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ASSESSMENT OF DABENA MINI HYDRO POWER PLANT AT DABENA RIVER

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ABSTRACT

The number of electricity users is increasing with the increase of fuel cost and environmental pollution. The mini hydro power has grown as an alternative energy source that can be easily constructed with the minimal environmental impact. This research access the mini hydro power plant implemented on Dabena River 50 years ago by German missionaries. But it is not functioning these days. The available Gross head of the river measured using a GPS receiver and was found to be 11.5m. It has a potential for producing 150 KW. With this output power, we can supply Bedelle Agricultural and Forestry College under Mettu University and nearby rural area. Having the head, flow rate and output power of the river into consideration, the turbine selected was cross flow turbine with specific speed of 243 rpm, runner diameter of 52 cm, runner length of 82 cm, blade radius 17 cm and blade number of 18. 24 poles synchronous motor was selected as the Generator with rotational speed of 250 rpm. International renewable energy agency cost analysis was used to analyze financial viability of the project. The annual energy production estimated was 289,908kwh and the anticipated revenue to be generated is 136,256 birr. The initial cost of the project estimated to be 2.475 million birr.

1. INTRODUCTION

Hydro-power is most common and widely used resource of electric power generation. Around 1880 the generation of electricity derived from hydro-turbines, and the capacity of installation worldwide has grown at about 5% per year since. 20% of world's electric generation is now from hydro power [1], [2]. Output depends on the terrain and rainfall. Hydro-power is defined as generating electric power from falling water. It is energy from water sources such as the rivers, ocean, and waterfalls. The power or energy of flowing water is harnessed by turbines, which are placed in the path of the water flow. The force exerted by water moving over turbine blades rotates the turbine runner; the turbine runner rotates the generator, which produces electricity.

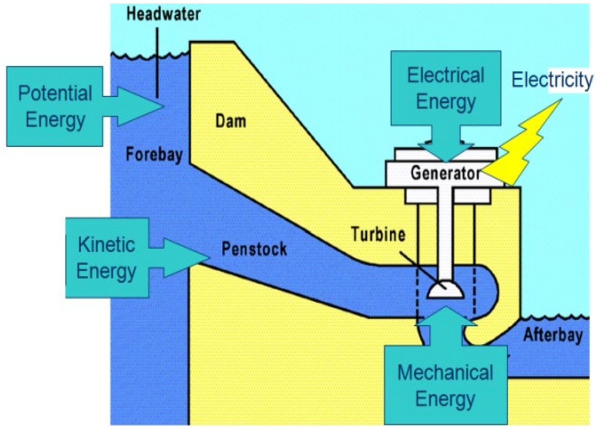

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Figure 1: The general flow of Hydro power plant [2]

Water is required to run electric generating unit. It's held in a lake behind the dam, and the water force released from the lake via the dam spin the turbine blades. The electricity can be produced in such a way that turbine is connected to the generator. The water that passes the turbine, joins the river on the down side of the dam.

1.1. MINI-HYDRO POWER

Mini-hydro can be applied ranging from electrifying a single user to a number of few users with hundreds of kilowatts to be sold for National Grid or to be used as standalone. Small-scale hydropower is one of most considered technology that provides clean electricity production.

The key advantages are [2]:

1) It is highly efficient (70 - 90%).
2) Its capacity factor is high (typically >50%).
3) It is easily predictable.
4) Its rate of change is slow.
5) It is highly correlated with demand.
6) It is highly robust technology.

In this work we have assessed a mini HPP at Dabena river, which is located at the geographical coordinates latitude 08^0 24' N and longitude e 36^0 18' E near to Bedele agricultural and forestry college of Mettu university. Debena MHPP was designed and implemented 50 years ago by German missionaries to provide an electric power to Debena TVET College. Unfortunately this MHPP is not functioning these days. The driving forces that motivated us to conduct this research are: (i) Bedelle substation is highly loaded so that Bedelle agricultural and Forestry College introduce a high interruption of power (ii) Rural area peoples around Debena river needs electric power as EEPCO power hasn't addressed.

