IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 13, Issue 9, September 2023, ||Series -I|| PP 40-48

The untapped potential of river Nnwankwo: A survey on renewable energy alternative for pump storage power generation in Akwa Ibom State

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Abstract

Globally, the demand for cheap energy source has risen as a result of population growth, urbanization, and industrialization. While the electricity consumption in emerging nations like Nigeria is rising, the supply, which is often derived from fossil fuels is diminishing, leading to an energy crisis and pollution. Thus, in order to cover both the present and future energy needs, it is necessary to investigate alternate or renewable energy sources. This study seeks to offer a broad overview of the economic design consideration, practical implementation parameters, and interconnections of the key components of small hydropower plants for River Nnwankwo, in Ikot Ekpene local government area of Akwa Ibom State, Nigeria. The focus is to offer a foundational understanding of micro-hydro systems, planning, the advantages and limitations of micro-hydro energy estimation, which is a function of head and flow rate. If this exploitable source of energy could be harnessed using environmentally friendly technology, the entire energy situation in Ikot Ekpene sub urban which has a thriving population would be improved.

Keyword: Renewable energy, Pump storage, Flow rate, hydroelectric power, River Nnwankwo.

I. Introduction

Electric power is one of the ingredient which residential, industrial, and commercial consumers require. As most of the electric power supply targets have not been met, Nigeria's journey toward a sustainable electric power supply has been a protracted, somewhat strategic, but unremarkable process. Nigeria's generating system capacity continues to be irregular and unreliable and is unable to keep up with the rising load demand. Although the electricity sector has undergone significant reorganization, the initiatives do not appear to have an impact on the users' access to power. Thus, the establishment of effective damless mini and micro hydroelectric power plants that utilize the kinetic and partially potential energy of the water flow without the construction of dams is an urgent approach to be considered for small renewable energy. The most popular types of damless hydroelectric power plants are submersible, on floating pontoons, garland, and sleeve hydroelectric power plants. However, other designs are possible depending on the size of the river segment and the water flow rate. In Nigeria the potentials of small rivers that has potentials for small hydroelectric capabilities is clearly illustrated in table 2 (Ugwu et al., 2022; Kela et al., 2012; Okedu et al., 2020). On the hand, despite the drawbacks associated with them, such as the influence on the environment and the resource's steady depletion, more than 81% of the world's energy consumption originates from fossil fuels (Safarian et al., 2019). Despite the various forms of renewable energy, hydropower is one of the most efficient and dependable in terms of producing electricity globally, accounting for around 15.9% of worldwide electricity generation and 2.5% of the world's energy resource.as seen in table 3 and table 4 the energy access per capita in some African states is not adequate (Bozorg Haddad et al., 2011; Safarian et al., 2019). In a typical small hydroelectric power plant, to generate electricity, water must be in motion. When the water is falling by the force of gravity, its potential energy converts into kinetic energy. This kinetic energy of the flowing water turns blades or vanes in some hydraulic turbines, the form of energy is changed to mechanical energy. The turbine turns the generator rotor which then converts this mechanical energy into electrical energy and the system is called hydro-electric power station For run-of-river hydropower plants, a weir is often in charge of directing the river's water toward the intake.Usually, the water travels through a desilting tank before reaching the turbine. A canal might also transport water to a forebay, where it would subsequently be transported to a turbine by a penstock (Jung et al., 2021; Vougioukli, et al., 2017; Anaza et al., 2017; Jung et al., 2021). Nigeria is blessed with an abundance of natural resources, some of which may be quickly and inexpensively used to generate electricity, the energy type that is most commonly changed. Small hydropower resources are one of the ways the country generates electricity. Small rivers are used to produce hydroelectric power. A tiny river is generally understood to be one whose catchment area is less than 500 km2, or more specifically, less than 300 km2. Rivers, lakes, and streams with catchments smaller than 100 km2 are highly interesting from the perspective of minor hydropower production (Ebhota & Tabakov, 2018; Omojolaa & Oladejib, 2012). Today Ikot Ekpene has become a thriving metropolis that has experienced a surge in population and is in dire need of energy sources that can help ameliorate the epileptic power supply from public utility company (Udoh & Efiong, 2021). River Nnwankwo (aka inyang Nwankwo) untapped potentials is the focus of this research study in order harness its viability for small hydroelectric power (SHP) plant that can help generate energy for the needs of the ikot Ekpene sub urban inhabitants for the purposes ranging from irrigation for agriculture and other immediate power needs of the surrounding communities.

