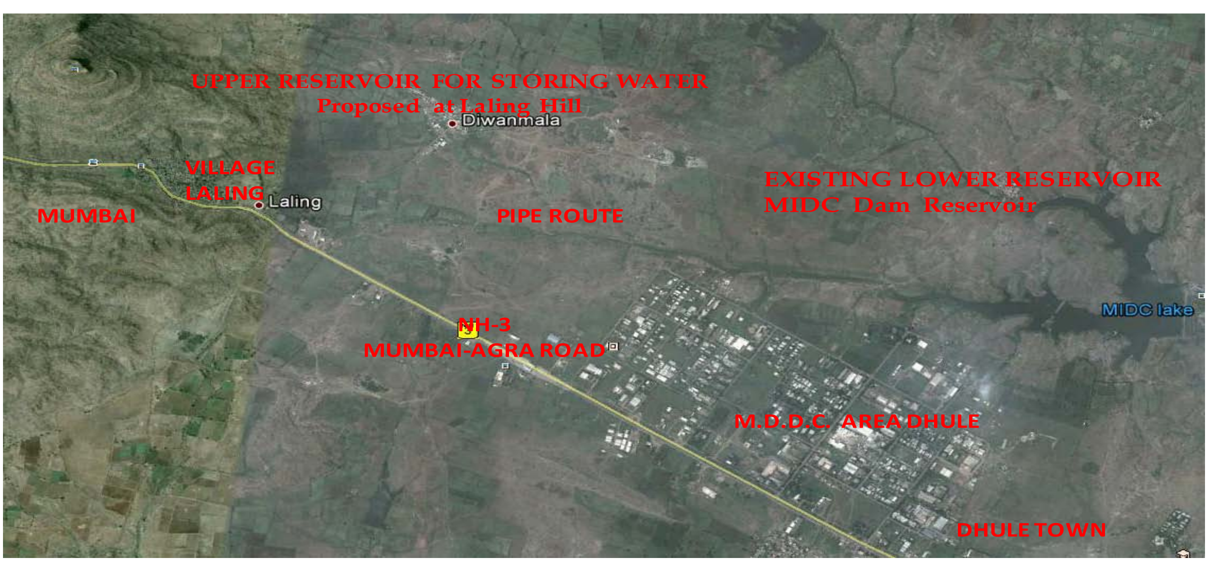

Figure 1 : Geography of Area showing Existing and Proposed Locations of Reservoirs

V. Design

a) Design and Economical Diameter of Rising Main

The pumping system is designed for 9.30 hours of pumping as the excess electricity is available for this period. The schematics diagram showing the levels of lower reservoir from which the water is to be lifted to upper reservoir, where the water is to be stored for generation is shown in Figure - 2.