The rest of the paper is organized as follows. Section 2, assessment of civil work components. Section 3, assessment of electromechanical components. Section 4, contains economic analysis of MHPP and section 5 concludes the paper.

2. ASSESSMENT OF CIVIL WORK COMPONENTS

The primary data from field work as well as secondary data obtained from Bedelle Meteorology station has been used to conduct this research. Both primary and secondary data are put in tables bellow

Table 1: Primary Data from Field Survey Direct Measurement

Data Collected	Value
Gross Head of the river	11.5 m

Flow rate of the river	98.2 (m^3 /s)
Weir Length and depth	30m and 1.5m respectively
Forebay tank Length, width and depth	4.5m,2.5m and 1.9m respectively
Penstock length and diameter	60m and 0.9m respectively
Open channel length and depth	145m, 1.3m respectively

Because the share of the civil work to the total cost of a MHP system is not less than 30%, proper design of this part of a system is vital [1]. Not only is this but also there are other reasons that make the proper and careful design of the civil work vital. For example, it is this component which will drive the required flow rate to the turbine and which creates the required head. Therefore, civil work components design should be done carefully and most of the time it accounts more than 60% of the overall design of a MHP system [1]. Here under is the assessment of design of some civil work components depending on the available head and flow rate at the site considered.

2.1. OPEN CHANNEL

- Manning coefficient for well finished cement is 0.012 [4]
- Rectangular Type open channel that has 145 m length from the weir to forebay tank.
- Nominal velocity (V) of water flow in the channel is 1.28 m/s
- Net head of Debena MHEPP is 10 m

L= 145m
W=1.3m
H=1m
Where L = channel length
W = channel width
H =channel height
A=WxH = 1.3x1
A= 1.3m^2
Q= A x V
Where A= area of open channel
Q=flow rate of the open channel
Q= 1.3x 1.28= 1.664 m^3/S

Figure 2: Open channel of the plant

2.2. WEIR

For the rivers with low discharges (usually < 4 cubic meter per second); weir may be built. Weir can be restricted as it is a small wall or dam in the stream that can be measured with a notch with which overall water will be channeled. We can calculate the flow rate of rectangular body as follow [4]:

$Q=1.8*(W-0.2h)*h^{1.5}$

With,

W= Width of the Weir in (m)

h = Heightof Weir in (m)

For Debena River case:

Weir length 30 m and height 1.5 m

$Q= 1.8 *(W- 0.2 h)* h^{1.5}$

$Q= 1.8 *(30- 0.2 *1.5)* 1.5^{1.5}$

$Q= 98.2\ m^3/s$

Figure 3: Weir of the plant

2.3. FOREBAY TANK

H= 1.9

W= 2.5

L= 4.5

Where L = forebay length

W = forebay width

H = forebay height

The water volume it contains can be calculated as:

V= HxWxL = 1.9 x 1.5 x 4.5

$V= 21\ m^3$

The water storage time is

V= Q X T

T=V/Q

T=21 second

Figure 4: Forebay tank of the plant

3. ASSESSMENT OF ELECTROMECHANICAL COMPONENTS

Under this topic we have assessed electromechanical components such as Penstock, Turbine and Generator with reasonable engineering criteria.