Table 1: Hydropower categorization (Dragu et al., 2001)

Terms	Power Output
Pico HP	<5 kW
Micro HP	5kW- 100 Kw
Mini HP	100Kw – 1000Kw
SHP	1MW- 30MW
Medium HP	30MW- 100MW
Large HP	>100MW

Table 2: Nigeria’s SHP potential sites and estimated output (UNIDO, 2006)

States	Potential sites	Estimated output
Adamawa	3	28.600
Akwa Ibom	13	
Bauchi	1	0.150
Benue	10	1.306(one site)
Cross River	5	3.0
Delta	1	1.0
Ebonyi	5	1.399
Edo	5	3.828
Ekiti	6	1.2472
Enugu	1	
FCT	6	
Gombe	2	35.099
Imo	71	
kaduna	15	25.0
Kano	2	14
Katsina	11	234.34
Kebbi	1	
Kogi	2	1.055
Kwara	4	5.2
Nassarawa	3	0.452
Niger	11	110.580
Ogun	13	115.610
Ondo	1	1.3
Osun	8	2.622
Oyo	3	1.062
Plateau	14	89.1
Sokoto	1	
Taraba	9	134.720
Yobe	5	
Zamfara	16	

Table 3: Global contribution by each renewable energy (Dragu et al., 2001)

Energy Source	Percentage
Large hydro (>10 MW)	86 %
Small hydro (<10 MW)	8.3 %
Wind and solar	0.6 %
Geothermal	1.6 %
Biomass	3.5 %

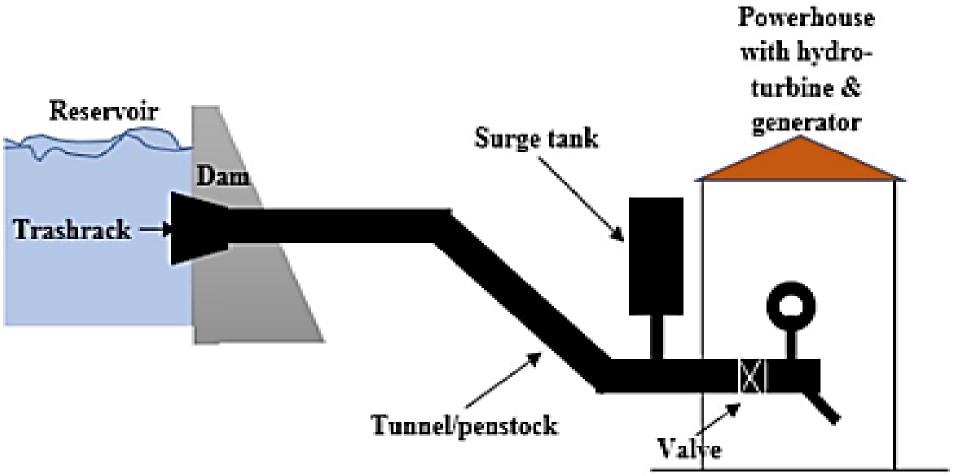

Figure 1: A schematic of a typical micro HP plant

Table 4: Access to electricity per capita in West African state (Beals, 2023; West African Economic Size and Access to Electricity)

SN	Country	Average KWh/Capita
1	Benin	36.5888
2	Burkina Faso	16.8222
3	Cape Verde	87.9555
4	CoteD’lvoire	64.1
5	Gambia	76.4111
6	Ghana	36.3444
7	Guinea	29.8444
8	Guinea	17.6555
9	Bissau	39.1666
10	Liberia	41.5333
11	Mali	17.0222
12	Mauritania	55.1333
13	Niger	63.1111
14	Nigeria	20.8222
15	Senegal	46.81
16	Sierra Leone	36.5888
17	Leone	16.8222
18	Togo	87.9555

