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ORIGINAL RESEARCH ARTICLE

A FEASIBILITY STUDY OF MINI-HYDROELECTRIC POWER PLANT FOR SEASONAL BASE LOAD

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ABSTRACT

This paper presents a feasibility study of a mini-hydroelectric power plant for seasonal base load at the main campus of University of Abuja, along Airport Expressway, Abuja, Nigeria. The study was premised on the need to mitigate the insufficient electricity supply being experienced by the University. The use of backup diesel and petrol generating sets was noted to increased the overall operating costs of the University due to the need to purchase fuel, in addition to the associated maintenance cost. The presence of River Wuye within the University brought to fore the need to explore the establishment of a hydropower plant as an alternative means of mininmizing the energy shortage. The methodology adopted included determination of the University electricity demand using clamp-on meter, determination of the river run-off via data obtained from Nigerian Meteorological Agency (NIMET), flow rate with the use of float and river geometry, while the head was obtained by Global Positioning System (GPS). Furthermore, the hydroelectric power potential, site layout for equipment installation and project cost were determined. The results indicated that the monthly lowest energy consumption (base load) at the University during the period of study was at 667 kW, while the highest (peak) load was 883 kW. River Wuye assessment favoured conventional hydro power plant instead of hydro power plant technologies with out dam such as paddle wheel system as Giri river flow was low and seasonal. River Giri has run-off of 1,330 mm with the proposed dam estimated to have height and length of 10 m and 120 m, respectively. River Wuye has a flow rate of 14.5 m3/s, maximum head of 10 m and hydropower potential of about 855 kW. The cost of the proposed hydro power plant ranged from 80.3-615.6 million Naira (N) (equivalent to N93,960/kW- N720,000/kW or $261/kW-$2000/kW).The range arose due to variation on cost of refurbished or new turbine-generator system and civil works. The electricity generation unit cost from the hydropower plant is expected to be N24.74-50.14/kWh. This feasibility work is significant as it will aid commencement of detailed project report (DPR) that will highlight detailed study of hydrology and geology, environmental impact assessment, flood control and weir structures for a hydropower plant on River Wuye at 885 kW. In addition, when River Wuye has low flow, wind and solar power plants could be deployed to provide the shortfall in electricity supply to the University

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1.0 Introduction

Electricity generation from flow of river is a clean and environmentally friendly renewable energy source. Hydropower system relies on the kinetic and potential energies in flowing river (Abebe, 2014). Hydropower plant as a renewable energy system has continued to be a major contributor to the energy mix of Nigeria (Zarma, 2006). Hydropower plant is currently the least expensive source of electric power and is much cleaner than power generated from fossil fuel. Hydro power plant has remained a leading energy technology for isolated rural locations and is reliable; particularly for steady minimum electrical energy consumption in a period in a facility (base load). Conventionally, the decision to establish a hydropower plant depends on an outcome of feasibility study. The economic evaluation of the hydro power by levelized cost of electricity (LCOE) will guide choice of unit energy cost for returns on the project and level of profitability between other alternative energy sources (FICHTNER, 2016). LCOE is useful to estimate future cost of electricity from a proposed hydropower plant. Feasibility of hydropower also involves study of natural conditions such as topography, hydrology and energy potential that will aid commencement of detailed project report (DPR). Detailed project report includes extensive study of hydrology, geotechnics, water quality, environmental impact assessment, flood control and weir structures, turbine-generator and power house, layouts among others. Feasibility and detailed project reports are initial two stages, which are followed by tender and construction in development of a hydropower plant.

Hydropower plant technologies without dam and the conventional hydropower plant with dam are choices available in feasibility decisions. Hydropower plant without dam includes paddle wheel hydropower plant that produces electric power out of flowing river (Akinyemi and Liu, 2015). The paddle wheel hydropower plant without dam, has easily rotatable pairs of paddle wheel by river flow and anchored in a river while water passes through the equipment. The kinetic energy of river rotates the paddle wheel with high torque at their axes. The rotating paddle will then drive a synchronous generator to produce electric power. Another variant of a hydropower plant without dam is the turbulent hydropower plant. This technology involves the installation of a basin into which is lowered a generator. The river then flows through the associated canal into a turbine and produces energy as long as the river is flowing. The hydro power plants without dam needs floating platform and are useful in hill regions with rich water source (Magureanu *et al.*, 2011).