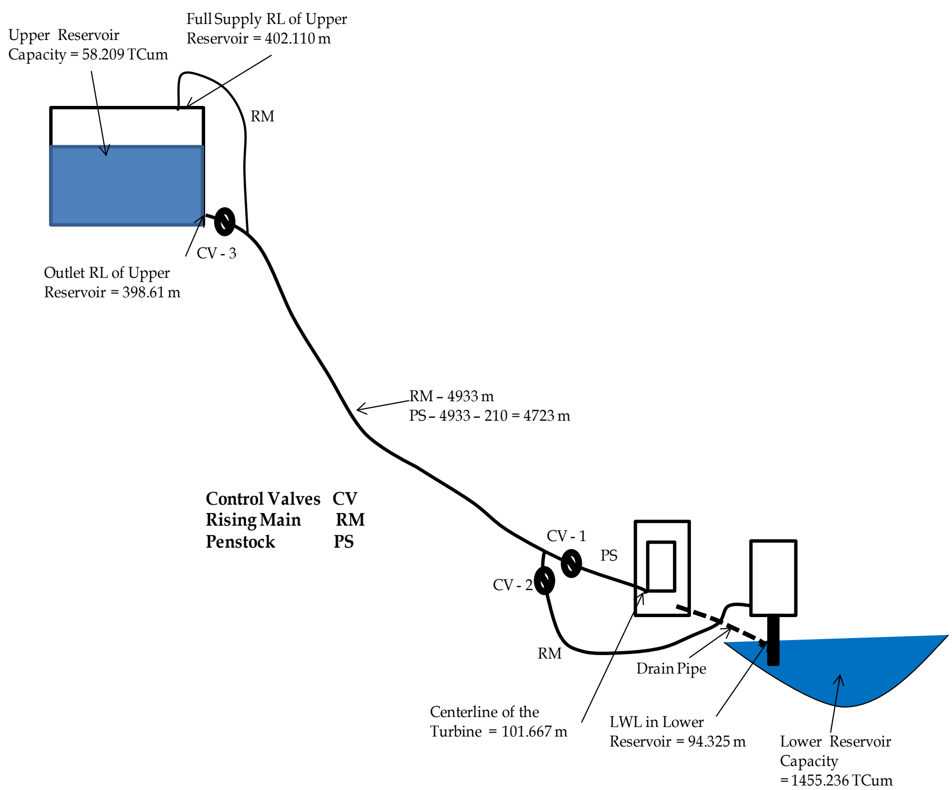

Figure 2 : Schematic Diagram showing the Pumping & Generating System

The annual water requirement for MIDC area for industrial and other activities is 280.000 TCum whereas for pumped hydroelectric power generation the water in circulation is 58.209 TCum, which is very less as compared to live storage capacity of MIDC reservoir.

As the gross head is around 299.40 m, it is decided to use the pre stressed concrete cylinder pipe (PCCP) of class 30.00 kg/cm^2 is considered. The economical diameter of the rising main is calculated by considering the different diameters of pipe ranging from 600 mm to 1300 mm. The pipes made of other materials are not considered while calculating the economical diameter. The cost calculations are done by considering the following data –

- Rate of Interest – 10%
- Useful life of Pumps – 20 years
- Useful life of Pipe – 40 years
- Period of Analysis – 40 Years
- Rate of Pipe – As per DSR of MJP 2011-12.

A plot of annual cost of pump, pumping and rising main versus diameter is shown in Figure - 3. It is clear from the plot that the annual cost is minimum corresponding to 900 ~ 1000 mm, hence economical diameter of the pipe is considered as 900 mm. The design and cost analysis of the rising main and pumping system is shown in the Appendix – A.

b) Selection of Turbine

The schematic diagram of generation and pumping system is shown in Figure - 2. A three unit pumped storage power system is proposed, which consist of Rising Main / Penstock, Pumping System and Turbine & Generation System.

The generation phase is designed to fulfill the demand during the peak hours. In the present case the demand at the peak hours of MIDC is not taken into consideration. The availability in the market of turbine-generator system is considered as criteria for the same. The gross head on the turbine is 299.940 m. The Pelton wheel of make "Litostr & Jpower" with two nozzles is selected which is suiting to the available head. The pitch diameter of the selected turbine is 1170 mm and its output under the net head of 233 m is 4140 kW. The design and cost analysis of the generating system is shown in the Appendix -B.

VI. Cost Analysis

The annual operation cost for running the plant on salaries of technical and non-technical staff

