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Software Scrutiny of Standalone hydro power plant - A case Study

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Abstract: *The utilization of electrical energy is ever increasing in the developing countries like Ethiopia, India, Libya, Ghana, Algeria, Eretria etc., As the fuel cost is becoming very high for the thermal plants, in order to keep the fossil fuels to our future products we have to use the renewable energy more. Hydro power is the one of the most renewable energy which is available plenty in nature. The African countries have a plenty of hydro power but they are not utilizing properly. The country like Ethiopia has a plenty of water resources and some new power plants are also developing. In this paper a case study had done on the one of the hydro power plants of Ethiopia. The development status of hydro power of Ethiopia has been presented. And the simulation graphs have been plotted for hydro power plant.*

I. Introduction

In generally we can say Electricity from water is usually referred as hydro power, where the hydro is the Greek word for water and hydro power is the energy contained in water. It can be converted in the form of electricity through hydroelectric power plants. Energy is a key issue for sustainable development [1]. The Energy Commission estimates that the global energy demand will increase by 70% over a period of 30 years (2000-2030). The growth in energy demand will cause a considerable increase in greenhouse gas emissions. CO2 emissions are projected to increase by 18% in 2030 compared to the 1990 level, in the Renewable are the solution to climate change. One of the important and oldest renewable energy is the “Hydro power Energy”[3].

Hydropower has been used in the U.S. since the late 1800’s and the origins of the technology reach back thousands of years. Ancient cultures from the Greeks to Imperial Rome to China used water-powered mills for essential activities like grinding wheat. The ancestor to the modern hydro turbine was developed in the mid-18th century. Wisconsin was home to the world’s first hydroelectric power plant, which began operations on September 30, 1882. The plant was built by a paper manufacturer, H.J. Rogers, and at first, the Appleton plant generated enough power to light his home, the plant and a nearby building. One hundred years later, inventors were steadily improving the efficiency of these technologies [1]. In 1849, an engineer named James Francis developed the Francis Turbine, the type of turbine that is most widely used today. In the year 1887 the first hydro power plant opens in the west, in San Bernadio, California. From that day the hydro power development started very rapidly. Many Dams, reservoirs has been constructed for the production of Electrical Energy [14].

The main source of the hydro power is the Water. Commonly the Hydroelectric plants are classified based on their hydraulic characteristic that is with respect to the water flowing through the turbines and the structure of the dam. In generally there are run off river schemes, storage schemes, and Pumped storage schemes [2]. Now the present era of the industrial sector is mainly concerning the development of the pumped storage plants. These plants are playing a key role in the peak load times, many industries, companies they are planting their own pumped plants in their own sites [9].

II. Recon view of hydro power plants:

This is general layout of the hydro power plants. Some of the main important components of the hydro power plants are Turbines, Generators, penstocks, spillways, surge tanks, fore bays, spill gates, power house equipments and the important parts and the availability of the water to run the plants [10]. The Dams are playing a key role to store the water; they are providing the sufficient head. There are some important considerations while selecting the dam site. Apprehension for the environmental effects of large projects which destroy wildlife surroundings, displacement of aboriginal people and upset perceptive downstream ecologies coupled with often heavy handed and insensitive planning. The planning works should be more concern to the civil development authority; they have to design the hydro power plants without damaging the environment [4].

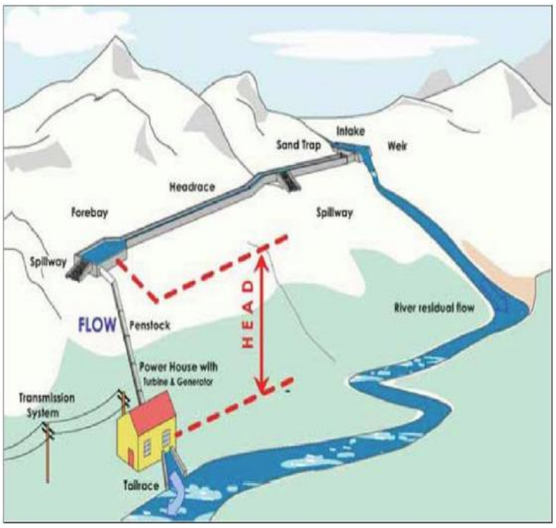


Fig.01 Layout of the Hydro power plants

III. Development of Hydro power

The hydro power development is escalating rapidly from 1900's. From 1980's Conventional hydropower capacity is nearly triple compared with 1920 level. The developing countries like Brazil, Canada, India, Ethiopia, Libya and Egypt etc they are enthusiastically developing the hydro power plants to save the fossil fuels and also save the environment from the different gases which are releasing by some power plants.