Conventional hydro power plants on the other hand require some levels of heads to establish a dam. The water in dam enters into turbine through a penstock or pipeline with valves to regulate flow (Figure 1). Water is returned to river at the down-stream of a turbine through a tail race with minimum wastage, after the energy had been extracted as it passes through the turbines. The generator transfers electricity to a step-up transformer for transmission to the area where the electricity is needed. The turning shaft of the turbine leads to the generation of electricity with regulated voltage and frequency (Figures 1 and 2).

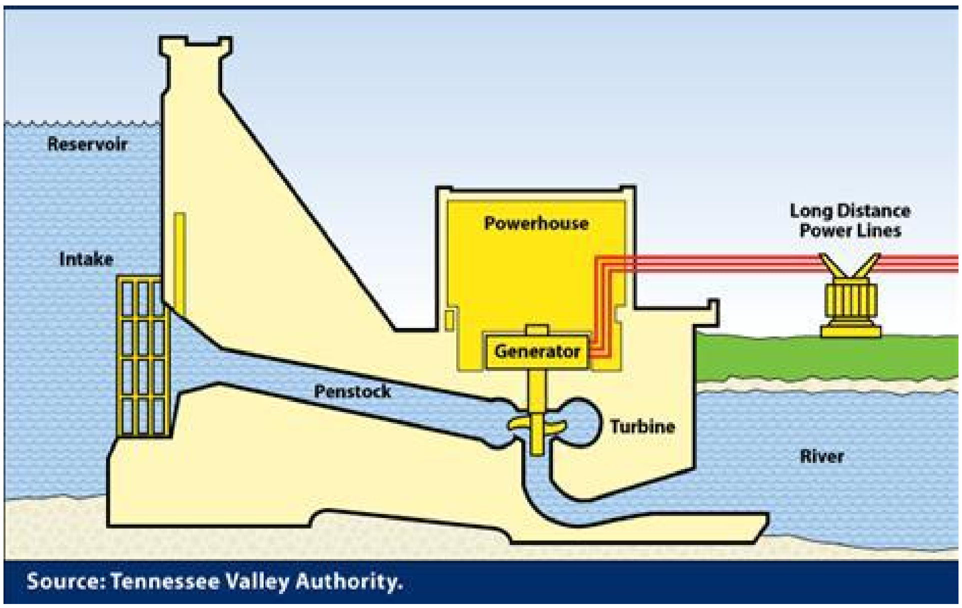

Figure 1: A schematic diagram of hydro power plant (Johnson *et al.*, 2012).

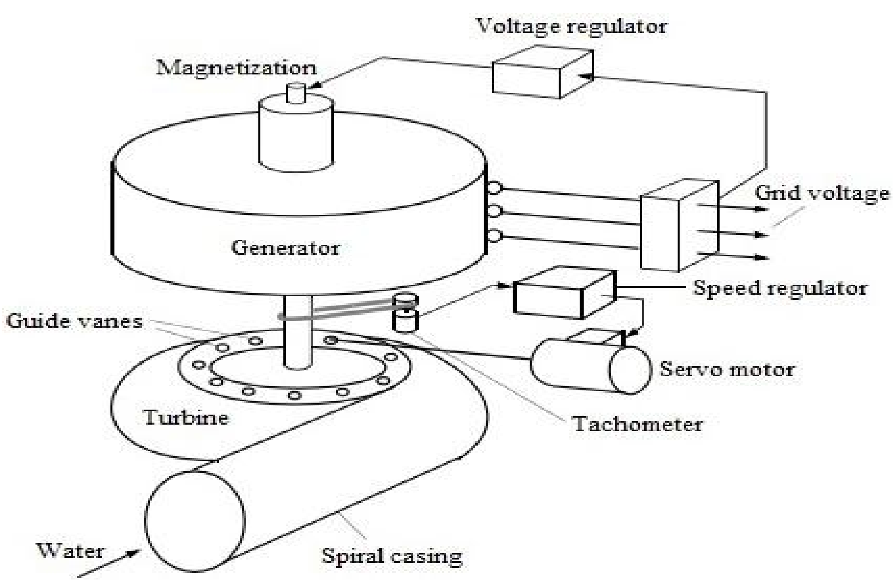

Figure 2: A schematic diagram of turbine-generator system (Haugen, 2013).