II. Study Area

In accordance with FIG. 1, Ikot Ekpene is situated between latitudes 5° 10' and 5° 30' north of the equator and 7° 30' and 7° 45' east of the Greenwich Meridian. It is located on Akwa Ibom State's western flank. Its location makes it one of the Akwa Ibom State's economic entryways. Ikot Ekpene has a distinguished local government administration in Nigeria due to its transformation into a leading model in 1951. It shares a border with the local governments of Essien Udim, Obot Akara, and Ikono. The Ikot Ekpene Senatorial District, which now has 10 Local Government Areas, is headquartered in Ikot Ekpene. The wet season and the dry season, which define the study area's climate, alternate every year. The impact of excessive rainfall over evaporation is the amount of water that is available for surface water flow and groundwater recharge. Mid-November is when the dry season starts, and it lasts until March. For a brief time, the research region is covered by the entire continental tropical air mass, its accompanying north-easterly winds, and the accompanying dry and dusty harmattan haze. The mean annual temperature at Ikot Ekpene ranges from 26°C to 36°C all year round, making for extremely high temperature figures. The research area has relative humidity that fluctuates between 75% and 95%; the highest and lowest values are seen in July and January, respectively. According to Wokocha and Kamalu (2009), the research area's relief is typified by the coastal plain of southeast Nigeria;