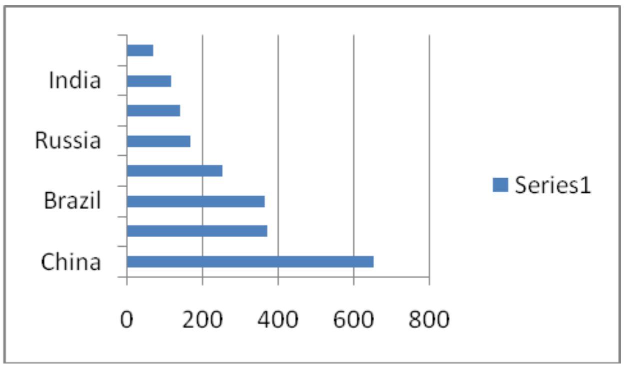


Fig.02 Graphical view of the hydro power generated by some countries [13]

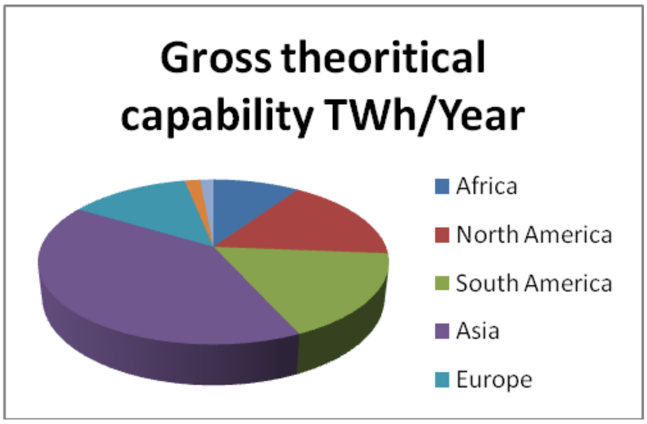


Fig.03 Regional hydropower potential.[13]

The above two graphical representation shows the hydro power developed by each country in fig.01 and in the fig02 and the gross theoretical power developed by each continent.

IV. Major planning in constructing a hydro power plant

In constructing a Hydropower plant the following procedures will taken in to consideration, in design, layout, optimization and layout.[12]

A. Project formulation and layout

Hydrological study (flow duration, flood conditions, dry/wet year conditions)

i) Basic topographical overview (possible head, access conditions, existing roads)

ii) Preliminary assessment of slope stability and sediment loads

iii) Basic project layout with first approximation of electricity generation

B. Engineering design and layout optimization

i) Pre-design of hydraulic structures with cost estimations

ii) Optimization of sizing

iii) Evaluation of layout alternatives

C. Definition of project layout

(i) Detailed field investigations

(ii) Detailed engineering design and bill of quantities

(iii) Budgetary quotations for equipment

V. Different Mathematical analysis for Hydro Power Generation

An standard empirical formula for approximating electric power production at a hydropower plant is given as[11]

$$P = \rho h r g k \quad \text{........(1)}$$

Where

P= power in watts

ρ is the density of water

h is height in meters

r is flow rate in cubic meter per second

g is the acceleration due to gravity of 9.8m/s^2

k is the constant of efficiency ranging from 0 to 1.

Hydraulic turbines occupy a special role in the hydro power plants. These turbines are used to convert the hydraulic energy in to mechanical energy which in turn in to an electrical energy. In generally the turbines will have runner, buckets at its periphery connected to the shaft, a mechanism which controls the quantity of water and passage leading to and from the wheel. Different types of turbines are using in the present industry like, Pelton, Francis, Kaplan, Deriz etc. In designing the turbine the important parameters will be considered like speed, Runner diameter, casing etc.[5]

The speed of the turbine can be calculated as

$$n' = \frac{n'_s H^{5/4}}{\sqrt{p} * 1.358} \quad \text{......(2)}$$

Where $n'$is trail synchronous speed/ rotational speed,and the rated speed is calculated as

(n= 60*f)/P. ....(3)

Apart from the turbine there are different parts in the hydro power plants like surge tank, penstocks, pressure shafts, gate valves, fore bays etc. There are different types of penstocks based on the construction surface penstocks, embedded penstocks, in tunnel penstocks, in shaft penstocks. In designing the hydraulic penstocks they have to consider some sever losses like frictional losses, bend loss, expansion, contraction, at trash rack, at entrance etc[6].