The first sets of hydropower plants in Nigeria, were established in North Central Nigeria, on the *Sanga* River system at *Ankwil* I (1MW), *Ankwil* II (2 MW) and *Kurra* (8MW) in 1929. Nigeria has well established and fully operational hydropower plants at Kainji (760 MW) commissioned in 1968; at Jebba (570MW) commissioned in 1984; at Shiroro (600MW) commissioned in 1990 and many others as reported by Zarma (2006). Sizes for small hydropower plants in various capacities such as small (l- 10 MW), mini-hydro (0.5 - 1MW), micro-hydro (50 to 500 kW) and pico-hydro (0- 50 kW), are found across Nigeria (Adejumobi *et al.* 2013). Available head between reservoir and tail race levels can be used to classify a hydropower into classes such as low head (H < 30 m), medium head (30 m < H <100 m) or high head (H >100) as stated by Rao and Parulekar (2004). Nigerian landscapes, therefore, has great potential for more hydropower plants on account of her numerous rivers, to increase her electricity generation from hydro power plants into the national grid. The proposed location of weir on River Wuye at Giri is as shown in Figure 3.

Figure 3: River *Wuye* at *Giri*, Abuja, Nigeria

The study area is located within Abuja, Nigeria (Figure 4). The main user of the proposed hydro power plant is the main campus of the University of Abuja, located along Airport-*Giri* Expressway, Abuja. *Giri* mean temperature ranges from 21ºC to 34ºC within the period of the study (NIMET, 2016). River *Wuye* is normally affected by the rainy, harmattan and dry seasons resulting in fluctuations occurring in its flow. Seasonal rainfall prediction is useful in renewable energy studies particularly in the design of hydro, wind and solar power plants as reported by NIMET (2016) and Odeh (2014). River *Wuye* traverses the University land at *Giri* bounded by longitudes 7º09'54''E and 7º10'38''E and latitudes 8º59'13''N and 8º59'49''N. The river flows into River *Usuma*, which is a tributary of River *Gurara* (Dikedi, 2012).

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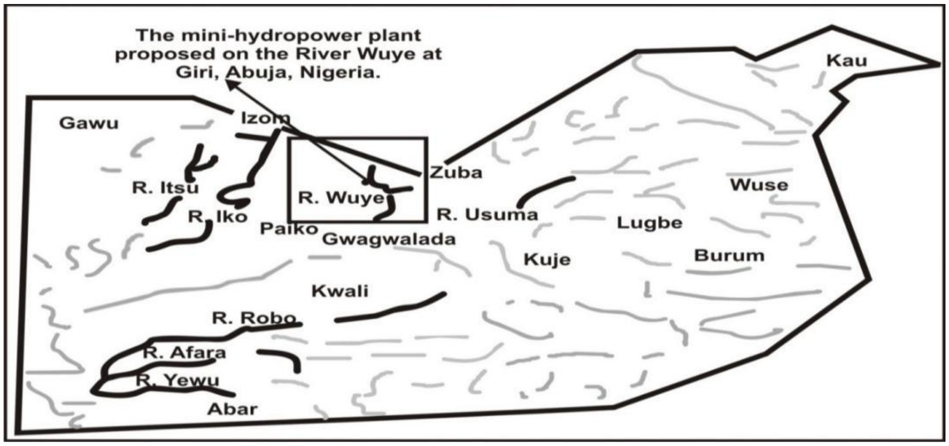

Figure 4: River *Wuye*, *Giri*, Federal Capital Territory, Abuja, Nigeria (Dikedi, 2012).

Nigerian Meteorological Agency (NIMET, 2016), has several weather stations with rain gauges and mercury-in-glass type thermometers that measures rainfall and temperature, respectively. The records of both rainfall and temperature against time, are useful in the generation of river run-off, flow duration curves as well as storage capacity for dams (Rajput, 2012).

The Nigerian Rural Electrification Agency reported in an energy audit that 37 Nigeria Federal Universities and 7 University Teaching Hospitals, use over 1,068 diesel electricity generating sets to provide electricity in their campuses (REA, 2018). The electricity supply from the national grid does not meet the needed energy for various activities in the University of Abuja. This is compounded by load shedding, power outages and high costs of fuel and maintenance for backup electric generators, in addition to air and noise pollutions (Ezema *et al.,* 2016).