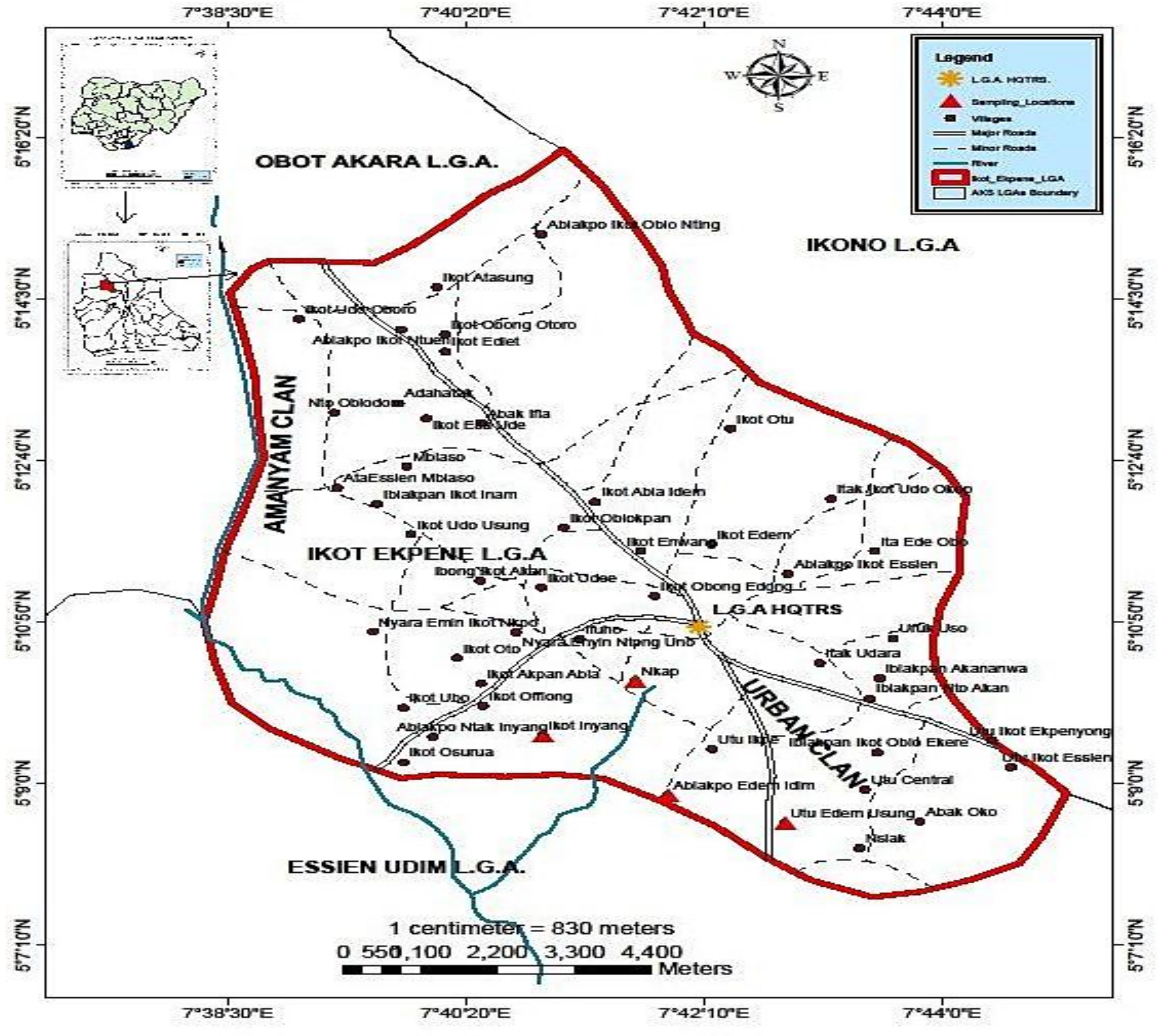

Figure 1: Map of Ikot Ekpene Local Government in Akwa Ibom State

III. Basic principle of small hydro power plant and Experimental Design component consideration and Parameterization

The representation of mini and micro hydroelectric power facilities along a riverbed like that of River Unwankwo will require a substantial height difference which a pipe suffice. Water is drawn into the pipe from the stream in the top portion, where it enters the hydraulic unit in the lower portion as a result of gravity forces. The height difference is between two and three tens of meters. Such hydroelectric power stations should only be built on Mountain Rivers with a significant natural slope. They are quite efficient, but its construction necessitates high capital costs and has a bigger influence on the environment due to human activity. The most promising are small and mini damless hydroelectric power plants of the submersible type and hydroelectric power stations on floating pontoons with torsos or on pinholes for rivers with a small slope but with a flow velocity over 1 m/s. Although the power of these hydroelectric power plants often varies from several kW to

30–50 kW, and less frequently up to 100 kW, even these capacities may be adequate to supply electricity to small working camps, recreation facilities, or to operate a variety of independent telecommunication systems (Pandey & Kumar, 2015). There are numerous factors that need to be planned for and taken into account while designing a micro-hydroelectric power plant. These factors include:

3.1 Major Component of the SHP

The following are the main elements of a comprehensive hydropower system, and they are covered in this section.

i. Water storage and water filtering mechanism
ii. Penstock with valves
iii. Turbine
iv. Power-converting device (Generator or direct-drive)

3.2 Water Storage cum water filtering mechanism

Getting solids out of the water before it enters the turbine is a crucial component of system design that is sometimes overlooked. If such a system is not put in place, the turbine may be damaged by sticks and stones and may perform worse due to leaves being stuck on the blades. This design's turbine will undoubtedly need cleaning at some point because it can never be completely removed.

3.3 Pumped storage

These facilities, which are sometimes equated to batteries, store energy by pumping water via a penstock from a lower reservoir to a higher reservoir during periods of low power demand. The water is returned to the lower reservoir during periods of high demand, pushing the turbine to produce electricity. The greatest of these facilities, the Bad Creek Hydroelectric Station in Oconee County, South Carolina, which uses water from three artificial lakes to produce 1,065 MW of power is lower in capacity than its diversion and impoundment counterparts (Phillips et al.,2020).

3.4 Penstock Design

From the dam or reservoir to the turbine, water is transported through the penstock. Materials, diameter, wall thickness, and joint style all describe a penstock; The material is chosen based on the terrain, ease of access, weight, jointing mechanism, and cost. The diameter is chosen to bring the amount of frictional losses inside the penstock down to a manageable level. The wall thickness is chosen to withstand the anticipated transient surge pressure as well as the highest internal hydraulic pressure.

3.4.1 Diameter of penstock

The diameter of the penstock can be evaluated the following formula. Thus, for calculating the diameter of a penstock is:

$$Dp = [C\ Qp / V\ ]0.5 \qquad (1)$$

Where Dp is the penstock diameter, C is a constant equal to 1.273, Qp is the water flow, V is the water velocity. The penstock's composition is influenced by the water pressure, environmental issues, and the topography of the area. Only the diameter of the penstock affects the thickness; the strength of the material is unaffected. The penstock pipe's length, diameter, and water flow rate, as well as the wall material's roughness, all have an impact on the head loss (Kumar, 2022).