The rated turbine output of the any machine can be calculated as

$$P_r = \frac{HQ\gamma}{1000}\,\eta_t \eta_s \quad \text{......(4)}$$

Where

H is rated head in meters,

Q is rated discharge (cumecs)

γ is the specific weight of water (N/m^3)

η are the rated turbine efficiency and efficiency of speed increaser.

In generally there are different types of dams are there for hydro power plants. Different types of dams are Rock fill dams, Earthen Dams, Butters Dams, Gravity dams. Coming to the construction of the dam at the Tekeze power plant, the dam construction is arch dam. In constructing the arch dam the economic angle is $133^0.34'$. The development of Tekeze hydroelectric power plant involved the construction of a 188m high, mass concrete double curvature arch dam, spanning 450m across a 350m deep natural gorge, two river diversion tunnels, an underground powerhouse, water conveyance tunnel and outlet works.

VI. Brief analysis of Ethiopian electric power corporation

Ethiopia first got electric light during Emperor Minilik II era in 1898, when his majesty acquired a generator to light up his palace. In addition to the use of generators, Minilik got constructed the first Hydro Power Plant on Akaki River in the year 1912 in order to supply power to small factories after sometimes it was extended to public places and major roads in the vicinity of the palace. However, the effort of the government to extend the power supply to the public was hindered by the Italian invasion of Ethiopia in the years 1936.

During this temporary invasion, the Italian company called Coneil overtook the authority of generating and distributing electric power. The company installed generators at different places and extended the power supply to the then major towns. After the Italians were driven out from Ethiopia in the year 1941, an organization called “Enemy property Administration” was established and took over along with other activities the generation and distribution of power to the people.[15]

In the year 1948, an organization that had been vested with the power to administer the enemy property was evolved to an organization called “Shewa Electric Power”. The new organization also has limited capacity, managed to increase the power supply not only in Shewa but also other administrative regions. In light of its function, its name was changed to “Ethiopian Electric light and Power” in the year 1955.Soon after its establishment, the supervision and management of the organization was vested in the Board of Directors appointed by the government.[15]

After eight months of its establishment, the Ethiopian Electric Light and Power was transformed to the "Ethiopian Electric Light and Power Authority" (Charter of the Ethiopian Electric Light and Power).The newly established Authority was conferred with the powers and duties of the previous Ethiopian Electric Light and Power. The purpose of the Ethiopian Electric Light and Power Authority was to engage in the business of production, transmission, distribution and sell of electric energy to the people of Ethiopia and carry on any other lawful business. In addition to this, it was also determined that the Head Office of the Authority would be in Addis Ababa, with branch offices at different places as necessary [15].

VII. Analysis for Hydro Power Generation using simulation software

To do the simulation analysis of Hydro power plant we had considered some data from Tekeze is one of the largest hydro power plants currently on the way to develop the resources in the Ethiopian country and it is suited in Tigray regional state approximately eighty kilo meters west of town Mekele. The Tekeze River, which forms the boundary between the regions of Tigray and Amhara, flows northwards and is a major tributary of the Atbara River, which itself a tributary of Nile River. The dam is a double curvature arch dam which is able to with stand the heavy pressure of the reservoir water. It is 188m high and 450m wide and is constructed from mass concrete.

The reservoir is one of the biggest man made water body in Ethiopia, with a total water storage capacity of 9.23 billion cubic meter. The reservoir is almost 70km long at full supply level and it has a catchment area of over 30,000 square meters, with long term average annual inflow of 3.75billion cubic meter. But the data for the simulation work is not sufficient. So we had considered some assumptions in the simulation work, like water discharge rate, E total, etc. These data is included in the appendix-I

The simulation has been done with some data of the Tekeze power plant. The data which we had collected from the Tekeze power plant .

