ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering
Tome VI (Year 2013) – FASCICULE 2 [April–June]
ISSN 2067–3809

[1.] G. ADEDOKUN, [2.] J.A. OLADOSU, [3.] T. K. AJIBOYE

SMALL HYDRO POWER POTENTIAL CAPACITY ESTIMATION FOR PROVISION OF RURAL ELECTRICITY IN NIGERIA

[1,2.] DEPARTMENT OF ELECTRICAL/ELECTRONICS ENGINEERING, OSUN STATE COLLEGE OF TECHNOLOGY, ESA-OKE, NIGERIA
[3.] MECHANICAL ENGINEERING DEPARTMENT, UNIVERSITY OF ILORIN, NIGERIA

ABSTRACT: Nigeria's electricity demand increases due to growth in industrialization and socioeconomic weight. Regrettably, power industry of the country has not been able to satisfy the need of their customers. Therefore, if the country is to meet its energy demand alternative sources of power generation are very essential. Opportunities abound in hydropower scheme development as a viable energy source of electricity which will curtail and minimize greenhouse gases and emissions into environment. Meanwhile, there are small rivers all over the country with potential sites suitable for small hydropower scheme, development of which will ensure the supply of electricity to remote communities. This can be used as a substitute for commercial fuels, which effect reduce cost of fuelling and raise the earning potential of the rural communities.
KEYWORDS: power, generation, small hydropower, potential, capacity, install, gross head, net head, electricity

INTRODUCTION

Energy is the essential locomotive for economic growth and accelerated development of a country. There is a straight correlation between per capital earnings and the use of energy; thus, this is a direct gauge of quality of life and a key factor in fight for poverty lessening.

Country`s energy demand increases day by day; unluckily, myriad of technical and administrative challenges have been bedeviling electrical power generation and utilization in Nigeria. Hence, alternative sources of power generation have to be invented if country is to meet its energy demand and attain the desired industrial and economic development. Opportunities thrive in small hydropower (SHP) schemes development as a viable source of energy for electricity generation.

Small hydro power scheme is defined as any hydro power installation rated less than 10MW installed capacity (Odesanya, 2005). There are many small rivers all over the country with potential sites fitting for SHP schemes, the progress of which will provide electricity to isolated communities; then, used as a substitute for commercial fuels, which effect reduces cost of fuelling and raises earning potential of the rural communities.

However, the only problem often encountered in SHP growth is how to determine the potential capacity of the proposed site because the hydropower potential is limited by the intermittent nature of rivers flows which have high water discharges during rainy and very low discharges in dry season. Consequently, in hydropower projects site selection, water discharge and head are fundamental; so the proposed site having a good combination has to be investigated.

While the head at a site is constant, the available flow rates are highly variable; so, study of maximum flows is very important from the point of design or installed capacity; the average flows is important from the consideration of the energy output and minimum flows are required to predict dependable plant capacity. Since, the entire quantity available at a site (except flood flow) is utilized in power production, the study of water demand for hydropower amount to collection of stream flow data and their analysis. Usually the analysis relates to the preparation of flow-duration curves, which indicates the magnitude of discharge against the percentage of time the discharge is exceeded at a site (Nwachukwu, 2005).

Therefore, stream flow is an important parameter in determining the maximum power derivable from any flowing river, hence the focus of this work is to examine the easy and less expensive methods of estimating the potential capacity of a stream for effective power generation.

METHOD OF STUDY. Theoretical background

Small hydropower scheme makes use of falling water in a stream, river or storage dam to generate electric power. The water falling through the storage and level of the turbines gains kinetic energy which it then impacts to turbine blades of alternator.

The power P available from a hydro scheme is given by (Weedy, 1979)

$$P = \rho g Q H (watt) \tag{1}$$

where, Q is the flow rate (m^3/s) of the water through the turbine blades,

ρ is the water density (1000 kg/m^3),
g is the acceleration due to gravity (9.81 m/s^2), and
H is the gross head (m).
Substituting,

$$P = 9.81QH \ (kW)$$

The expression above gives available power, P as a function of flow rate Q, which is volume of water passing through a given area in a given time measured in cubic metres per second; and H, which is the gross head in metres.

Accordingly, to estimate the hydro-potential capacity of a site it is important to know the variation of the discharge throughout the year and the available gross head.