3.5 Transportation of water

In a small hydroelectric power plant with respect to River Unwankwo, a penstock is a system of pipes used to move pressurized water from a reservoir (dam) to the turbines. Penstocks may be above or below ground and made of steel, reinforced or prestressed concrete, composite materials (fibreglass reinforced polyester, HDPE, etc.), or even cast iron, depending on the topography of the site and the technological options available at the time of their construction. Penstocks are designed to withstand the highest water pressure, particularly water hammer. In addition to being highly pricey, they are essential components of the water conductor system. Depending on the conditions at the site, the penstock may be put on the ground, embedded in concrete, or underground. The penstocks are equipped with extras such bell mouth intakes, expansion joints, manholes, matching components, and bends. The losses are estimated using the Darcy Weisbach Equation, and flow in the penstocks equals pipe flow (Kumar, 2022; Pandey & Kumar, 2015).

$$\text{Headloss} = fLV^2\,(2gD)^{-1} \qquad (2)$$

Where f is the material-dependent friction coefficient of the inner surface of the penstock, L is the penstock's length (in meters), V is its speed (in meters per second), g is its gravitational constant, and D is its diameter (in meters).

3.6 Head measurement

The vertical separation between the water surface level at the intake and tailrace for reaction turbines (like Francis and Kaplan turbines) and the nozzle level for impulse turbines (like Pelton, Turgo, and Cross-flow turbines) is known as the gross head (Hg). Modern electronic digital levels have a measurement accuracy of (0.4 mm) and automatically show height and distance in around (4) seconds. Global placement System (GPS) surveying is already common, and a handheld GPS receiver is perfect for preliminary mapping and field placement. The losses along its journey, such as open channel loss, trash rack loss, can be easily subtracted from the gross head to obtain the net head (H_n). Whenever the total amount of head is known, the net head (H_n) can be calculated by simply deducting any losses along the way, including friction loss in the penstock and losses from open channels, trash racks, intakes, and valves (Kumar, 2021; Samora et al., 2016; ESHA,2010).

3.7 Flow duration curve (FDC)

The net head and maximum water flow rate, which must be defined by the river or stream where the turbine should be installed, influence the choice of turbine type, size, and speed. The maximum water flow capacity of the turbine must be calculated using the river or stream's flow duration curve since micro-hydroelectric power plants are typically constructed as run-of-the-river facilities. Plotting a flow duration curve, which displays for a specific spot on a river the percentage of time during which the discharge there equals or exceeds predefined values, is one method of organizing discharge data. It can be found in the hydro-graph if the data are arranged by magnitude rather than chronologically. The potential power of a stream can be estimated from the mean yearly flow. FDC can be created for specific time periods as well as specific years (Samora et al., 2016; ESHA, 2010).

3.8 Flow rate measurement

There are a number of techniques available to estimate the water flow rate (discharge). For medium-sized to large rivers, the velocity-area approach is a common technique that involves measuring the cross-sectional area of the river and the mean velocity of the water flowing through it. It is a practical method for quickly determining the stream flow. (Samora et al., 2016; ESHA, 2010). The area should be clearly delineated, and the river should be a consistent width. This can be further expressed in terms of viz:

a. Cross-sectional area (A_r) measurement

It is necessary to divide a natural water flow into a number of trapezoids in order to calculate the cross-sectional area. The cross-section would be determined by: Measuring the trapezoid sides, using the marked rules.

$$A_v = \frac{(a+b)}{2} * \frac{h_1+h_1+h_{3+}+\cdots+h_k}{\dot{k}} \text{ (m^2)} \qquad (3)$$

Where a is width of top river (m), b is width of bottom river (m)

$$\frac{h_1+h_1+h_{3+}+\cdots+h_k}{\dot{k}} = \text{average height of water in the river (m)} \qquad (4)$$

b. Measuring the velocity (V_r)

It is important to measure the water velocity at a number of sites in order to obtain a main value because the velocity both across the flow and vertically through it are not constant. A floating object in the stream's flow center can be used to measure the velocity. It is noted how long (t) it took to travel a specific distance (L) in meters. Given is the surface speed (m/s).

$$Vrs = L/t \quad \text{(m/s)} \qquad (5)$$

In order to determine the average flow speed (Vr), this number must be multiplied by a correction factor, which can range between (0.6) and (0.85) depending on the depth of the water channel, the roughness of the river bank's bottom, and other factors (0.75 is a widely accepted value).