3.1. PENSTOCK DESIGN

To transfer water to power house from the intake, Penstocks (pipes) are used. There are two possibilities to install pipes: over and under the ground. This is basically relies on factors such as the ground nature, materials where the penstock is made, temperature and the effect of the environment. The penstock in our case is underground. The estimated flow rate, length of the pipe and gross head are used to calculate the internal diameter rof penstock (Dp) as [4].

$$D_p = 2.69 * ({n_p}^2 * Q^2 * L_p/H_g)^{0.1875} \quad \text{(m)}$$

With
n_p=Manning's coefficient.
Q=the flow rate of water in (m^3/s).
L_p=penstock length (m).
H_g=gross head (m).
The penstock thickness relies on the materials of the pipe, its tensile strength, and diameter of the Pipe and on the pressure where it operates.
We can calculate the minimum thickness of the pipe wall as [4]:

$$t_p = \frac{D_p + 508}{400} + 1.2 \qquad (mm)$$

With
Dp = Diameter of the penstock in (mm).
tp= Minimum thickness of the penstock in (mm).
The pipe (welded steel) has capacity to withstand deformation in the field.
Hg = 11.5m
Q= 1.664 m^3/s
Penstock length = 30 m
Where, Hg= gross head
Q= Design Discharge
n = roughness coefficient

L= length of penstock

$$D_p = 2.69 * ({n_p}^2 * Q^2 * L_p/H_g)^{0.1875}$$

$$Dp = 2.69 * (0.012\text{^}2 \; * 1.664\text{^}2 * \; 60/11.5)^{0.1875}$$

$$Dp = 0.85m \text{ or } 85cm$$

$$t_p = \frac{D_p + 508}{400} + 1.2 \qquad \text{(mm)}$$

$$tp = \frac{850 + 508}{400} + 1.2$$

$$tp = 4.6 \text{ mm}$$

3.2. TURBINE POWER

Falling water is the major factor that determines generation of all hydro-electric power. We can calculate the generated power in the turbine regardless of the path of the water in pen stock or in an open channel as: [4]

P_t = r*g*H_n *Q* η_t (watt)

P_t =Generated turbine shaft power in Watt

r= Density of water = 1000 kg/m^3

H_n = net head (m)

Q= Flow rate of the water in (m^3/s)

g= gravitational constant (9.8m/s^2)

η_t = turbine efficiency (Normally 80-90%)

From the above parameters, the output power we can obtain from the River can be:

$$Pt = 1000 \frac{kg}{m^3} * 9.81 \frac{m}{s} * 11.5m * 1.664 \frac{m^3}{s} * 0.8$$

$$Pt = 150 \text{ kw}$$

3.3. TURBINE SELECTION

Turbine selection is based on the output of turbine and available head for the site. From the turbine application chart below, the turbine for this plant is Cross flow turbine.

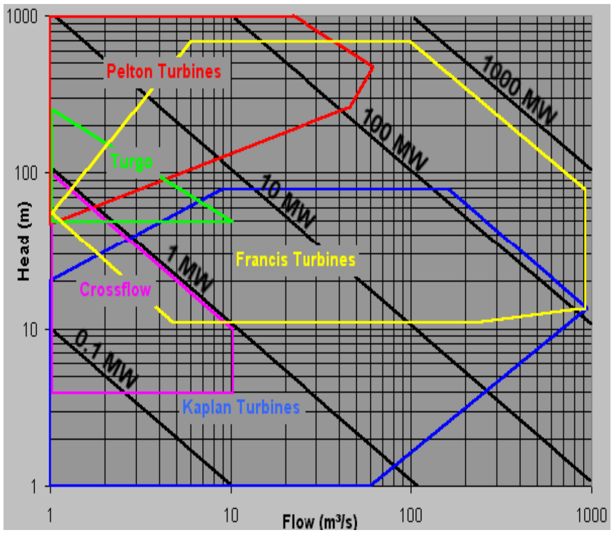

Figure 5: Turbine application chart [4]

Cross flow turbine has high efficiency at low head and fabricated easily in local companies. After determining the turbine type, we can easily estimate the turbine dimensions [18], [13].