The aim of this study is to develop feasibility study for the establishment of a hydropower plant on River *Wuye*, at *Giri*. The objectives are: the determination of the electricity demand of the University of Abuja; estimation of River *Wuye* run off and hydrology in *Giri*, Abuja; determine the characteristics of the hydro power plant (riverflow rate, head, capacity) and outline the plant layout as well as carry out the economic analysis of the hydro power plant

2 Methodology

2.1 Electricity Demand of the University of Abuja

The estimated energy load was determined based on a walkthrough audit of the electrical supply to buildings using clamp-on meter of model 605 with accuracy of ± 2%, for example, 17.63 ± 0.35A (AEMC, 2012). The current in conductors were measured with clamp-on meter according to procedures described by AEMC (2012). Also, taken were records of installed electrical equipment and appliances ratings and the periods energized per day in all faculties/units, according to procedures reported by Gul and Patidar (2015) and Delmastro *et al.* (2016).

2.2 River Run-Off and Hydrology of Giri, Abuja

The river run-off and hydrology provides insight into amount of water available and seasonality for prediction of energy generation at the potential site for hydropower plant.

2.2.1 River Giri Run-off Estimation

Rainfall and temperature data for *Giri*, Abuja, were obtained from Nigerian Meteorological Agency (NIMET, 2016) and adopted for this work. River run-off was determined using equation (1) as follows (Rajput, 2012):

$$R = F - 4.811T \quad (1)$$

where:

R is the annual run-off in the area in mm,

F is the annual rainfall (mm) and

T is the mean monthly temperature (^oK)

2.2.2 Hydrology of Giri Area

The characteristics of the River Wuye discharge and storage capacity at the Giri, for the proposed hydropower plant was evaluated by flow duration curve (FDC) according to the procedures outlined by Rajput (2012) and Karki (2014). The FDC to determine the storage capacity was carried out by Ministry of Water resources, Abuja (FMWR, 2014) and was adopted for this work.

2.3 The Characteristics of the Proposed Hydro Power Plant.

The specifications of hydropower plant covered in this work were river flow rate and head of River Wuye at *Giri*, Abuja as well as theoretical and available hydro power.

2.3.1 Measurement of River Flow Rate

The river flow rate was determined with the use of a half-filled plastic bottle with water as float with accuracy of readings at ± 5% (Michaud and Wierenga, 2005). Tools such as a measuring tape, stakes, and a stop-watch were used. The river length was traversed by the researchers,

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during the period of study, with particular interest on the river bank, breadth and geometry to identify likely location for weir, upstream and downstream facilities An equal interval of distance were marked along the length and across the river profile. On the river speed measurement, intervals along the river length were taken for float travel. As the float were released on the river, stop-watch was used to record time for the float to travel from one location to other, within the interval. The river speed measurements were also repeated three times at three interval along the breadth of the river. The time it takes the float to travel on the river through a designated distance were recorded. On completion of the speed measurements at first interval, the process were repeated for several intervals established along the river. Thereafter, mean of the river speed were calculated.

The cross sectional area was taken between consolidated banks at three equal interval across the river. The depths occupied by the river during the period of study, were measured vertically across the breadth of the river at each interval along the river. The measurements of the mean river speed by the float and the river cross-sectional area were calculated as follows (Nasir, 2014):

$$V_R = C\frac{D}{t} \tag{2}$$

where:

D is the distance between two stakes to demarcate a segment along the river (m)

t is the time taken for the float to travel from stake 1 to stake 2 (s).

C is the correction factor that ranges between 0.6 and 0.85, depending on the river course, bottom and bank.

The cross-sectional area was given as (Nasir, 2014):

$$A = (\frac{a+b}{2})(\frac{h_1 + h_2 + h_3 + ... + h_k}{k}) \tag{3}$$

where:

a is the width at the top of the river (m),

b is the width at the bottom of the river (m)

h is the height measured on the stake (m),

k is the number of stakes placed between the distance (interval)

$(\frac{h_1 + h_2 + h_3 + ... + h_k}{k})$ is average height (m)

River flow rate was obtained as follows:

$$Q = AV_R \quad (4)$$

where:

A is the cross-sectional area of the river (m^2),

V_R is the river speed (m/s)