Thus, we can deduce that

$$Vr = 0.75 * Vrs \quad \text{(m/s)} \qquad (6)$$

Thus the river flow rate can be evaluated as

$$Q = Ar * Vr \quad (m^3/s) \qquad (7)$$

Where Q denotes water as the water flow rate (ie the discharge) of the stream or river

3.9 Weir and open channel:

It would be conceivable to construct a Weir in the event of low discharge rivers (less than 4 m^3 /s). It is a little wall or dam that spans the stream and is measured with a notch so that all of the water can be directed through it. The flow rate (discharge) can be calculated using a straightforward linear measurement of the height difference between the upstream water surface and the bottom of the notch. It is possible to utilize a rectangular, Vee, or trapezoidal notch, among other shapes. The flow rate through the actual notch, which may be made of hard wood or metal plate with sharp edges (ESHA, 2010; Samora et al., 2016). It can be expressed as:

$$Q = 1.8 * (W - 0.2h) * h^{1.5} \quad (m^3/s) \qquad (8)$$

Where W denotes the Weir width (m) and

h represents the Weir height (m)

The Weir dimensions can be computed if w = 3h. The most crucial factor to take into account when building the headrace open channel is to keep the slope of the channel just slightly elevated because a larger slope will result in a higher water velocity, which can then cause channel surface erosion.

There are two conditions that must be met for open channel foundation:

i. The channel's stiff construction prevents deformations, which increases stability.
ii. The Channel cannot withstand pressure during uplift or push.

Then it can be agreed that When:

i. The water depth, area, and velocity in every cross-section of the channel are constant, the flow of water in an open channel is regarded as uniform.
ii. The bottom channel line, surface line, and energy gradient line are all parallel to one another. based upon on these approach Manning factor can be evaluated

$$Q = \left({}^{1}/_{n_{Ch}}\right) * S_f * S_{\mathrm{ch}}^{1/2} \qquad (\mathrm{m}^3/\mathrm{s}) \qquad (9)$$

In this case Q represents the flow of water in uniform open channel, n_{ch} is the manning factor Sf is the section factor S_{ch} is the channel bottom line slope which is the hydraulic gradient (bed of the slope).

$$S_{ch} = \left[\frac{Q * n_{Ch}}{\mathrm{Ach} \cdot RCh\hat{\ }0.66}\right]^2 \qquad (10)$$

Thus, the open channel cross sectional area is given by Equation 11 while the hydraulic radius of the cross section is expressed in Equation 12:

$$A_{\mathrm{ch}\,=} = (W * h) \quad (m^2) \qquad (11)$$

$$R_{\mathrm{ch}} = A_{\mathrm{ch}}/(W + 2h) \quad (\mathrm{m}) \qquad (12)$$

Then the open channel velocity (V_{ch}) can be evaluated using Equation 11(ESHA, 2010; Samora et al., 2016).

$$V_{\mathrm{ch}} = Q/A_{\mathrm{ch}} \qquad (13)$$

3.10 Trash rack design

Bars at certain intervals (referred to as garbage racks) are positioned in a slanting position (at an angle of 60 deg. to 80 deg. with the horizontal) to prevent rubbish from entering the entrance flume. The turbine makers typically specify the widest possible space between the bars. For Pelton turbines, typical values are (20–30 mm), for Francis turbines, 40–50 mm, and for Kaplan turbines, 80–100 mm. To prevent the entry of floating debris, a screen or grill is always present near the entrance of both pressure pipes and intakes. A head loss is also produced by the water flowing through the rack. The trash rack coefficient (K_{tr}), which can range from (0.8) to (2.4), is dependent on the shape of the bar (ESHA, 2010).

3.11 Turbine speed

A specific amount of spinning component inertia is needed to ensure that the turbine speed can be controlled by adjusting the water flow rate. A flywheel on the turbine or generator shaft can offer extra inertia. When the load is disconnected, the extra power accelerates the flywheel; when the load is later attached, the addition inertia's deceleration provides further power, reducing speed variance (ESHA, 2010). The fundamental formula for the rotating set up is given by Equation 14:

$$\frac{dw}{dt} = \frac{1}{J * n}\left(P_t - p_l - B * w^2\right) \qquad (14)$$

From the above expression we deduce that:

P_t is the turbine power measured in watts, P_l is the load power measured in watts, B is the frictional torque coefficient of the turbine and generator measured in N.m/(rad/sec), J is the moment of inertia of the rotating system measured in $\mathrm{Kg/m^2}$.

