DEVELOPING SMALL HYDROPOWER POTENTIALS FOR RURAL ELECTRIFICATION

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ABSTRACT
Electrical energy is an integral component of the overall development of any nation. About sixty – five percent (65%) of the Nigerian rural populace do not have access to electricity. This work therefore presents the surveyed and analyzed potential hydropower sites for rural electrification scheme in Nigeria using the available hydrological data. The fundamental energy equations that determine the theoretical power output, turbine and generator capacities for small hydropower schemes were presented, considering the hydrological head (H) in metres (m), discharge (Q) in cubic metres per second (m^3/s) as collected from selected streams, rivers and dams at different parts of the country. The average energy consumption patterns for rural communities in the selected sites were also presented. The results from the analysis showed that theoretical electrical power ranging from 5.13 kW to 5,000 kW which is enough to cater for average rural community loads is realizable in Nigeria if the identified small hydropower sites are developed.

Key words: *Electrical energy, Development, Rural Electrification, Small hydropower scheme, Rural loads, Nigeria.*

1. INTRODUCTION

Electricity is a basic and integral component of the overall development of any nation and one of the critical infrastructural requirements for agricultural, industrial and socio–economic development of rural or remote environment. Currently more than 1.5 billion people are without access to electricity and it is estimated that not more than 20%, and in some countries as little as 5%, of the population in Africa (excluding South Africa and Egypt) have direct access to electricity [1]. The figure falls to 2% in rural areas [1]. Nigeria electricity generation capacity is currently within the range of about 3,500MW to 4,500MW, which is far short of the required energy demand (in the range of 20,000MW to 25,000MW**)** **[**2] to support economic growth and development. The electricity generation utility, Power Holding Company of Nigeria (PHCN), has been unable to cope with the electricity demand that is growing at an average range of 7% annually. More so, about 65% of Nigerian rural populace does not have access to the available conventional power. Since lack of access to electricity and rural poverty are closely correlated, the low level of electricity generation in Nigeria has not only posed great threat to the living standards of about 65% rural populace but also to the rapid socio – economic development of these sets of people [3]. There are two general options for supplying electricity to the rural or remote communities. These include the grid connection and the off-grid methods. Since the electricity supply from the National grid is insufficient, it is imperative for adoption of the off-grid alternatives. Hence, the renewable and sustainable electrical energy plays a prominent and leading role in this respect. Small hydropower scheme is one of the potential renewable energy technologies that is suitable and can be very vital for rural electrification in Nigeria owing to the fact that majority of rural environments are blessed with rivers, streams and run-off waters that have the capacities to generate hydroelectric energy. With this, the establishment of small and medium cottage industries, farm produce storages and information communication technology (ICT) schemes are realizable.
This work therefore presents some identified small hydropower potential sites for generating reasonable electrical energy capacities for electrifying rural communities in Nigeria.

2. RURAL ELECTRIFICATION AND ITS CHARACTERISTICS

Rural electrification is a term difficult to define precisely because the concept varies widely from country to country. Basically, rural electrification refers to the process of supplying electricity to rural and remote areas [4].
Rural electrification systems are generally characterised by:

- Dispersed consumers with often limited consumption and that require long supply lines and/or diesel-based or other generating units.
- A low load factor of between 0.2 – 0.4 [5, 6, 7].

- Villages located 3-30 km away from existing grid or even more [6] and with relatively low quality of power supply.
- Dispersed consumers that require long supply lines and/or diesel-based or other generating units.
- Low income consumers with low paying capacity.
- Consumers located in difficult terrain areas like forests, hill areas and deserts [6].

2.1 Significance of Rural Electrification in Nigeria

Promoting universal access to electricity services is a key component of the Federal Government's commitment to reduce poverty. Today many Nigerians are without electricity for lighting, essential health services and the development of economic opportunities, especially in agriculture and micro enterprises [8]. No meaningful development can take place without access to modern energy services. Likewise, without electricity, extending common democratic norms and values through radio and television will be a very difficult and unaccomplished task. Hence, rural electrification is indispensable factor for socio-economic development of the citizenry.Zomers [4] and Kamalapur and Udaykumar [6] classified various benefits accrued from rural electrification scheme into two: quantifiable and non-quantifiable. The quantifiable benefits among others include its industrial, commercial, domestic and agricultural applications. Non-quantifiable however is its effects on socio-political and employment creation for the people including rural populace.