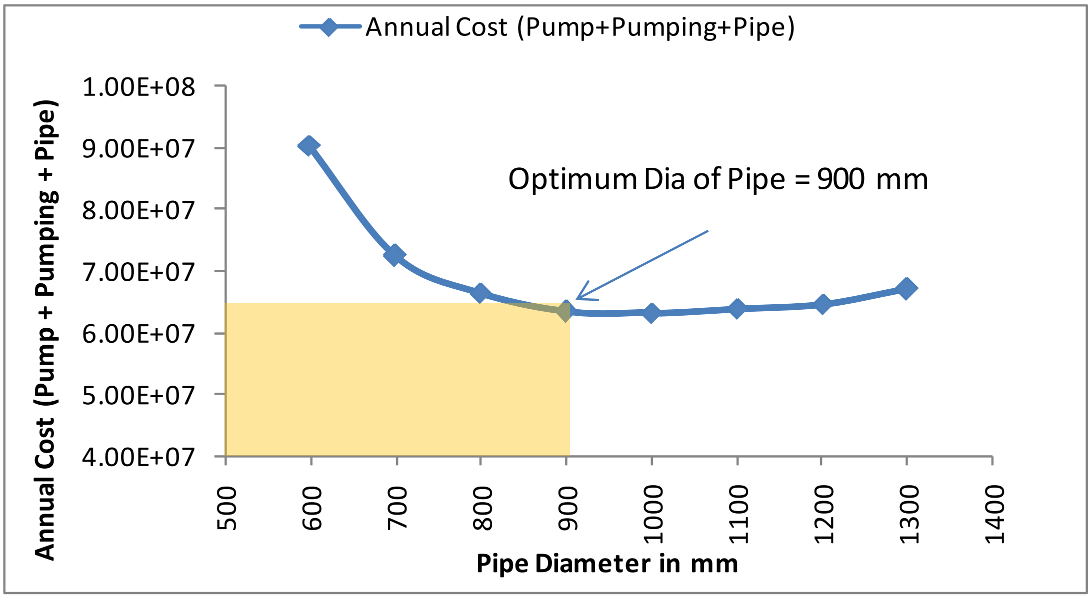

Figure 3 : Economical Diameter of Pipe

excluding the maintenance and energy cost which is already taken into account) is Rs.1332000.00. The cost estimate of the upper reservoir is done for which the annual cost including maintenance is estimated as Rs.3750152.18. The capital cost of power house building is estimated on the basis of unit cost per unit area @Rs.8000.00 per sqm. The annual cost of which is calculated as Rs.722372.47.

All the annual costs estimated are summarized as under;

Annual Cost of Pumps (In both Phases)	Rs	986068.52
Annual Cost of Pumping	Rs	54312000.00
Annual Cost of Penstock/Rising Main	Rs.	8193101.62
Annual Cost of Turbine & Generator	Rs.	1217142.68
Annual Cost of Power House	Rs.	722372.47
Annual Cost of Upper Reservoir	Rs.	3750152.18
Annual Administration Cost (Operation)	Rs.	1332000.00
Total Annual Cost	Rs.	70512837.46

The annual earnings from the sale of electrical units during the peak hours is Rs. 74268101.25. Thus net annual benefit from the project is Rs.3756263.78, which exhibit the financial feasibility of project.

VII. Senstivity Analysis

The net annual benefit depends upon many external factors. Some of the financial parameters such as rate of interest and the rates of purchase of electricity during pumping and rate of sale of electricity generated are important, which directly affects the net annual benefits.

a) Rate of Interest

The rate of interest with which the money will be borrowed from the financial institutions do have direct impact on the net annual benefits of the project and thus its affect should be critically studied. The net annual benefits corresponding to different rates of interest varying from 6% ~ 14% is shown in Figure – 4, which explains that the economical feasibility of the project lies at the rate of interest below 12.75%, which if increases beyond this, the annual benefits becomes negative i.e. loss.

b) Unit Rate of Electricity during Pumping and Generation

The rates of purchase of electricity during the slack hours for pumping and rate of sale of electrical units during the peak hours for generation affects the net annual benefits. The sensitivity of the annual benefits for variation in the purchase and sale rates of electrical units is tested and is shown in Figure – 5 and 6. The effect on net annual benefit is estimated by varying the rates of purchase of electricity during pumping from Rs.2.30/kWh to Rs.2.80/kWh. It is clear that the economical feasibility of the project is possible only if the electrical units are available at the rate of Rs.2.67/kWh or less than that and at the same time the unit price of the sale of generated electricity during peak period is Rs.9.00/kWh.

The effect on net annual benefit is estimated by varying the rates of sale of generated electricity from Rs.8.45/kWh to Rs.9.00/kWh. It is clear from the plot that the economical feasibility of the project is possible only if the sale of electrical units is at the rate of Rs.8.55/kWh or more than that and at the same time the unit cost of the electricity to be purchased during slack hours for pumping is Rs.2.50/kWh.

