Design and Analysis of Hydropower Generation in Wabi Shebelle River, Somali region, Ethiopia

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Abstract: *This research article presented as design of hydropower project on shebelle river as per the feasibility study. And it is obvious that, Ethiopia is richest with abundant water resources distributed in many parts of the country however; it has not made significant progress in the field of water resources development. Considering the substantial hydropower resources, Ethiopia has one of the lowest levels of per capita electrical consumption in the world. It enhances the economic development by providing sufficient energy. The objective in kebridahar hydropower project deals with the assessment of available alternative water resource for irrigations well as power production and to verify whether the potential projects appear technically, economically and environmentally feasible or not. The total design discharge of the spillway is* $23.1m^3/sec.$ *by gumbell's distribution method. The mass inflow curve is prepared using the consecutive critical dry periods for the years 2008 and 2012 and the total storage capacity of the reservoir is* $397990m^3$*. The total capacity in kilowatts or million kilowatts of all turbines –generator units installed in a power house, is 16723.892KW.*

Keywords: *Hydropower, Kebridahar, Mass Curve, Gumbells distribution, Power house.*

Introduction

Hydropower has played an important role in the safe, stable and efficient operation of electric power systems for a long time. Hydropower not only generates electricity as the largest global renewable source, but also shoulders a large portion of the regulation and balancing duty in many power systems all over the world.

Hydropower technology is relatively mature, but new challenges are still emerging. First, with current trends toward de-carbonization in the electricity sector [1], the amount of electricity generated by variable renewable energy (VRE) sources has been constantly growing [2, 3]. Dealing with generation intermittency of VRE in an effective and efficient manner is a growing research field [3-6]. High VRE integration [7] and fewer heavy synchronously connected generators, which imply less inertia [8], lead to crucial consequences for power system stability. Second, a hydropower generation system is a complex nonlinear power system including hydraulic, mechanical and electrical subsystems (details in section 1.2). The generator size and the complexity of waterway systems in hydropower plants (HPPs) have been increasing. Especially in China [9, 10] dozens of HPPs with at least 1000 MW capacity are being planned, designed, constructed or operated. Third, many large HPPs are located far away from load centres, forming many hydro-dominant power systems, such as the cases in Sweden [11] and China [12]. In recent years, there has been a tendency that the new turbines experience fatigue to a greater extent than what seem to be the case for new runners decades ago [13], and the maintenance needs at HPPs are affected [14], due to more regulation movements caused by increasingly more integration of VRE. In some countries, as in Sweden, primary frequency control (PFC) is a service that the transmission system operator (TSO) buys from the power producers. In other countries, as in Norway and China, there is also an obligation for the producers to deliver this service, free of charge. However, there are costs related to this, e.g. due to design constraints and auxiliary equipment when purchasing a new unit or system, due to wear and tear that affects the expected life time and maintenance intervals, and due to efficiency loss when a unit operates in a condition that deviates from the best efficiency point, etc. Based on the aforementioned aspects, the demand on the quality of regulation emanating from hydropower units has been increasing. Stable and efficient operation of HPPs and their interaction with power systems is of great importance.

Study Area

The project area is located at Kebri Dahar (Somali: Qabridahare) is one of the woredas in the Somali Region of Ethiopia . Part of the Korahe Zone, Kebri Dahar is bordered on the south by Debeweyin , on the west by the Gode Zone, on the northwest by Shekosh , on the north by the Degehabur Zone , on the east by the Werder Zone, and on the southeast by Shilavo Kebri Dahar (Somali: Qabridahare) is a town in the eastern part of Ethiopia known as the Ogaden. With an altitude of a latitude and longitude of 6°44′N 44°16′E and 6.733°N 44.267°E respectively and an elevation of 493 meters above sea level. It begins in the highlands of Ethiopia, and then flows southeast into Somalia towards Mogadishu. Based on figures from the Central Statistical Agency in 2005, Kebri Dahar has an estimated total population of 100,191 of whom 51,327 are men and 48,864 are women. (CSA, 2005)