Type	SF78-20/6400
Rated capacity (S)	86.7 MVA
Rated power (P)	78 MW
Rated voltage (VLL)	13.8 KV
Rated current (IL)	3.627 KA
Power factor (cos f)	0.9 lagging
Number of phase	3
Rated speed	300 rpm
Runaway speed	540 rpm
Rated frequency	50 Hz
Direction of rotation	Clockwise viewed from top
Insulation class	F
Type of excitation	Static SCR

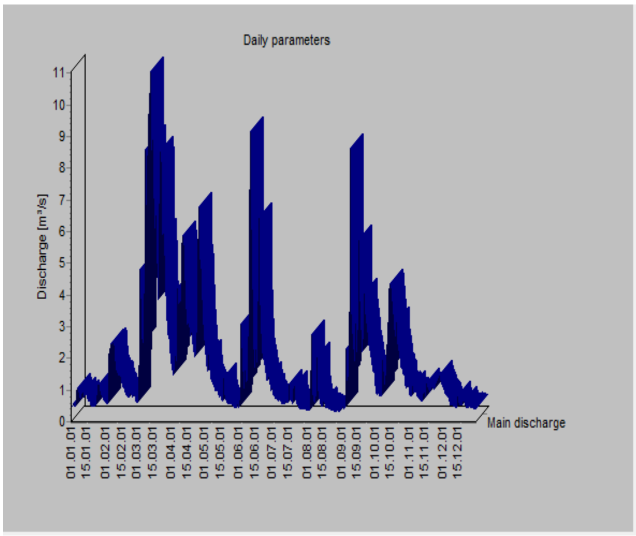
Tabel.01 Generator data of the Tekeze hydro power plant

Based upon the data collected from the hydro power plant and data collected from the Canadian hydro power stations. By combining the both on the simulation software we analyzed some results like turbine Q, Main Q, Q usable, Q weir, Q minimum flow regulation, Power, Efficiency, Head, Financial Return, Daily energy[7].

The data collected by the Canadian hydro power station, is Main Q, Minimum flow, Head, Turbine Q, Eta total. The data collected is shown in the appendix.

VIII. Results and Explanation

On simulating the data of hydro power plant the results has been concluded below.



Graph.01 Main Q Discharge of Water at the power plant

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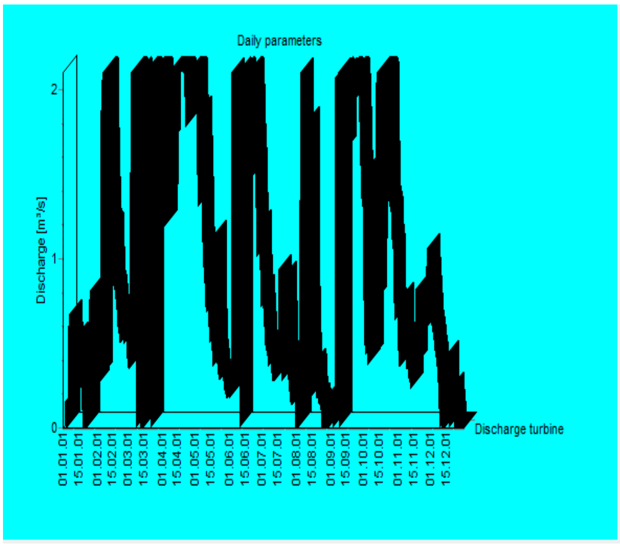
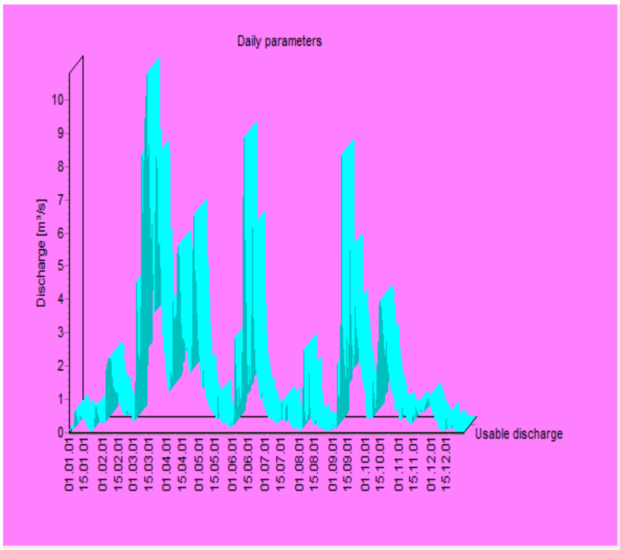
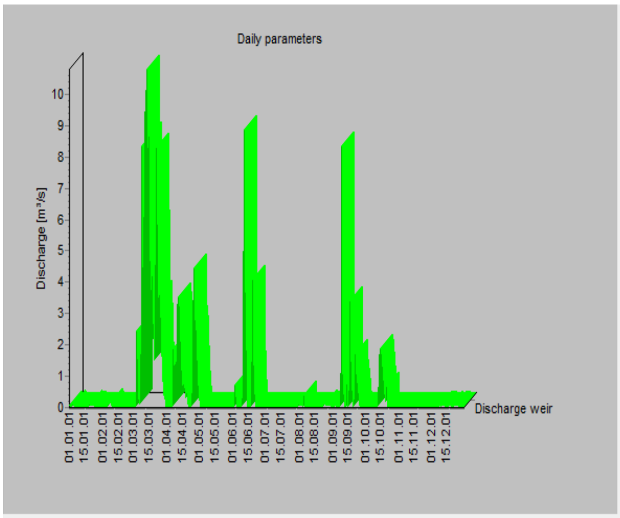