2.2 Energy Consumption Estimate of Rural Community

Electricity consumption shows large variations depending on climate, culture, reliability of supply, and location. Generally, rural households in developing countries such as Nigeria have very low electricity consumption, with the primary uses being for lighting and operation of radios, fans and televisions. In Nigeria, official definition of a rural community is one with a population less than 20,000 [3], with an assumed average household of 10. An average energy demand estimate, E in kWh, of a given household within a rural setting may be computed using the energy equation described by (1):

$$E = P_r t n \qquad (1)$$

Where P_r is the wattage rating of a given household appliance (component) in kilowatt (kW)

t is the duration for which the appliance is to be operated in hours (h)

n is the number of the appliance

The energy demand estimate has been expressed in kWh because it is fundamental unit in which quantity of electricity (electric energy) used is measured. One kilowatt-hour is equivalent the amount of work done by one kilowatt of electric power in one hour.Hence, in a rural household where lighting is the only primary use of electricity, for instance, six 60-watt incandescent lamps used for about five hours each night will have a daily consumption of 1.8 kWh based on equation (1). A radio set and a small fan of wattage ratings 20 W and 50 W respectively can be used for 10 hours each day for an additional consumption of 0.2 to 0.5 kWh. A small TV set of wattage rating used for 6 hours a day will add a further 0.72 kWh. A family could accommodate all these uses easily within a consumption range of 4 kWh daily. Adejumobi et al. [9] in their work using Nigeria as a case study estimated the energy needed by typical rural/remote environment ICT infrastructures, banking and hospital services. These results revealed that for a typical rural/remote environment as it is applicable in Nigeria because the definition of a rural community varies from communities to communities across different countries of the world, the total weekly hour energy consumptions of ICT infrastructures, banking and hospital services could respectively be in the range of 48.836kWh, 72.908kWh and 12.660kWh equivalent to a daily average of 6.976 kWh, 10.415 kWh and 1.809 kWh respectively.

3. SMALL HYDROPOWER POTENTIALS IN NIGERIA

A small hydropower scheme requires both water flow and a drop in height called a head to produce useful power. Water in nature is considered a source of power when it is able to perform useful work, particularly turn water wheels and generate electricity at a rate such that the development of power can be accomplished in a most efficient and economical way [3]. Virtually, all the six geo-political zones in Nigeria are blessed with rivers, streams or run-off waters, which are suitable for small hydropower schemes.

The fundamental components of any hydropower scheme according to JICA [10] include:

- Intake: This is a barrier built across the river used to divert water through an opening in the riverside into a settling basin.
- Settling Basin: This is used to trap sand or suspended silt from the water before entering into the penstock.
- Headrace: This is a channel leading water to a forebay or turbine.

- Headtank or Reservoir: This is a pond at the top of a penstock or pipeline which serves as final settling basin, provides submergence of penstock inlet and accommodation of trash rack and overflow/spillway arrangement.
- Penstock: This is a close conduit or pressure pipe for supplying water under pressure to a turbine.
- Water Turbine and Generator: The water turbine is a machine which converts the kinetic energy of the flowing water into a useful rotational energy whereas the generator is a device used to convert mechanical energy into electrical energy. These two machines are very essential in any small hydropower setting.

A basic hydro power arrangement is shown in Figure 1.

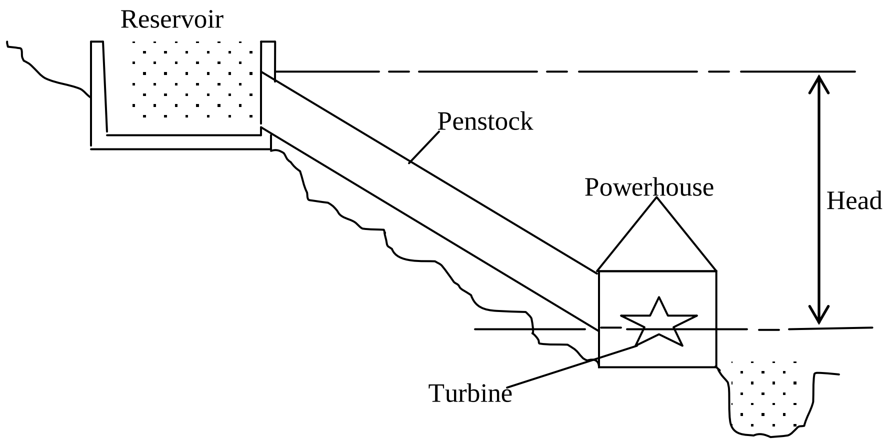

Figure 1: Schematic diagram of a typical hydropower system [3]

The use of Capacity Range to classify small hydro-power schemes varies from country to country. However, the terms small, mini, micro and pico are often referred to as small-scale hydro schemes. In this work, the classifications in the Table 1 can be suitable for Nigeria system [2, 3].

Table 1: Small Hydro-power Scheme Classification [2, 3]

Small Hydro-power Scheme	Capacity Range (MW)
Small	1.0 – 10
Mini	0.5 – 1.0
Micro	0.05 – 0.5
Pico	0 – 0.05

4. DESIGN AND ANALYSIS

The equations describing the power outputs and the sizes of the materials needed for small hydropower scheme are presented.