Figure 1 Shebelle River Basin

HYDROLOGIC DATA ANALYSIS

Hydrology, which treats all faces of the earth water, is subject of great importance for people and their environment. Practical applications of hydrology are found in such tasks as the design and operation of hydraulic structures. The role of hydrology is to help analyzing the problems involved in these tasks and to provide guidance for the planning and management of water resources. Different attributes of hydraulic structures are directly dependant on the peak flood magnitude adopted in the design process and the stream flow records available at the project site. Hence, stream flow records are the major data required in planning and operation of hydraulic structures. To plan these structures we need one of the following;

i) The flood of certain frequency

ii) Daily flows for determine the storage capacity of the reservoir

iii) The discharge available for a certain percentage of time.

Hydrology finds its greatest application the design and operation of water resource engineering projects such as irrigation, hydropower and flood control projects. Hydrological studies involve the collection of relevant data and analysis of the data by applying the principles and theory of hydrology to seek solution to practical problems.

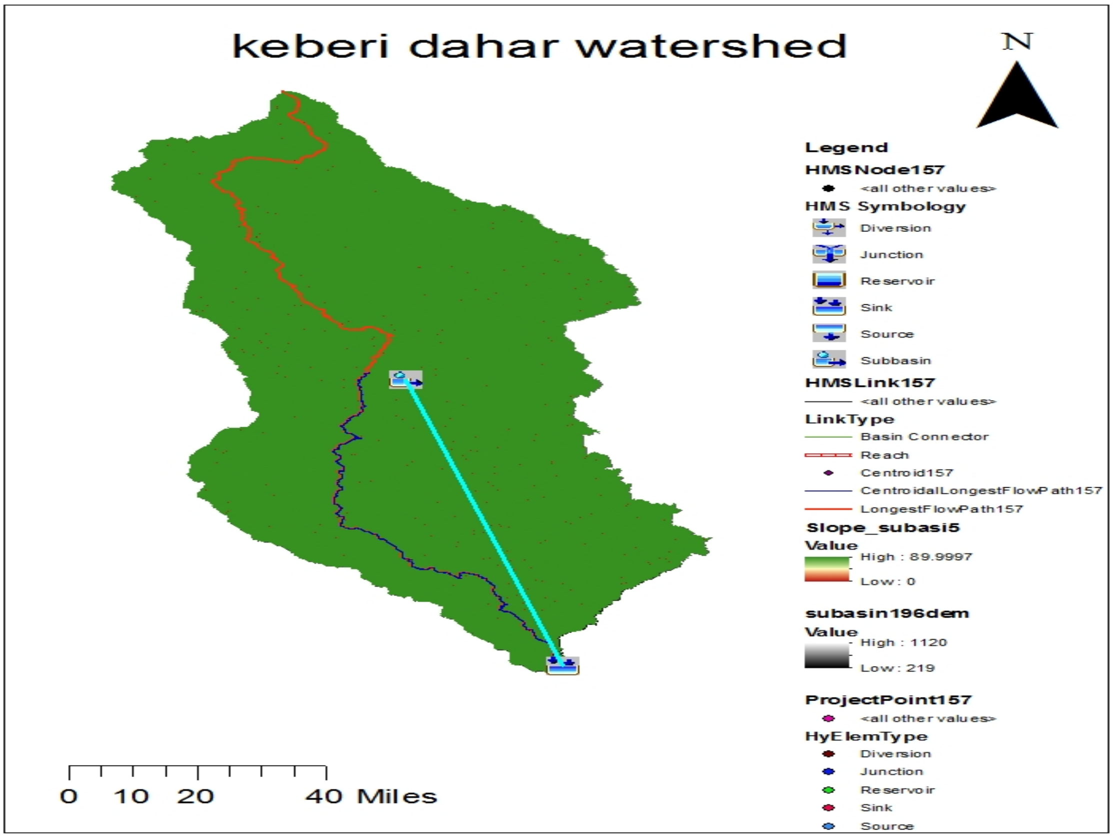

Figure 2 Keberidahar watershed

Result and Discussion

FLOW DURATION CURVES

Flow duration curves show the percentage of time that certain value of discharge weekly,
Monthly or yearly were equaled or exceeded in the available number of years of record. Flow duration curves find considerable use in water resources planning and development activities. Some of the important uses are:

1. In evaluating various dependable flows in the planning of water resources engineering projects.
2. In evaluating the characteristics of the hydropower potential of a river

There are methods in order to utilize the flow data available for the entire period, such as;

- Total period method
- Calendar year method

In total period method, the entire available record is used for drawing the flow duration curve. Thus the 24 year record would produce 288 values of monthly average flows. These are first tabulated in the ascending order starting from the driest month period and ending with the wettest month of the 24 years of duration or vice versa.
The resulting flow duration curve would then be drawn with the help of 288 values.

In calendar year method, each year's average monthly flow is first arranged in ascending order. Then the average flow values corresponding to the driest month, second driest month and so on up to the wettest months are found out by taking arithmetic mean of all values of the same rank. These average values are then used for plotting flow duration curve.

The total period method gives more accurate results than the calendar year method which averages out extreme events. Therefore, for this project the total period method is used.

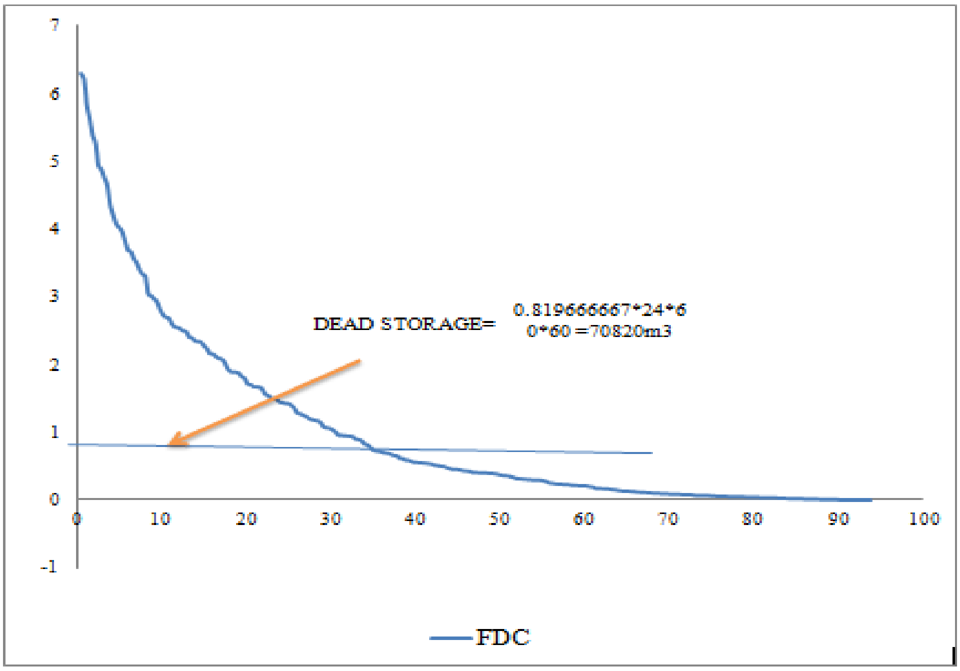

Figure 3 Flow Duration Curve

FLOOD FREQUENCY STUDIES

When stream flow peaks are arranged in the descending order of magnitude they constitute astatistical array whose distribution can be expressed in terms of frequency of occurrence. There are two methods of compiling flood peak data

- the annual floods and
- The partial duration series.