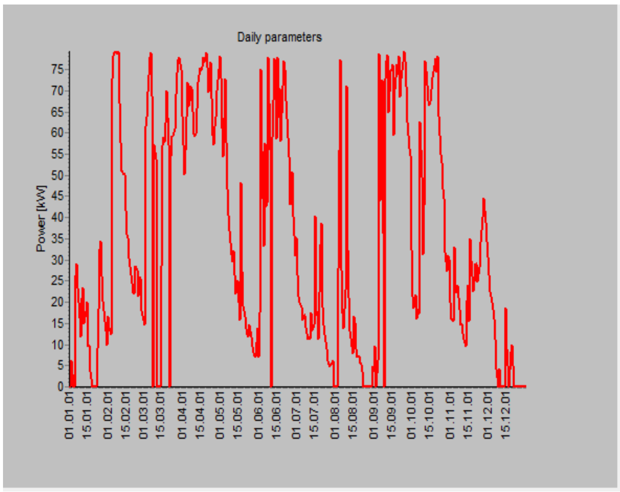
Graph.02 Turbine Q Discharge at the power plant



Graph.03 Q usable at the power plant

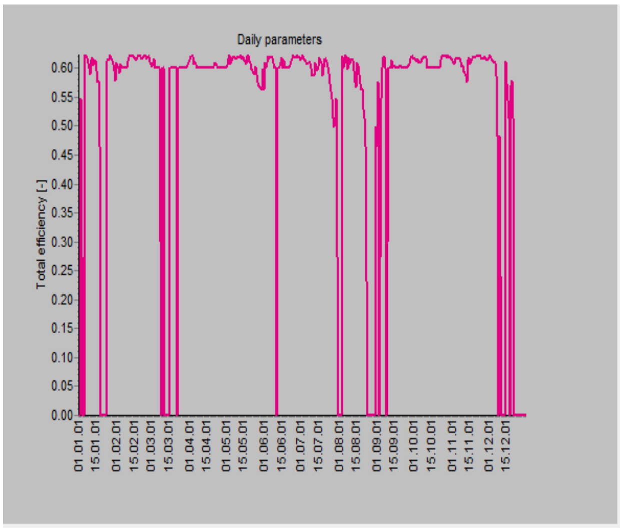


Graph.04 Discharge Q weir at the power plant

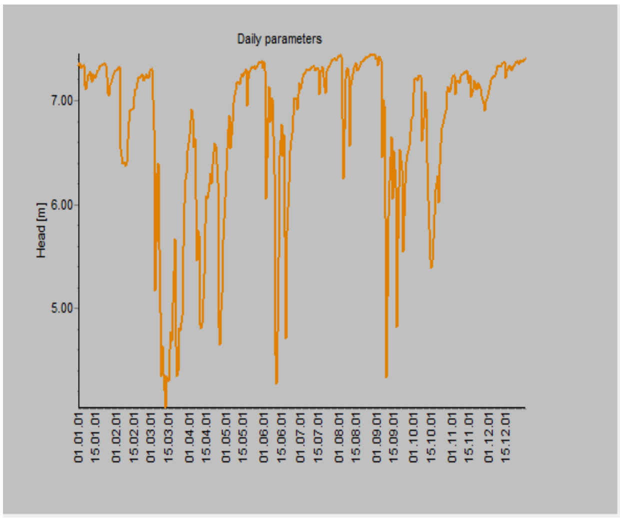


Graph.05 Power generated at the hydro power plant

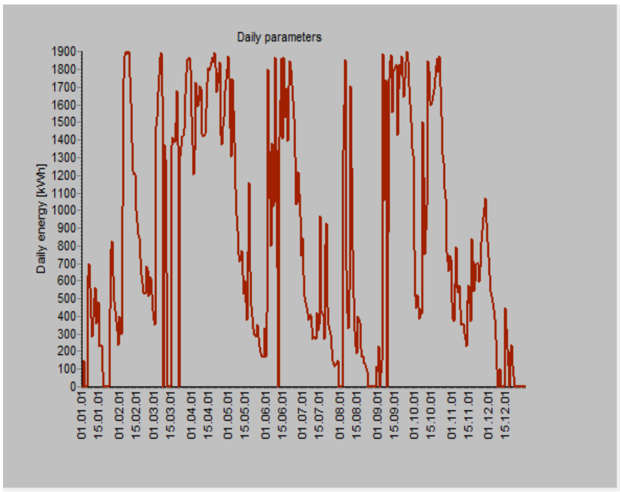
With respective to main Q discharge



Graph.06 Efficiency of power at the hydro Power plant with respective to main Q discharge



Graph.07 Head of power at the hydro Power plant with respective to main Q discharge



Graph.08 Daily energy parameter of the hydro power plant.

The above shown graphs.01 to graph.08 show the simulation results of the hydro power plant parameters like Power generation, Main discharge, discharge through turbine, Q usable, Q wire, Daily energy parameters etc.

In the appendix-II the results has been conclude in the form of mean parameters, maximum, minimum, and the total annual production of the power annual discharge, usable discharge, discharge through wire for an year has been presented.

VIII. Conclusion

The hydro power plants are one of the important renewable energy sources [8]. As the fossil fuels are decreasing day by day we have to save the fossil fuels to the future, and in order to use the renewable energy sources sufficiently [16]. The renewable energy sources like wind, hydro, geothermal, ocean energy have to utilize properly. In this paper some practical data of the hydro power plant has taken and simulated in the software tool, and the results has been presented in the paper. As compared with the practical results the simulations results are good. And mainly the losses have been reduced. The graphs have been plotted for power, efficiency, discharge rate etc for the hydro power plants. From the ministry of electricity board of Ethiopia, they provided that the maximum power production capacity of Tekeze power plant is 300MW but by using the software tool with the same water flow data the maximum power production is 309.46MW

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Appendix-I:

(a) Main Q discharge day by day

DATE	Q(m^3/s)	DATE	Q(m3/s)	DATE	Q(m3/s)	DATE	Q(m3/s)
01.12.12	0.47	01.04.12	1.84	30.06.12	0.96	28.09.12	1.8
02.01.12	0.44	02.04.12	1.63	01.07.12	1.07	29.09.12	1.61
03.01.12	0.56	03.04.12	1.44	02.07.12	0.85	30.09.12	1.56
04.01.12	0.49	04.04.12	1.59	03.07.12	0.74	01.10.12	1.16
05.01.12	0.47	05.04.12	2.09	04.07.12	0.71	02.10.12	0.89
06.01.12	1	06.04.12	1.91	05.07.12	0.68	03.10.12	0.83
07.01.12	1.07	07.04.12	4.23	06.07.12	0.61	04.10.12	0.9
08.01.12	0.94	08.04.12	3.68	07.07.12	0.64	05.10.12	0.77
09.01.12	0.78	09.04.12	3.78	08.07.12	0.64	06.10.12	0.82
10.01.12	0.68	10.04.12	5.64	09.07.12	0.58	07.10.12	0.8
11.01.12	0.88	11.04.12	5.87	10.07.12	0.52	08.10.12	1.97
12.01.12	0.94	12.04.12	5.6	11.07.12	0.53	09.10.12	1.59
13.01.12	0.75	13.04.12	4.49	12.07.12	0.52	10.10.12	1.13
14.01.12	0.81	14.04.12	3.56	13.07.12	0.65	11.10.12	1.42
15.01.12	0.86	15.04.12	3.05	14.07.12	0.56	12.10.12	2.44
16.01.12	0.63	16.04.12	3.11	15.07.12	0.59	13.10.12	3.13
17.01.12	0.64	17.04.12	2.98	16.07.12	1.19	14.10.12	4.2
18.01.12	0.51	18.04.12	2.65	17.07.12	0.66	15.10.12	4.37
19.01.12	0.5	19.04.12	2.82	18.07.12	0.64	16.10.12	4.23
20.01.12	0.47	20.04.12	2.48	19.07.12	0.52	17.10.12	3.83
21.01.12	0.46	21.04.12	2.21	20.07.12	1.03	18.10.12	3.39
22.01.12	0.46	22.04.12	2.02	21.07.12	1.15	19.10.12	2.93
23.01.12	0.48	23.04.12	2.08	22.07.12	0.68	20.10.12	2.68
24.01.12	0.82	24.04.12	2.81	23.07.12	0.59	21.10.12	3.17
25.01.12	1.16	25.04.12	5.75	24.07.12	0.54	22.10.12	2.48
26.01.12	1.21	26.04.12	6.79	25.07.12	0.47	23.10.12	2.12
27.01.12	1	27.04.12	5.15	26.07.12	0.41	24.10.12	1.74
28.01.12	0.87	28.04.12	4.83	27.07.12	0.39	25.10.12	1.68
29.01.12	0.76	29.04.12	3.86	28.07.12	0.38	26.10.12	1.52
30.01.12	0.71	30.04.12	3.07	29.07.12	0.39	27.10.12	1.46
31.01.12	0.64	01.05.12	2.59	30.07.12	0.41	28.10.12	1.14
01.02.12	0.63	02.05.12	2.13	31.07.12	0.34	29.10.12	1.03
02.02.12	0.58	03.05.12	1.75	01.08.12	0.32	30.10.12	1.12
03.02.12	0.54	04.05.12	1.55	02.08.12	0.31	31.10.12	1.1
04.02.12	2.12	05.05.12	2.12	03.08.12	0.33	01.11.12	0.86
05.02.12	2.3	06.05.12	1.65	04.08.12	1.59	02.11.12	0.77
06.02.12	2.45	07.05.12	1.35	05.08.12	2.74	03.11.12	0.76
07.02.12	2.44	08.05.12	1.2	06.08.12	0.88	04.11.12	1.17
08.02.12	2.51	09.05.12	1.11	07.08.12	0.65	05.11.12	0.94
09.02.12	2.42	10.05.12	0.97	08.08.12	0.57	06.11.12	0.91
10.02.12	1.94	11.05.12	0.93	09.08.12	0.77	07.11.12	0.95
11.02.12	1.65	12.05.12	0.99	10.08.12	2.06	08.11.12	0.82
12.02.12	1.46	13.05.12	0.85	11.08.12	1	09.11.12	0.74
13.02.12	1.44	14.05.12	0.75	12.08.12	0.73	10.11.12	0.75