4.1 Power Equations for Small Hydropower

The power equation applied to a conventional hydro-power plant is also applied to SHP. The power available at the generator output P_{output} in kW is given by equation (2) [10]:

$$P_{output} = P_{gross} \times \eta \tag{2}$$

Where P_{gross} is the gross power in kW

η is the overall efficiency of the hydropower scheme.

The gross power is the product of the gross head (H) in metres, the design flow Q in m^3/s and a coefficient factor that is the acceleration of free fall g in m/s^2 [10]. Hence, we have:

$$P_{gross} = gHQ \tag{3}$$

Where g is assumed $9.81 m/s^2$

The use of equation (3) in equation (2) yields:

$$P_{output} = gHQ\eta \tag{4}$$

The overall efficiency according to JICA [10]:

$$\eta = \eta_{civil\ work}\eta_{penstock}\eta_{turbine}\eta_{generator}\eta_{drive\ system}\eta_{line}\eta_{transformer} \tag{5}$$

However, given the efficiencies of turbine and generator preference over others as the major determinants of the available power from small hydropower scheme, equation (4) can then be modified as:

$$P_{output} = gHQ\eta_{turbine}\eta_{generator} \tag{6}$$

In a situation where Q has not been obtained by measurement, it is calculated by equation (7) [2, 3]:

$$Q = \frac{\pi d^2}{4}\sqrt{2gH} \tag{7}$$

Where d is the diameter of the penstock in metres.

4.2 Penstock size

The penstock diameter, d, in metres can be computed if the flow rate 'Q', Manning Coefficient 'n', the net head 'H' and the length of the penstock 'L' are known from the equation (8) [2, 3].

$$d = 2.69\left(\frac{n^2Q^2L}{H}\right)^{0.1875} \tag{8}$$

Where L = Length of Penstock (m).

The length of a penstock for a given design consideration can be obtained from the equation (9) [2, 3].

$$L = gHt_g/V \tag{9}$$

Where t_g = Water acceleration constant in the pipe (s)

V = Flow velocity in ms^{-1}

The Manning's Roughness Coefficient n is a coefficient which represents the roughness or friction applied to the flow by the channel. Typical values of n are given in the Table 2 [2, 3].

Table 2: Manning Coefficient n for Several Commercial Pipes [2, 3]

Kind of pipe	n
Welded steel	0.012
Polyethylene (PE)	0.009
PVC	0.009
Asbestos cement	0.011
Ductile iron	0.015
Cast iron	0.014
Wood-stave (new)	0.012
Concrete (steel forms smooth finish)	0.014

4.3 Turbines

A turbine converts the energy in falling water into shaft power. There are various types of turbine which can be categorized in one of several ways. The choice of turbine will depend mainly on the pressure head available and the design flow for the proposed small hydropower station. The maximum output of turbine in kW is calculated using equation (10) [10]:

$$P_{maxouput} = gHQ\eta_{maxturbine} \tag{10}$$

Where $\eta_{maxturbine}$ is the maximum turbine efficiency.

Tables 3 and 4 respectively give the variation of turbine with efficiency and classification of turbine according to head for small hydropower scheme.

Table 3: Variation of Turbine Types with Efficiency [2, 3]

Turbine (Prime mover)	Efficiency
Pelton	80-90%
Turgo	80-95%
Cross-flow	65-95%
Propeller	80-95%
Kaplan	80-90%

Table 4: Different Classification of Turbine According to Head for small hydropower [10]

Turbine Type	Head		
	High < 40m	Medium 20 – 40m	Low 5 – 20m
Impulse	Pelton Turgo	Crossflow Turgo Pelton	Crossflow
Reaction		Francis Pump – as – Turbine (PAT) Kaplan Propeller	Propeller Kaplan

5. RESULT AND DISCUSSION

For the purpose of this work, hydrological data for selected dams and rivers were collected from River Basin Development Authorities in Nigeria as shown in Table 5. Applying the power equations described in (2) to (10), the theoretical electric power generating capacities for the selected sites were also shown in Table 5. Following the standard small hydropower guide and past works [3, 10], the turbine and generator efficiencies were selected between 80-85% and 95% - 98% respectively to compute equation (5). Where the flow-rate Q was not available from the data collected, equation (6) was used to determine it. The selected sites showing the theoretical calculated electrical power capacities across the country are presented in Table 5. The results showed that the calculated theoretical electrical power ranging from 5.13 kW to 5000 kW obtainable if the identified small hydropower sites are developed for rural use.