In the annual floods, only the highest flood in each year is used thus ignoring the next highest in any year, which sometimes may exceed many of the annual maximum. In the partial duration series, all floods above a selected minimum are taken for analysis, regardless of the time interval, so that in some years there may be a number of floods above the basic stage, while in some other years there may not any such flood at all.

Annual Flood Series:-The return period or recurrence interval (*T*) is the average number of years during which a flood of given magnitude will be equaled or exceeded once and is computed by one of the following methods.

1. California method (1923):

$$T = \frac{n}{m}$$

2. Allen Hazen method (1930):

$$T = \frac{n}{m - 1/2} = \frac{2n}{2m - 1}$$

3. Weilbul method (1939):

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

Where n = number of events, *i.e.*, years of record, m = order or rank of the event (flood item) when the flood magnitudes (items) are arranged in the descending order (m = 1 for the highest flood, $m = n$ for the lowest flood) T = recurrence interval (T = n-yr for the highest flood, T = 1 yr for the lowest flood, by California method)
The probability of occurrence of a flood (having a recurrence interval T-yr) in any year,
i.e., the probability of exceedance, is P=$\frac{1}{T}$ or the percent chance of its occurrence in any one year, i.e., frequency (F) is F=$\frac{1}{T} * 100$ and the probability that it will not occur in a given year, *i.e.*, the probability of non-exceedance (P'), is P'= 1-P

Gumbel Frequency Distribution

Resume of formulae: For large values of n,

$P = 1 - e^{-e-y}, T = \frac{1}{P} = \frac{1}{1-e^{-e-y}}$

$Xmean = (P1 + P2 + P3 \ldots \ldots . Pn)/n = \frac{4.213+5.26+2.26+4.08+\cdots+2.396}{24}$

$$X_{mean} = 3.698$$

$$y_T = -\ln\{ln\frac{Tr}{Tr-1}\}$$

where Tr depends on storage capacity hence our storage capacity is less than 60Mm^3 so Tr=200 years.

$$=-\ln\{ln\frac{200}{200-1}\}=4.6$$

$\delta_x = \sqrt{\frac{1}{n-1}(X-\bar{X})^2} = 1.55473$ Refer Annex

$K_T = \frac{YT-Yn}{\delta n} = K_T = \frac{4.6-0.5296}{1.09145} = 3.73$

$X_{T=}\delta_X + K_T * X_{mean} = 1.554731 + 3.73*3.698 = 15.35 m^3/s$

The design discharge for our project will be; $X_{T=}$15.35*1.5(factor of safety)

$$XT = 23.1 m^3/s$$

Mass curve (Ripples mass curve)

Ripples mass curve is a plot of cumulative inflow volume against time in chronological order. The slope of the mass curve at any point represents the rate of flow.

A mass diagram is a graphical representation of cumulative inflow into the reservoir versus time which may be monthly or yearly. A mass curve is shown in Fig. below for a 2-year period. The slope of the mass curve at any point is a measure of the inflow rate at that time.
Required rates of draw off from the reservoir are marked by drawing tangents, having slopes equal to the demand rates, at the highest points of the mass curve. The maximum departure between the demand line and the mass curve represents the storage capacity of the reservoir required to meet the demand.
Procedure for determining the storage volume:

- The mass inflow curve is prepared using the consecutive critical dry periods for the years 2008 and 2012.
- Two lines are drawn parallel to the demand line and also tangential to the mass curve at the lowest point and the highest point respectively.