14.02.12	1.44	15.05.12	0.82	13.08.12	0.56	11.11.12	0.7
15.02.12	1.23	16.05.12	0.71	14.08.12	0.48	12.11.12	0.67
16.02.12	1.09	17.05.12	0.61	15.08.12	0.44	13.11.12	0.63
17.02.12	1.07	18.05.12	1.39	16.08.12	0.63	14.11.12	0.87
18.02.12	0.95	19.05.12	0.87	17.08.12	0.6	15.11.12	0.95
19.02.12	0.85	20.05.12	0.69	18.08.12	0.47	16.11.12	0.76
20.02.12	0.81	21.05.12	0.63	19.08.12	0.42	17.11.12	1.22
21.02.12	0.76	22.05.12	0.57	20.08.12	0.43	18.11.12	1.09
22.02.12	0.75	23.05.12	0.54	21.08.12	0.4	19.11.12	0.92
23.02.12	0.9	24.05.12	0.53	22.08.12	0.39	20.11.12	0.97
24.02.12	0.88	25.05.12	0.59	23.08.12	0.36	21.11.12	1.07
25.02.12	0.74	26.05.12	0.53	24.08.12	0.34	22.11.12	1.07
26.02.12	0.84	27.05.12	0.48	25.08.12	0.34	23.11.12	0.97
27.02.12	0.83	28.05.12	0.45	26.08.12	0.32	24.11.12	1.05
28.02.12	0.66	29.05.12	0.43	27.08.12	0.3	25.11.12	1.2
01.03.12	0.61	30.05.12	0.42	28.08.12	0.32	26.11.12	1.27
02.03.12	0.59	31.05.12	0.57	29.08.12	0.31	27.11.12	1.35
03.03.12	1.76	01.06.12	0.42	30.08.12	0.29	28.11.12	1.46
04.03.12	4.79	02.06.12	0.65	31.08.12	0.38	29.11.12	1.32
05.03.12	3.92	03.06.12	3.09	01.09.12	0.36	30.11.12	1.21
06.03.12	2.63	04.06.12	1.59	02.09.12	0.48	01.12.12	1.11
07.03.12	2.45	05.06.12	1.02	03.09.12	0.35	02.12.12	1.12
08.03.12	4.03	06.06.12	1.64	04.09.12	0.41	03.12.12	0.92
09.03.12	8.59	07.06.12	1.25	05.09.12	2.32	04.12.12	0.86
10.03.12	6.82	08.06.12	1.27	06.09.12	1.28	05.12.12	0.82
11.03.12	8.4	09.06.12	2.65	07.09.12	1.39	06.12.12	0.77
12.03.12	9.7	10.06.12	7.32	08.09.12	3.45	07.12.12	0.67
13.03.12	11.0	11.06.12	9.14	09.09.12	8.61	08.12.12	0.52
14.03.12	8.54	12.06.12	6.06	10.09.12	3.42	09.12.12	0.49
15.03.12	8.91	13.06.12	4.19	11.09.12	2.78	10.12.12	0.52
16.03.12	7.05	14.06.12	2.28	12.09.12	2.31	11.12.12	0.49
17.03.12	6.09	15.06.12	1.68	13.09.12	1.87	12.12.12	0.45
18.03.12	6.55	16.06.12	2.29	14.09.12	3.11	13.12.12	0.44
19.03.12	5.02	17.06.12	1.83	15.09.12	2.19	14.12.12	0.43
20.03.12	3.84	18.06.12	3.79	16.09.12	2.89	15.12.12	0.83
21.03.12	6.87	19.06.12	6.43	17.09.12	5.75	16.12.12	0.62
22.03.12	8.56	20.06.12	3.7	18.09.12	3.83	17.12.12	0.54
23.03.12	8.23	21.06.12	2.79	19.09.12	2.9	18.12.12	0.49
24.03.12	5.86	22.06.12	2.19	20.09.12	2.16	19.12.12	0.6
25.03.12	5.97	23.06.12	1.96	21.09.12	2.58	20.12.12	0.64
26.03.12	5.24	24.06.12	1.82	22.09.12	4.07	21.12.12	0.54
27.03.12	3.99	25.06.12	1.55	23.09.12	3.43	22.12.12	0.47
28.03.12	3.2	26.06.12	1.26	24.09.12	2.82	23.12.12	0.43
29.03.12	2.75	27.06.12	1.27	25.09.12	2.44	24.12.12	0.43
30.03.12	2.63	28.06.12	1.45	26.09.12	2.26	25.12.12	0.45
31.03.12	2.19	29.06.12	1.19	27.09.12	2.06	26.12.12	0.46