Table 5: Identified Small Hydro-Power Sites in Nigeria

S/N	Name of Site	Site Location	Site State	Hydro Source	Average Water Head (m)	Suggested Turbine Set	Theoretical Plant generating capacity (KW)
1	Ayiba	Ayiba	Osun	Dam	11.58	Crossflow	122.40
2	Erinle	Ede	Osun	Dam	10.50	Crossflow	110.94
3	Otin	Eko-Odo	Osun	Dam	13.70	Crossflow	140.75
4	Osun	Esa-Odo	Osun	Dam	11.30	Crossflow	120.00
5	Erinle	Nelo-Erinle	Osun	Dam	28.00	Pelton	285.80
6	Tage	Kishi	Oyo	Dam	11.00	Turgo	116.2
7	Olupo	Igbeti	Oyo	Dam	9.00	Turgo	95.00
8	Fofo	Shaki	Oyo	Dam	14.60	Crossflow	148.26
9	Osune	Asejir	Oyo	Dam	26.22	Pelton	270.00
10	Ona	Eleiyele	Oyo	Dam	14.60	Crossflow	148.26
11	Oyo	Awon	Oyo	Dam	13.00	Crosssflow	130.30
12	Oba	Oba	Oyo	Dam	13.50	Crossflow	139.20
13	Opeki	Opeki	Oyo	Dam	12.00	Turgo	126.80
14	Esinowu	Irawo	Oyo	Dam	10.00	Turgo	105.60
15	Konsi	Igboho	Oyo	Dam	10.00	Turgo	105.60
16	Okugba	Ayete	Oyo	Dam	10.00	Turgo	105.60
17	Ibu	Ajura	Ogun	River	2.00	Propeller	21.13
18	Yewa	Yara Mata	Ogun	River	2.60	Turgo	28.0
19	Ona-Nla	Idi Ayanra	Ogun	River	1.50	Propeller	15.84
20	Oshun	Ijebu-Igbo	Ogun	River	2.10	Propeller	22.20
21	Yewa	Eggua	Ogun	River	1.85	Propeller	16.70
22	Oni	Effon Alaye	Ekiti	Dam	6.25	Turgo	60.06
23	Ero	Ikun Ekiti	Ekiti	Dam	24.50	Pelton	250.96
24	Ele	Itapaji	Ekiti	Dam	25.10	Pelton	264.00
25	Little Ose	Egbe Ekiti	Ekiti	Dam	25.00	Pelton	262.25
26	Erita	Igbara-Odo	Ekiti	Dam	3.50	Turgo	37.00
27	Tagwai	Tagwai	Niger	Dam	15.70	Crossflow	165.95
28	Agboh 2	Agboh	Niger	River	6.10	Turgo	64.48
29	Mfum 2	Mfum	Niger	River	7.00	Turgo	79.28
30	Belle	Baata	Niger	Dam	72.60	Pelton	719.00

31	Onitsha	Onitsha	Anambra	River	7.50	Turgo	79.28
32	Itu	Itu	Cross River	River	3.50	Turgo	37.00
*33	Owena	Owena	Ondo	Dam	24.00	Pelton	5000.00
*34	Tunga	Kakara	Taraba	Dam	10.50	Pelton	400.00
**35	Evboro II	Benin	Edo	Run-off River	5.00	Turgo	40.00
*36	Ikeji-Ile	Ikeji-Ile	Osun	Dam	7.50	Turgo	70.00
*37	Awieke	Awieke	Benue	Dam	24.00	Turgo	1200.00
38	Onitsha-2	Onitsha	Anambra	River	5.65	Turgo	55.00
39	Ikun	Ikun	Niger	River	8.50	Turgo	85.00
*40	Oyan	Oyan	Ogun	Dam	30.44	Pelton	3000.00
41	Ogun-Osun	Alabata Road	Ogun	Dam	3.30	Propeller	5.13

* Development in progress **Pilot project embarked on by UNIDO-SHP [11]

6. CONCLUSION

Electricity has been identified as one of the basic factors for the overall development of any nation. Majority of Nigerian populace are rural dwellers and are suffering from poor living standards coupled with poor socio – economic development due to their inability to get access life – enriching facilities of which electricity supply plays a leading role. Using the collected available sampled hydrological data for Dams and rivers across rural areas in Nigeria, the adopted power equations were used to determine the theoretical electric power capacities of the forty one (41) identified Small Hydro Power sites. Results from the analysis showed the generating capacities ranging from 5.13kW to 5000kW are realizable from the sites, which is averagely enough to cater for rural household energy demands and small and medium cottage industries. These sites are few out of many possible small hydropower sites that can still be employed across the country. Although UNIDO Small Hydropower Development Centre for West Africa in conjunction with Federal Government is intensifying effort in the regards, it is recommended that private individuals and international organizations venture into the development of these sites.

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