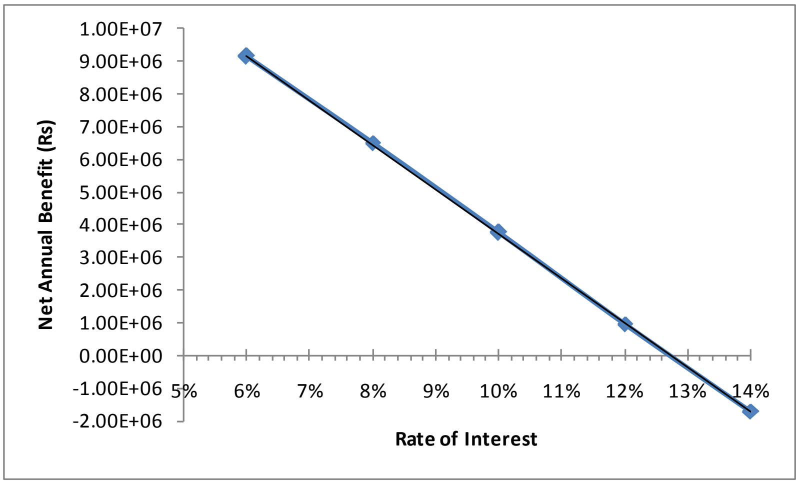

Figure 4 : Sensitivity Analysis – Rate of Interest

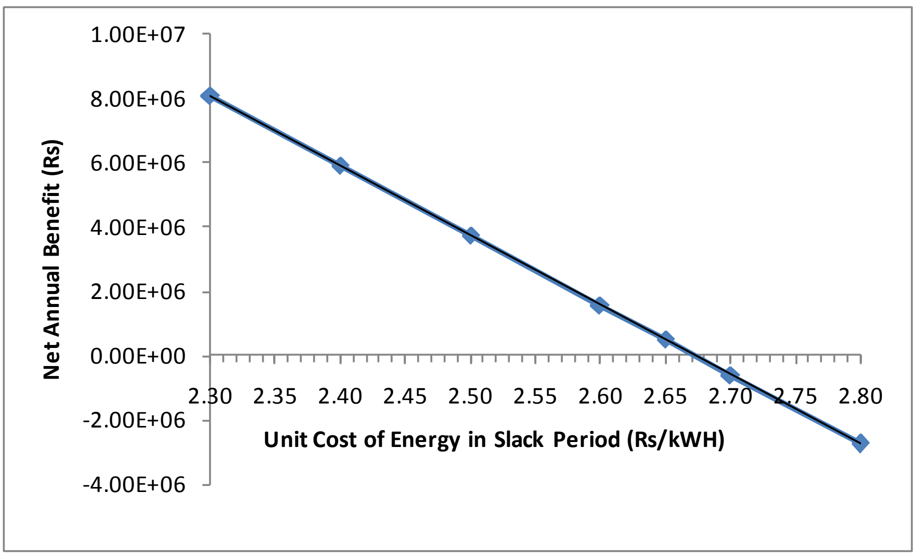

Figure 5 : Sensitivity Analysis – Rate of Electricity in Pumping Phase

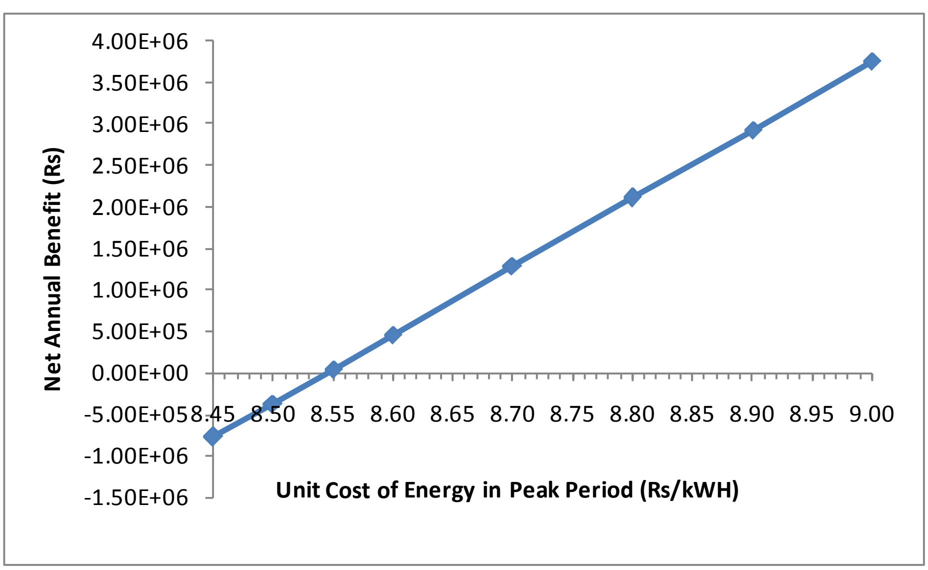

Figure 6 : Sensitivity Analysis – Rate of Electricity in Generating Phase

VIII. Conclusions

The main aim of work is to prepare a detailed engineering plan, preliminary estimate for installation of pumped hydro electric power plant and to check its economic feasibility, which includes a detailed planning, designing along with the cost analysis. The following conclusions are drawn from the study -

(i) The optimum diameter of the pipe as rising main is obtained from economical analysis as 900 mm and the same is proposed as penstock. The pipe proposed is pre stressed concrete cylinder pipe (PCCP).