(b) Discharge dependent Q (m3/s)versus head (m)

Main Q (m^3/s)	**Head (m)**
0.1	7.55
0.4	7.4
0.47	7.35
0.66	7.29
0.91	7.2
1.11	7.1
1.31	7
1.56	6.85
1.88	6.65
2.45	6.4
5.3	4.9
8.5	4.35
20	2.95

(c) Total Efficiency Turbine Q(m^3/s) Versus E total

Turbine Q(m3/s)	**E total**
0.1	0.45
0.17	0.563
0.36	0.608
0.61	0.623
0.81	0.615
1.01	0.619
1.26	0.623
1.58	0.615
2.1	0.6
8.5	0.6
20	0.6

Appendix-II

The total annual results of the hydro power plant is shown in the below table

	Mean parameters	**Maximum**	**Minimum**
Power	35.33 kW	79.27 kW	0.00 kW
Efficiency	52.74 %	62.30 %	0.00 %
Main discharge	1.82 m^3/s	11.05 m^3/s	0.29 m^3/s
Usable discharge	1.52 m^3/s	10.80 m^3/s	0.00 m^3/s
Head	6.75 m	7.46 m	4.04 m
Daily energy	847.82 kWh	1902.49 kWh	0.00 kWh
Turbine flow	0.94 m^3/s	2.10 m^3/s	0.00 m^3/s
Discharge weir	0.57 m^3/s	10.80 m^3/s	0.00 m^3/s