Thus, when $P_t = P_l + B * w^2$, dw/dt = 0 and w = constant. (15)

Therefore, when the system operation is running smoothly. The governor must step in when P_t is larger or less than ($P_l + B * w^2$) in order to maintain a consistent speed and ensure that the turbine output power is equal to the generator output power. However, the first-order differential equation that describes the motion of the entire system can be numerically solved using MATLAB Simulink or a closed form solution. Then the turbine speed in that respect of rpm can be evaluated thus:

$$N = \frac{60 * w}{2\pi}(r \cdot p \cdot m) \qquad (16)$$

Thus depending on the turbine type selected even if the sizes differ, a turbine with identical geometric proportions will have the same specific speed (N_s). The definition of the precise speed can be achieved using Equation 17.

$$N_s = \frac{N * \sqrt{Pt}}{H_n^{5/4}} \quad (r.p.m) \qquad (17)$$

Where N represents the turbine's speed in rpm, which may be determined from the motional equation's solution, H_n is the net head in meters, Pt stands for turbine power in Kilowatts.

A reasonable criterion for choosing the type and size of a turbine is its specific speed (ESHA, 2010). The gear box ratio and generator type can be chosen after the turbine speed (N) has been determined.

3.12 Turbine Selection

The collection of turbine types (either Pelton or Francis Turbine) that apply to this project and the flow characteristics are determined by the rated flow and net head. The volumetric flow rate is predicted to be in the range of 0.85 m^3/s, and the gross head is 200 m. The tiny turbine's efficiency at design flow can range from 80% to 90%. Can be selected (ESHA, 2010).

3.12.1 for Pelton turbine

In consideration Pelton turbine, if the runner speed denoted N and the flow rate Q are well known, it is assumed the dimension of the Pelton turbine can be reasonably be estimated from these computations.

The diameter with respect to the bucket center line of the circle in Equation 18, the bucket width in Equation 19, nozzle diameter in Equation 20 and jet velocity in Equation21 and jet velocity in Equation 22.

$$D_1 = 40.8 * \sqrt{\frac{H_n}{N}} \tag{18}$$

$$B_2 = 1 \cdot 68\sqrt{\frac{Q}{k}} * 1/\sqrt{Hn} \tag{19}$$

Where K denotes the number of nozzles

$$D_e = 1 \cdot 178\sqrt{\frac{Q}{k}} * \frac{1}{\sqrt{g}} * Hn \tag{20}$$

$$D_j = 0 \cdot 54\sqrt{Q}/1/\sqrt{Hn} \tag{21}$$

$$V_{jet} = 1 \cdot 97\sqrt{2} * g * Hn \tag{22}$$

It is worthy to note that the ratio D_1/B_2 must always be greater than the turbine power.

3.12.2 For Francis turbine

This covers a wide range of specific speed, corresponding to high head and low head respectively. The main dimensions for Francis turbine is determine as follows:

$$D_3 = 84.5((0.31 + 2.29 * \left(\frac{Ns}{995}\right)\sqrt{Hn/N} \text{ exit diameter expressed in meters} \tag{23}$$

$$D_1 = \left(0.4 + \frac{94.5}{N_s}\right) * \ D_3 \text{ inlet runner expressed in meters} \tag{24}$$

$$D_2 = \frac{D_3}{0.96+3.8*10^{-4}*N_s} \text{ inlet diameters expressed in meters} \tag{25}$$

It is worthy to note that if $N_s > 163$, it is assumed the inlet runner diameter is equivalent to the inlet diameter.

IV. Conclusion

As the demand for micro-hydro power increases globally, and the deteriorating power condition in Nigeria persist, it's critical to demonstrate to the public just how practical these systems are achievable in implementation of energy solutions when placed in the right environment. The sole prerequisites for micro-hydro power are water sources, turbines, generators, suitable design, and installation. This technology benefits everyone involved as well as the environment and globe at large. The available pressure head and water flow rate will be the major determining factors in the turbine selection. Impulse and reaction are the two primary modes of operation for a SHP. Water jets power impulse turbines, which are appropriate for high heads and low flow rates. Water-filled reaction turbines utilize the angular and linear velocity of the flowing water to run the rotor (usually at medium head). Controlled turbines can alter the amount of flow they pull by moving the inlet guide vanes or runner blades. For micro-hydro projects with a head of five meters or less and a water flow rate of one m3 per second or less, cross-flow turbines are seen to be the best option.

If this small hydropower plant is built using this natural resource (River Nwankwo), the community's electrical need will be permanently fixed and any extra energy will be added to the national grid. This would also lessen rural-urban migration, which occurs when farmers flee to metropolitan areas in pursuit of comfort. This lowers agricultural productivity, which could lead to a food shortfall. If investigated and implemented in Ikot Ekpene, a small hydropower plant will function superbly. There is need to explore other rivers in Akwa Ibom state that has similar characteristics like the one in this survey in order to build a formidable energy mix for the national grid.