(ii) The vertical turbine pumps totaling 6400 kW are proposed for pumping water from lower to upper reservoir.

(iii) The Pelton wheel of make "Litostr & Jpower" with two nozzles is selected as turbine. The pitch diameter of the selected turbine is 1170 mm and its output under the net head of 233 m is 4140 kW.

(iv) The total annual cost of the project is Rs.7,05,12,837.46, which is calculated on the basis of 10% rate of interest and 20 years life of pumping machineries, 40 years life of turbines and 60 years life of upper reservoir and pump house. The unit cost of electricity is considered as Rs.2.50/kWh for pumping and the sale price of generation during peak hours is Rs.9.00/kWh.

(v) The annual earnings from the sale of electrical units during the peak hours is Rs. 74268101.25. Thus net annual benefit from the project is Rs.3756263.78, which exhibit the financial feasibility of project.

(vi) The economical feasibility of the project lies at the rate of interest below 12.75% as concluded from the sensitivity analysis. In the case, the rate of interest increases beyond 12.75%, the annual benefits becomes negative i.e. loss.

(vii) The sensitivity analysis exhibit that the project is economically feasible only if the electrical units are available at the rate of Rs.2.67/kWh or less than that and at the same time the unit cost of the generated electricity is Rs.9.00/kWh.

(viii) The annual cost on different as % of the total annual cost is shown in the Figure 7, which indicates the annual cost of pumping have the maximum share i.e. 85.92%.

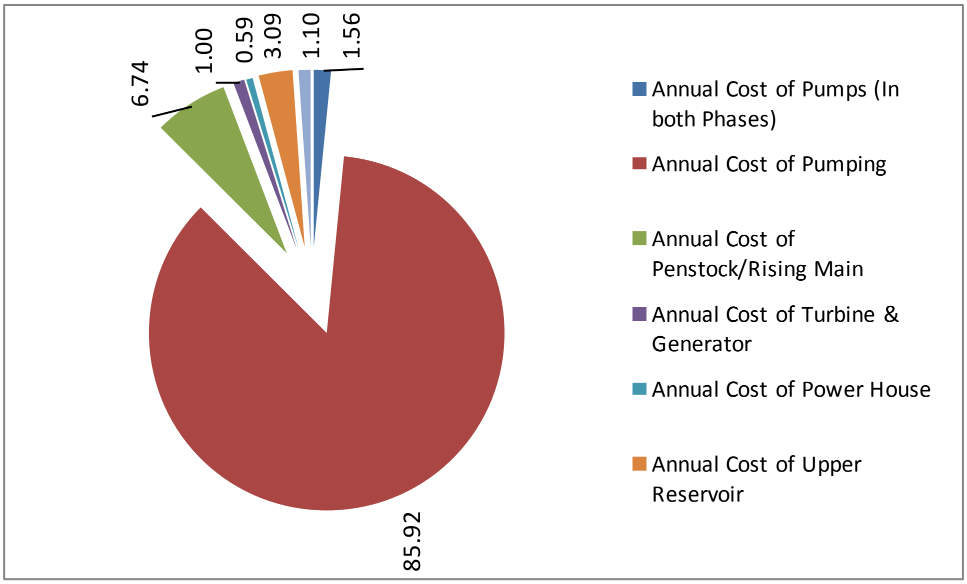

Figure 7 : Distribution of Annual Cost

a) *Limitation of Study*

In this analysis the actual demand pattern of the electricity in and around the MIDC area is not considered. The sensitivity of the net annual benefit is verified for rate of interest, unit rate of electricity for pumping and unit rate of electricity generated. There are many other factors for which the sensitivity analysis would have revealed more realistic results such as size of the upper reservoir, rate of construction, hours of pumping (i.e. availability of electricity in slack period), change in operation and administration cost and many more. In the present case the rate of inflation is also not taken into account.