❖ The required capacity is equal to the maximum vertical intercept between the two tangents. (See fig. below All the computation is shown on the table

Table 1 Two year minimum flow

month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
monthly flow	0.003333	0	0	0	0.142333	0	0.233667	0.399333	0.301333	0.592	0.469333	0.070667
cum flow	0.003333	0.003333	0.003333	0.003333	0.145667	0.145667	0.379333	0.778667	1.08	1.672	2.141333	2.212
monthly flow	0.036667	0.016	0	2.341667	0.549333	0.048667	0.044667	0.086333	0.279	0.502667	0.039	0.021667
cum flow	2.248667	2.264667	2.264667	4.606333	5.155667	5.204333	5.249	5.335333	5.614333	6.117	6.156	6.177667

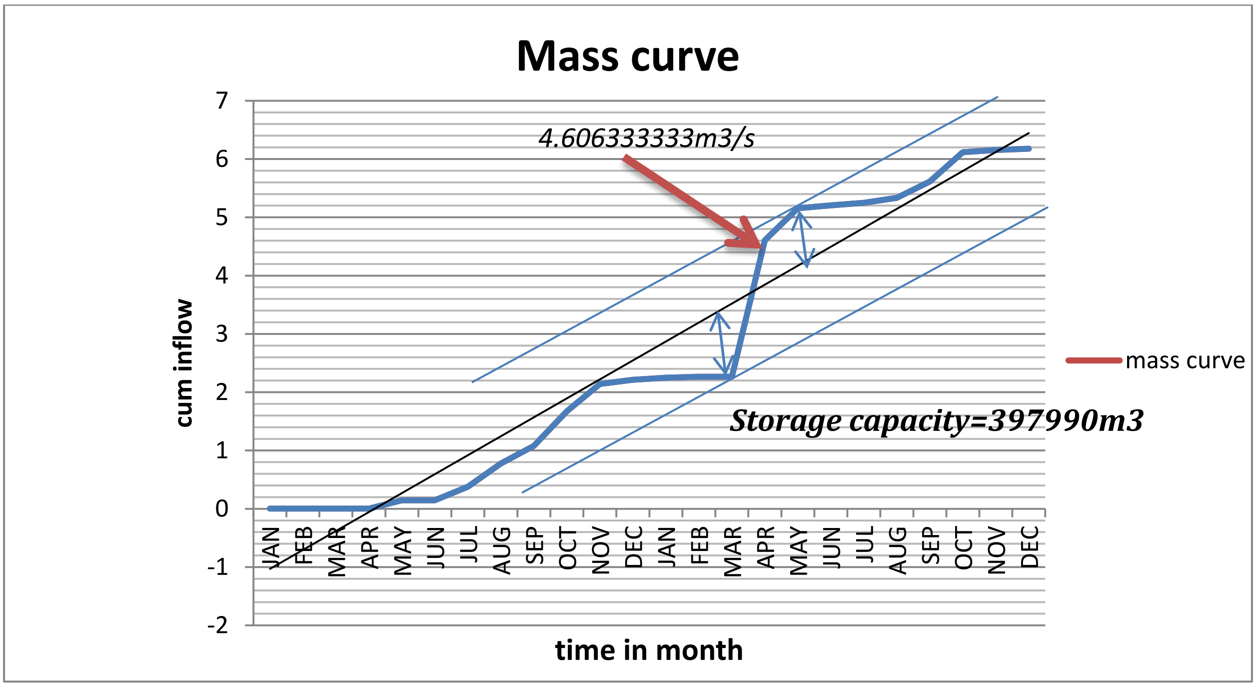

Figure 1 Cumulative flow Vs time (month) graph

This implies the storage capacity of the reservoir is =397990m^3

Design of gravity dams

Basically, Gravity dams are solid concrete structures that maintain their stability against design loads from the geometric shape and the weight and strength of the structure. Generally, they are constructed on a straight axis, but may be slightly curved or angled to accommodate the specific site conditions. Gravity dams typically consist of a non-overflow section and an overflow section or spillway. They are constructed with masonry or concrete but of late conventional concrete or roller- compacted concrete are popular. In our design of small dams may be based on adopting geometry, checking its adequacy, and effecting any minor modification necessary. But for larger dams a unique profile should be determined to match the specific condition applicable. From the given data:

Free board: is range from 4% to 5% of height of the dam.