3.4. GENERATOR SELECTION

The generator selection is based on the advantages we can get for intended site. Thus, the suitable turbine for our plant is synchronous generator due to the following reasons [18]. It provides voltage regulation, frequency and phase angle control. Because of excitation do not depend on grid Synchronous generators can isolately run from grid and then generate power. Pole calculation of synchronous generator

$$\mathbf{No} = \frac{\mathbf{120 * f}}{\mathbf{P}}$$

$$\mathbf{P} = \mathbf{120} * \frac{\mathbf{f}}{\mathbf{No}}$$

Where, No= is rated rotational speed, No= 243 rpm
f= is frequency =50 Hz
p= pole=24
Standard rated speed for 24 pole synchronous generator is 250 rpm.
The gearing ratio can be calculated as

$$\mathbf{G} = \frac{\mathbf{alternator\ rpm}}{\mathbf{turbine\ rpm}}$$

$$\mathbf{G} = \frac{\mathbf{250}}{\mathbf{243}} = \mathbf{1.02}$$

For better coupling system the speed of generator must match the speed of turbine. Since the speed of turbine is fixed the speed of generator increase or decrease via gear to match with the speed of turbine. In our case we have coupled our system with gear of gearing ratio 1.02.

4. ECONOMIC ANALYSIS OF MHPP

4.1. LOAD ESTIMATION FOR BEDELLE CAMPUS AND NEAR LOCAL HOUSE HOLD

Table 2: Load Estimation for Bedelle Campus

No	Load (device)	Connected load(kw)	Operation hours per day	Operation Day per year	Operation hours per year	Demand kwh per year
1	Lamp	52	8	300	2400	124800
2	Straight light	10	12	300	3600	36000
3	Electric mitad	33	3	300	900	29700
4	Electric stove	21.12	3	300	900	19008
5	Flour Mill load	20	2	300	600	12000
6	Office appliance	60	8	300	2400	144000
7	Local community load(100 house)	20	6	300	1800	36000
Total load (kw)=147.12 kw Total Demand Per Year (Kwh/Year) = 289,908 Kwh						

According to Ethiopian electric utility price rate, the average price for 1kwh is 0.47 birr. Therefore, the total revenue will be 136256.76 birr per year.

4.2. AVERAGE INVESTMENT COSTS

The large hydropower plants average investment cost with storage is in the range between USD 1050/kW and USD 7650/kW while small hydropower plants is between USD 1300/kW and USD 8000/kW. If the case is adding extra capacity at existing hydropower plant the cost can be cheaper, and can cost up to USD 500/kW [9].

According to International Renewable Energy Agency (IRENA) cost analysis [9], the rehabilitating cost is 500 - 1000 US dollar per kilowatt. Dabena MHPP power capacity is 150 kW therefore the average investment cost will be 112500 US Dollar or 2.475 million Ethiopian birr.

5. CONCLUSION

In this research the assessment of Dabena MHP is done. Primary data from the field and secondary data from Bedelle meteorological station has been taken, analyzed and used. The civil work Components like weir size, Open Channel size, Forebay Tank size, length and diameter of the penstock were measured directly from the site survey. Using the results from this calculations the flow rate of the river in Open Channel and weir has been calculated, which are the main parameter as an input to calculate the capacity of the plant. From the meteorological data we collected from Bedelle meteorological station, we saw that during winter time the level of river will be very small and at summer time it increases due to rain fall.

We didn't find a chance to see the powerhouse because it is long time since the powerhouse is closed and we did not find the key to open it. We did an assessment on Electromechanical Components based on internationally accepted techniques. Considering different criteria, we came to the conclusion that the turbine is Cross flow turbine and the generator type is synchronous generator.

Furthermore, we have estimated the load for Bedelle campus and near local house hold.

From our assessment we came to the point to identify the current capacity of the plant and it is about 150 kW.

The metrological data shows that rainfall increases during summer time. Thus, we can get more power during this period. But this problem can be solved by focusing on the civil work components. If we able to increase the size of fore bay tank, Weir and open Channel, their water storage capacity will be increased. As a result the chance to have more power in only summer season can be extended to winter season.

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CONFLICT OF INTEREST

The author have declared that no competing interests exist.

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