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Appendix

Appendix - A : Design and Cost Analysis of Economical Diameter of Rising Main

RISING MAIN -		
Live Storage Capcity of the MIDC Reservoir	1455.236	TCum
Live Storage Capcity of the MIDC Reservoir	1455.236	TCum
Gross Volume of Water Available for generation of Electricity in one cycle @ 5%	72.762	TCum
Gross Volume of Water Available for generation of Electricity in one cycle with 20% Loss	58.209	TCum
Pumping Hours	9.30	Hours
Discharge through Rising Main	1.739	m^3/s
Length of Rising Main (from Survey Record)	4933	m
Static Head	306.785	m
Type of Pipe Selected & Friction Factor	PCCP/0.0120	
Inner Diameter and Wall Thickness	900.00/27.50	mm
Total Head including frictional losses	367.50	m
Water Hammer Pressure	391.79	m
Suitable Water Hammer control devices are recommended at U/S of turbine		
Safe Time for Closure of Valve	148.73	seconds
PUMPING MACHINERY -		
Total Discharge of Pump	1.739	m^3/s
Total Head on Pump (Rounded up)	337.00	m
Efficiency of pump & motor (%)	90.00	
Power required (Roundup)	6400.00	kW
COST ANALYSIS -		
Annual Maintenance Cost for Pumps(as fraction of Annual Capital Cost)	0.08	
Annual Maintenance Cost for Pipes(as fraction of Annual Capital Cost)	0.025	
Total Number of Electrical Units to be consumed by pumps per cycle	59520.00	kWh
Unit Cost of Electrical Unit during off Peak Hours	2.50	INR/kWH
Cost of Electricity Consumed/Day	148800.00	INR
Cost of Electricity Consumed/Year	54312000.00	INR
Unit Cost of Pumps including the Cost of Electrical Items & Connection Cost	1000.00	INR /kW
Capital Cost of Pumps (0-20 Years)	6400000.00	INR
Present Value of Capital Cost of Pumps (21 - 40 Years)	1373108.53	INR
Annuity Factor	8.51	
Annual Cost of Pumps	913026.41	INR
Annual Maintenance Cost	73042.11	INR
Annual Pumps Cost including Maintenance	986068.52	INR
Annual Cost of Pumps and Pumping	55298068.52	INR
Unit Cost of Pipes	10223.00	INR/m
Cost of Excavation, Lowering, Laying and Jointing (as fraction of unit cost of pipe)	0.30	
Cost of Fittings such as WH Control, Valves etc (as fraction of unit cost of pipe)	0.25	
Gross Unit Cost of Pipe	15845.65	INR/m
Gross Cost of Pipe	78166591.45	INR
Annuity Factor	9.78	
Annual Cost of Pipes including fittings, excavation, lowering, laying and jointing	7993269.87	INR
Annual Maintenance Cost	199831.75	INR
Annual Pipe Cost including Maintenance	8193101.62	INR
Annual Cost of Pumps, Pumping and Pipe (Rising Main)	**63491170.14**	**INR**

Appendix - B : Detailed Calculations & Cost Analysis of Generating System

TURBINE & GENERATOR SYSTEM -		
Gross Head on Turbine = H	296.942	m
Maximum Head Loss for Optimum Power = Hf = H/3	98.981	m
Calculation of Discharge : Q = P / {9.81 x (H - Hf)}	2.132	Cum/s
Live Capacity of Upper Reservoir	58.209	Tcum
Actual Time of Running of Turbine	27305.017	s
Actual Time of Running of Turbine	7.585	Hours
Rated Power of Selected Pelton Turbine	4140.00	kW
Efficiency of Turbine System "Eff(T)"	80.00%	%
Power "Pa" - Actual = Eff(T) x Theoretical Power	3312.00	kW
Efficiency of Electricity Generation System "Eff(G)"	90.00%	%
Electrical Power "Pae" - Actual = Eff(G) x Pa	2980.80	kW
Period of Generation	7.585	Hours
Electrical Units Generated in One Cycle of Operation	22608.55	kWH
COST ANALYSIS -		
Unit Cost of Electrical Unit during Peak Hours	9.00	INR/kWH
Value of Electricity Generation/Day	203476.99	INR
Value of Electricity Generation/Year	74269101.25	INR
Unit Cost of Turbine & Generators including the Cost of Electrical Items & Connection Cost	2500.00	INR
Cost of Turbine & Generators including the Cost of Electrical Items & Connection Cost	10350000.00	INR
Annual Maintenance Cost for Turbines (as fraction of ACC)	0.15	
Annuity Factor	9.78	
Annual Cost of Turbine Generator Set	1058384.94	INR
Annual Maintenance Cost	158757.74	INR
Annual Cost of Turbine Generator Set including Maintenance	**1217142.68**	**INR**