Reference

[1]. Ugwu, C. O., Ozor, P. A., & Mbohwa, C. (2022). Small hydropower as a source of clean and local energy in Nigeria: Prospects and challenges. Fuel Communications, 10, 100046.

[2]. Kela, R., Usman, K. M., & Tijjani, A. (2012). Potentials of small hydro power in Nigeria: the current status and investment opportunities. Natural gas, 9(12), 1703.

[3]. Okedu, K. E., Uhunmwangho, R. A. D. I. U. S., & Odje, M. (2020). Harnessing the potential of small hydro power in Cross River state of Southern Nigeria. Sustainable Energy Technologies and Assessments, 37, 100617.

[4]. Safarian, S., Unnþórsson, R., & Richter, C. (2019). A review of biomass gasification modelling. Renewable and Sustainable Energy Reviews, 110, 378-391.

[5]. Vougioukli, A. Z., Didaskalou, E., & Georgakellos, D. (2017). Financial appraisal of small hydro-power considering the cradle-to-grave environmental cost: A case from Greece. Energies, 10(4), 430.

[6]. Anaza, S. O., Abdulazeez, M. S., Yisah, Y. A., Yusuf, Y. O., Salawu, B. U., & Momoh, S. U. (2017). Micro hydro-electric energy generation-An overview. American Journal of Engineering Research, 6(2), 5-12.

[7]. Jung, S., Bae, Y., Kim, J., Joo, H., Kim, H. S., & Jung, J. (2021). Analysis of small hydropower generation potential: (1) Estimation of the potential in ungaged basins. Energies, 14(11), 2977.

[8]. Jung, J., Jung, S., Lee, J., Lee, M., & Kim, H. S. (2021). Analysis of small hydropower generation potential: (2) future prospect of the potential under climate change. Energies, 14(11), 3001.

[9]. Ebhota, W. S., & Tabakov, P. Y. (2018). The place of small hydropower electrification scheme in socioeconomic stimulation of Nigeria. International Journal of Low-Carbon Technologies, 13(4), 311-319.

[10]. Omojolaa, A., & Oladejib, O. A. (2012). Small hydro power for rural electrification in Nigeria. American Journal of Science and Engineering, 1(2), 29-34.

[11]. Udoh, U. I., & Efiong, J. (2021). Access to potable water supply in Ikot Ekpene local government area, Akwa Ibom state, Nigeria. Pp 70-76

[12]. Wokocha, C. C. & Kamalu, O. J. (2009). Mapping of soils of Ikot Ekpene of Akwa Ibom State: A Remote Sensing Perspective. Agricultural Journal, 4(2), 63-65.

[13]. UNIDO, 22nd May, 2006, The Nigerian capacity to host the Regional Centre for SHP, UNIDO Regional Center for Small hydro Power, Abuja, Nigeria

[14]. Dragu, C., Sels, T., & Belmans, R. (2001). Small Hydropower State of the Art and Applications. International Conference Power Generation and Sustainable Development, Liege. pp. 265-270.

[15]. Kumar, A. (2022). Hydropower-Basics and its role in achieving energy sustainability for the developing economies. In Renewable Energy and Sustainability (pp. 107-134). Elsevier.

[16]. Pandey, M. K., & Kumar, A. (2015). Pumped storage hydropower in India for integration of intermittent renewable energy. Water and Energy International, 58(3), 49-57.

[17]. Phillips, R. C., Kaye, N., & Saylor, J. (2020). A Multi-Reservoir Study of the Impact of Uncertainty in Pool Evaporation Estimates on Water-Availability Models. Journal of South Carolina Water Resources, 7(1), 5.

[18]. Crettenand, N. (2012). Small storage and pumped storage plants in Switzerland. International Water Power & Dam Construction, 64(4), 22-24.

[19]. ESHA, E. (2010). Energy Recovery in Existing Infrastructures with Small Hydropower Plants. Switzerland: Mhylab.

[20]. Samora, I., Manso, P., Franca, M. J., Schleiss, A. J., & Ramos, H. M. (2016). Energy recovery using micro-hydropower technology in water supply systems: The case study of the city of Fribourg. Water, 8(8), 344.