Determination of available gross head

The gross head is the vertical height that the water falls through in generating electric power. The field measurements of gross head are usually carried out either by using any surveying techniques, namely; surveyor's staff and level, Clinometers or Abbey level, Digital Theodolites with electronic digital level or surveying by global positioning system (Tamunotonye, 2005).

Having estimated the gross head available it is necessary to allow for the losses that may arise from trash racks, pipe friction, bends and valves. The net head available to drive turbine is equal to the gross head minus the sum of all the losses.

Therefore,

$$H_n = H_g - \sum H_l \qquad (2)$$

where, H_n is the net head,
H_g is the gross head, and
ΣH_l is summation of all the head losses.

ESTIMATION OF STREAM FLOW. Data collection

The hydrological data required in SHP development are mainly stream flow and rainfall data. Stream flow fluctuates, and this fluctuation can be visualized when the flows are plotted against the time. Understanding the pattern reveals when to measure low flow and average flow.

Measurements of stream flow from a hydrological stream-gauging network are the main and best source of the surface water flow data (Ram S. Gupta, 1989). However, no national data collection program anywhere in the world collects sufficient data to satisfy all the design and decision-making needs in any catchment area (Fleming, 1976). The world meteorological organization recommended that when the data are inadequate; project activity should begin with installation of a hydrological gauging network.

In Nigeria, stream flow measurements are carried out by government through the River Basin Development Authority, who established gauging stations on rivers within their catchment area and these flow data can be obtained from them. However, in the past fifteen years there have not been stream flow measurements due to lack of funding. Therefore, flow data collections for most of the rivers have since stopped, resulting inadequate data for analysis (Nwachukwu, 2005).

In practice, streams of interest usually are not gauged and there are no flow records to work with, so gauging stations have to be established to obtain discharge for at least a year.

Measurement of stream flow

The volume of water passing through a given area in a given time measured in cubic metres per second is described as flow rate. Thus, the product of the cross-sectional area of the stream and the velocity be measured is the flow rate (Tamunotonye, 2005),

$$Q_{mean} = V_{mean} \times A \qquad (3)$$

where, Q_{mean} is the mean flow rate (m^3/s),
V_{mean} is the mean velocity (m/s), and
A is the cross-section area of the stream (m^2).

The cross-sectional area of a water course can be obtained by dividing the cross section into a series of trapezoids. Measuring the trapezoid sides, by marked rules the cross-section area would be given by,

$$A = b \times \left(h_1 + h_2 + h_3 + \ldots\ldots\ldots\ldots\ldots + h_n\right) / n \qquad (4)$$

where, h_1, h_2 , ……… = water depth at different points along the base level
b = width across the river

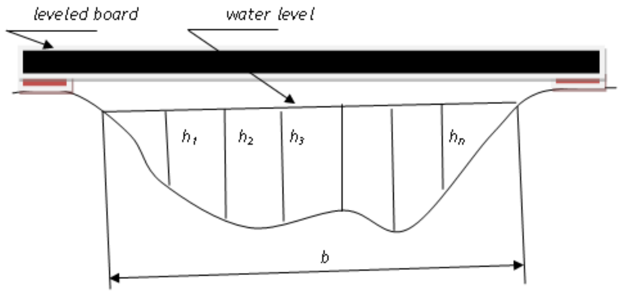

Figure 1. Cross-section of a river

The velocity across the flow and vertical is not constant; so, in order to obtain a mean value it is necessary to measure velocity of water at a number of points.

There are several methods applicable in measuring the stream flow, a few common and less expensive methods are stated: bucket, float, current meter and stage control methods

STREAM FLOW DATA REQUIREMENT

In designing a small hydropower scheme mean monthly and annual flow record are often used. The stream flow and rainfall data for the catchment area of the stream under investigation are required. The available record must be of adequate length in order for analysis to be meaningful. Generally, small hydropower schemes have a life span of range of 20-50 years depending on the make, type and capacity (Nigam, 1985). Therefore, 20 years stream flow record is considered adequate for the analysis and development of small hydropower schemes.

The desirable length of stream flow record will largely depend on the length of available, rainfall and availability of stream flow records of other rivers within the project area. Success of the scheme depends on how accurate has been the estimation of total quality of water available and its variability. Proper estimation of water availability is, therefore, very essential. This would require collection of data and then computation by suitable method on the basis of available data.

For computation of water availability, rain fall and run-off data should be collected. The water availability for SHP is based on 90% dependability

(Nwachukwu, 2005). Depending upon the type of data available, the water availability can be computed from one of the following method, namely; direct observation method and rain-fall run-off series method.