$FB = 5\%HD$

$H_D = H_W + 5\%H_D$

$H_{W=}H_D$- 5%H_D=48-0.05*48=48-2.5=45.5m

Therefore, height of water (H_W) is 45.5m take 46m;

Top width (b):

$b = 14\%H_D$=0.14*48=6.72m ≈7m

Bottom width

$B = \frac{H}{\sqrt{Sc}}$, where B is bed width is height of dam, S_c is specific unit weight of concrete S_c=$\frac{\gamma_c}{\gamma_w}$ =2400/1000=2.4m

B= $\frac{48}{\sqrt{2.4}}$=30.98m take 30m.

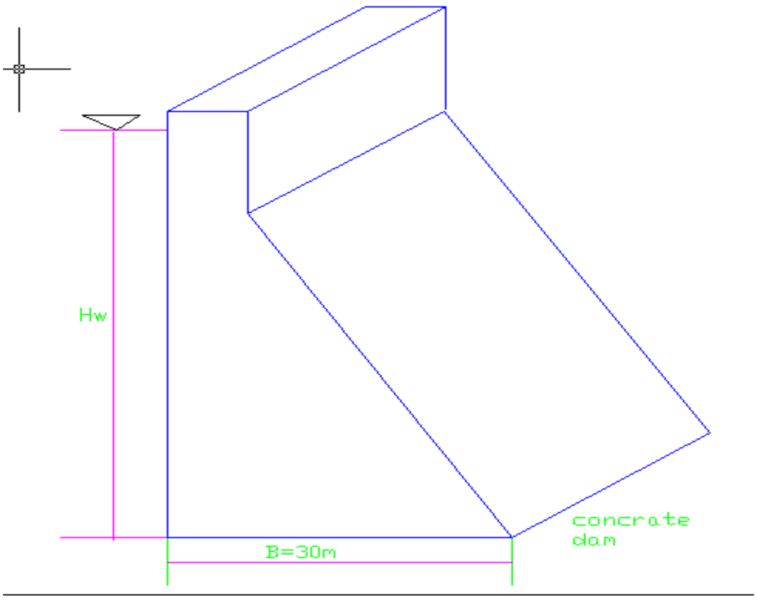

Figure 2 cross section of Gravity dam

Distinction between low and high gravity dam is usually made on the basis of the limiting height. The limiting height is the critical height by which the maximum values of the principal stress should not exceed the allowable stress for the material of the dam.

To decide whether the dam is low or high, first of all the height of the dam to be constructed should be checked so as to ensure whether it is low gravity dam or high gravity dam, if the height of the dam is less than given by

H_{cr}=$\frac{\gamma c}{\gamma w(Sc+1)}$ consider C-30kg/m^3

$H_{cr} = \frac{3000}{9.81(2.4+1)} = 88.7m$ Therefore, $H_{cr} > H_D$ from the result our dam is low.

Forces due to tail water P_V

$P_V = \frac{1}{2} * \gamma_w * h_w * b$ where, $\frac{b}{4} = \frac{23/37}{1}$, b=2.4

$= \frac{1}{2} * 9.81 * 4 * 2.4$

P_V=47 KN

Factor of safety against overturning

For a structure to remain stable, the moments which tend to topple it must be equal to the moments which balance it.

The factor of safety against over turning (F.S) is defined as the ratio of the sum of the stabilizing moment (resisting moment) to that of the over turning moment about the toe.

Usually a safety factor of a above 1.5 is applied.

$$\text{F.s} = \frac{\sum Mstabilizing}{\sum Moverturning}$$

$=\frac{\sum M(+)}{\sum M(-)} = \frac{370515}{159185}$ =2.3>1.5…………………..….Safe!

Factor of safety against sliding

$=\mu \frac{\sum V}{\sum H} = 0.7 * \frac{18329}{16346} = 1.24 > 1$………………….….safe against sliding!