STREAM FLOW DATA ANALYSIS

The main objective of stream flow record analysis in SHP development is to prepare a flow duration curve and then determine design flow, installed capacity, plant capacity factor and average discharge.

In order to ascertain how often flow of a given magnitude occurred during the period of record, a flow duration curve is prepared. From available data, the discharge is plotted as ordinate against the percent of time that discharge is exceeded on the abscissa and this can be of daily, mean monthly or mean annual flows.

Flow duration curves from long-term monthly stream flow records offer a convenient tool in plant capacity design (Nwachukwu, 2005).

The procedure used to prepare a flow-duration curve is as follows, demonstrated with a case study of Osun River.

Table 1: Mean monthly stream flow (m^3/s) of Osun River

YEAR	JAN	FEB	MAR	APR	MAY	JUNE
1979	84	89	74	97	158	127
1980	74	59	49	69	159	262
1981	42	58	76	111	228	176
1982	65	69	93	82	150	266
1983	73	132	62	116	154	144
1984	33	64	42	97	140	129
1985	105	97	42	67	114	132

YEAR	JULY	AUG	SEP	OCT	NOV	DEC
1979	89	56	48	47	72	136
1980	108	69	47	110	114	81
1981	118	66	47	46	65	65
1982	187	82	55	42	96	76
1983	129	68	42	84	145	155
1984	104	62	43	56	55	51
1985	144	75	50	35	23	24

The discharge in the range 0 to 300m^3/s has been divided into 15 classes of 20m^3/s each as shown in column1 in table 2. The data are scanned through and each item is noted in the class group in which it belongs. The total in each class is shown in column 2. Column 3 shows the accumulated number of items of column 2, starting from the bottom. The items accumulated are shown as percent in column 4. The plots of largest values in each class in column 1 against column 4 are shown in figure 2. From the plot, the design flow rate is Q corresponding to 40% exceed (Nwachukwu, 2005) Q_{40} = 100m^3/s and the capacity point is Q_{15} = 154m^3/s.

The mean flow rate Q_{av} (Nwachukwu, 2005) is computed from;

$$Q_{ay} = 0.025(Q_0 + Q_{100}) + 0.05(Q_5 + Q_{95}) + 0.075(Q_{90} + Q_{10}) + 0.10(Q_{20} + Q_{30} + Q_{40} + Q_{50} + Q_{60} + Q_{70} + Q_{80}) \quad (6)$$

where, Q_{av} = average discharge, Q_5, Q_{10} = discharge corresponding to 5%, 10%, exceed, Q_0, Q_{100} = discharge nearly 0 and 100% of time (any discharge of less than 5% and more than 95% respectively.

The real power equation [3] is between P = 7QH and P = 8.5QH (kW)

where, Q = design flow rate m^3/s taken as Q_{40}, H = available head measured in metres.

From flow-duration curve fig.2, Q_{40} = 100 m^3/s. Therefore, the power equation in the case of a low head plant (less than 10 m) in which the fore bay level varies, the gross head should be measured to the minimum force bay level.

Table 2: computation of flow-duration curve

1	2	3	4
Class flow range (m^3/s)	Number of items	Cumulative number of items	Percent of time
0 - 20	0	84	100
21 - 40	4	84	100
41 - 60	20	80	95.2
61 - 80	19	60	71.4
81 - 100	12	41	48.8
101 - 120	9	29	34.5
121 - 140	7	20	23.8
141 - 160	8	13	15.5
161 - 180	1	5	6.0
181 - 200	1	4	4.8
201 - 220	0	3	3.6
221 - 240	1	3	3.6
241 - 260	0	2	2.4
261 - 280	2	2	2.4
281 - 300	0	0	0

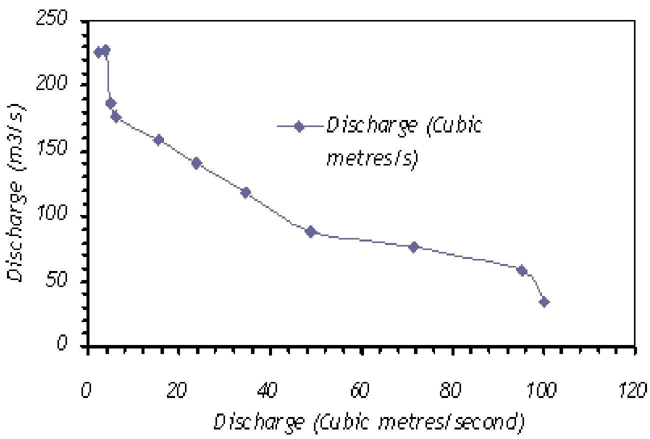

Figure 2: Discharge- percent of time exceeded

P = 7 x100x100 kW = 7000 kW or 7 MW

The corresponding design or installed capacity of the plant is based on maximum flow, which is usually as Q_{15} (i.e, flow exceeded 15% of the time) [3]. Flood flows above this magnitude are allowed to overflow without producing power.

The corresponding installed capacity is given by

$$P_{instal} = 7 \times Q_{15} \times H \quad (kW)$$

$$P_{instal} = 7 \times 154 \times 10 = 10780\,(kW)$$

$$P_{instal} = 10.7MW$$

Annual energy output E is given by

$$E = 7 \times Q_{ay} \times H \times 8760 \quad kWh$$

$$E = 613200\ Q_{ay}\ kWh \quad (H = 10\,m)$$

From the curve Q_{av} = 92 m^3/s

Therefore, E = 56414400 kWh or 56414.4 MWh

The plant capacity factor is the ratio of the average power production to the installed capacity and this is practically taken as $Q_{ay}/Q_{15} = 92/154 = 0.597$

A plant capacity factor of 0.6 is common for storage type power schemes (Ram, 1989).

CONCLUSIONS

Locating a good site for installation of a new plant is one of the main obstacles for small hydroelectric power generation. The site where the small hydropower is installed must have sufficient head and enough water flow rate to produce sufficient amount of energy and the site must also be close to the location where the energy is going to be utilized.

Flow rate is very essential for hydropower generation since the head at a proposed site is practically constant while the available flow is highly variable. Having known the water discharge, annual energy output of the proposed site under consideration can be estimated which will serve as an input energy to run hydro turbine of the SHP scheme to generate electricity. Since the entire quantity available at a site is utilized in power production, the study of water demand for hydropower amount to collection of stream flow data and their analysis. Therefore, stream flow is an important parameter in determining the maximum power derivable from any flowing river.

RECOMMENDATION

Exploring the potential of SHP scheme as eco-friendly source of energy serves the least cost option for provision of electricity to underdeveloped rural areas compared to the extension of grid. They are affordable if necessary subsidy is provided.

Furthermore, the value added benefits of the scheme is as follow:

Availability of local labour and materials; thereby, increasing the income of the poor.

They help to check rural/urban immigration.

They are flexible and can usefully be integrated into almost any kind of development programme such as rural development, poverty alleviation programme and environment protection programmes.

REFERENCES

[1.] Gundiri M.N (2005), Guidelines for the design of hydraulic structures for small hydropower schemes, paper presented at national workshop on capacity building in small hydropower for the provision of rural energy, pp. 1-8, Ogun-Osun River Basin Development Authority, Nigeria.

[2.] Nigam P.S (1085), Hand Book of Hydro Electric Engineering, Second edition.

[3.] Nwachukwu M.C (2005), Hydrological data collection and analysis for small hydropower development, national workshop on capacity building in small hydropower for the provision of rural energy, pp. 1-20, Ogun-Osun River Basin Development Authority, Nigeria.

[4.] Odesanya M.O (2005), Social impact assessment and its mitigation in SHP projects, national workshop on capacity building in small hydropower for the provision of rural energy, pp. 1 – 2, Ogun-Osun River Basin Development Authority, Nigeria.

[5.] Ram S. Gupta (1989), Hydrological and Hydraulic Systems Practice. Wall Inc.

[6.] Tamunotonye Brown (2005), Determining Potential Capacity of Small Hydropower Site, pp. 2 – 5, Ogun-Osun River Basin Development Authority, Nigeria.

[7.] US Bureau of Reclamations (1987), Design of small Dams, WR Technical Publ. 2nd edition.

[8.] Weedy B.M (1979), Electric Power Systems, third edition. Chichester New York: John Willy & Son.

[9.] Yanmaz A.M (2001), Applied Water Resources Engineering, Ankara, Ghana: METU Press

ACTA TECHNICA CORVINIENSIS – BULLETIN of ENGINEERING

ISSN: 2067-3809 [CD-Rom, online]