Spillway discharge

Dsign discharge $\boldsymbol{Q_d}$=23.1$\boldsymbol{m^3}$/sec

$$Q = CL_e He1.5$$

Where,L_e=effective length of crest

C= coefficient of discharge, H_e=actual total head over the spillway

Assuming L =20m, number of span =4, N=number of clear span =1m

Assuming 90˚ cut water noise piers and rounded abutments be provided

K_p =0.01(coefficient of piers)

Hydraulic turbine

Turbines are defined as the hydraulic machines which convert hydraulic energy into mechanical energy. The mechanical energy is converted into electrical energy. The electric power which is obtained from the hydraulic energy (energy of water) is known as Hydro electric power.

Classification of hydraulic turbines

Pelton turbine.

- The energy available at the inlet of the turbine is only kinetic energy.
- The hydraulic efficiency of pelton wheel lies between 85% to 95%.
- Pelton wheel is used for high head up to 200m.
- The deflection angle of buckets is 160° to170°.

Francis Turbine

Are the most versatile in use today. The initial design of the slow runner (ns=60) was for radial flow, but with experience they were transformed in to mixed flow runner, the last being a very fast runner (ns=400).For head up to 40m, the scroll casing can be either circular or T-shaped concrete section.

- Francis turbine is used for low head of 10m to 30m.
- Energy available at the inlet of the turbine is pressure energy.
- The frictional losses are less comparatively pelton wheel.
- The guide vanes are located at the outer periphery of the runner.

Gross head

Gross head is the difference in the water level elevation at point of diversion of water for the hide scheme and the point of return of water back to the river.

$$Hg = 240-194=46m$$

Net head or effective head

The effective head is the net head applied to the turbine, and is given by the difference of head at the point of entry and exit of turbine, and includes the respective velocity and pressure heads at both places.

$H = Hg - hf$ where hf(total head loss)=1.63+3.77=5.4m

H = 46 – 5.4 =40.6m

Take net head $H \approx 41m$

Preliminary Power Assessment

The power generated in hydropower plant is a function of the discharge and the e elevation difference (i.e. a net head available for the project). Hence site selection and plant layout are very important for economical execution of a specific project.

Firm power

The net amount of power which is continuously available from a plant without any break on firm or on guaranteed basis is known as firm power .this power should be available under the most adverse hydraulic conditions. The consumers can always be sure of getting this power. Firm (primary) power is the power which a plant can deliver throughout the year for 100% of the time.

$$P= \eta\gamma QH$$

= 0.9*9.81*23.1*41 =8361.95KW

Where, P=power generated
γ = specific weight of water
η= the overall efficiency
Q=discharge (maximum) in (m3/s)
H=net head available (m)

Load factor

Load factor is the ratio of the average load over a certain period to the peak load during the same period. A high load factor is indicative of the better utilization of the installed capacity and consequently the unit generating cost is less and vice versa and in developing countries its range is taken between 0.4 to 0.6 .

$$\text{Load factor} = \frac{avarage\ load}{maximum\ load}$$

Installed capacity of the power house

The total capacity in kilowatts or million kilowatts of all turbines –generator units installed in a power house, is called its installed capacity

$$Qmax\ = \frac{Q_{min}}{L.F} = 23.1/0.5 = 46.2m3/s$$

P =0.9*9.81*46.2*41 = 16723.892KW = 16.73Mw

Conclusion

As a result hydropower has been the cheapest and the main energy source in Ethiopia for supplying energy for domestic and other energy consumption. kebri daher hydropower development on shebelle rivers will solve the problem of shortage power. Also the development of this hydro power project in keberi dehar area will electrify the jigjiga town and rural areas so that the establishment of various infrastructural facilities and agro-industries will be encouraged throughout Somali regional state.

This project also feasible financially. Therefore, if fund is available from different governmental or non-governmental bodies, development of this project is the best solution of the nearby towns and rural areas electrification problems. And this may change the life of the society and that will help to ensure the country development.

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