2.3.2 Measurement of Head along the River Course for the Hydro Power Plant

Hand held Global Positioning System (*GPS*) was used to determine the head along the river course at measurement accuracy of 0.4 mm (Nasir, 2014). The gross head was measured at a predetermined position on top of the stake. The GPS model 12 Garmin, was switched on when at location one, then page button was pressed to display positions after booting. The positions displayed includes Northing, Eastening and elevation at interval one, which were read and recorded. The GPS was moved again to location two, location three up to the end and the process repeated to take readings and were recorded. Thus, the elevations at equal distances formed a profile along the path of the river including proposed weir and turbine locations. The difference in elevation measured in meters from one interval to the other interval, were read and recorded as the height difference. The head (height dfference) at each stake were added together to determine the gross head. The gross head was evaluated using the following expression:

$$H_g = h_2 - h_1 \quad (5)$$

where:

h_2 is the height of the river surface level at the intake (m) and

h_1 is the height at the top of tail-race downstream (m)

The net head was determined as follows:

$$H_n = H_g - H_L \quad (6)$$

where:

H_L is the head losses along flow path. This was taken as 10% of the gross head from an average of 5 to 15%, depending on pipeline length, number of bends, valves and the velocity of flow (Williams, 2003).

H_g is the gross head (m)

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2.3.3 Available Hydro Power in River Wuye at Giri, Abuja

Theoretical power available on the River *Wuye* at *Giri* was given as follows (Rajput, 2012):

$$P_{th} = \rho g Q H_g \tag{7}$$

where:

ρ is the density of water (kg/m^3),

g is the acceleration due to gravity (m/s^2)

Q is the flow rate of the river (m^3/s)

H_g is the gross head (m)

The overall efficiency for the hydropower plant was expressed as follows (Rajput, 2012):

$$\eta_o = \eta_1 \times \eta_2 \tag{8}$$

where:

η_o is the overall efficiency

η_1 is the efficiency of pipelines and intake in the upstream

η_2 is the efficiency of turbine-generator system

The actual power capacity of the hydropower plant (Rajput, 2012):

$$P_{act} = \eta_o \rho g Q H_g \tag{9}$$

where:

η_o is the overall efficiency

ρ is the density of water (kg/m^3),

g is the acceleration due to gravity (m/s^2)

Q is the flow rate of the river (m^3/s)

H_g is the gross head (m)

2.4 Plant Layout and Economic Analysis of the Hydropower Plant

2.4.1 Layout for the Hydro Power Plant

Plant layout aims to optimize the size of the hydro power plant to the unique natural conditions, technical and economic factors to efficiently exploit the available hydro power. The layout for the hydropower plant were made according to the procedure for diversion of scheme to exploit a higher head for a low head schemes as outlined by FICHTNER (2016). A walk-through survey of the proposed weir and turbine locations was carried out. Consideration was given to dimensions of turbine-generator systems and the electricity supply to the load centres (Singal and Saini, 2007).

2.4.2 Project Worth based on Total Cost and Actual Hydropower Capacity

The costs in this work were obtained from cost analysis for hydro power template provided by Williams (2003), IRENA (2012) and FICHTNER (2016), which were converted into Nigerian currency (Naira). The costs were for small hydro power plant in Africa as provided by UNIDO (2010). The evaluation of power worth (P_W) were calculated as follows:

$$P_w = \frac{T_c}{P_{act}} \tag{10}$$

where:

P_W is the power worth in the hydropower plant (₦/kW)

T_c is the total costs of the hydropower plant (₦)

P_{act} is the actual power in the hydropower plant (kW)

2.4.3 Economic Analysis of the the Hydropower Plant

The economic evaluation of the hydropower plant was based on levelized cost of electricity (LCOE). The data to the calculate the LCOE of hydro power plant were generated from this work while data for solar PV power plant were obtained from Oodo *et al.* (2017). LCOE model utilizes net present value (NPV) that incorporates capital (Capex) and operating costs (Opex) and were calculated with a discount rate (r) for the lifetime (eqn.11). The spreadsheet computation of LCOE was carried out according to procedures outlined by Singal *et al*. (2010) and FICHTNER (2016):

$$LCOE = \frac{NPV_{\cos t}}{NPV_{Gen}} = \frac{Sum\ of\ \cos ts\ over\ lifetime}{Sum\ of\ electricity\ generation\ over\ lifetime} = \frac{\sum_{t=1}^{n} (\frac{Capex_t + Opex_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{11}$$

where:

LCOE is the levelized cost of electricity (₦/kWh)

$\sum$ is the summation of costs or electricity generation over life time

n is the lifespan of the hydropower plant at 60 years

r is the discount rate (%)

t is the increment in years

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E_t is electricity generation at t years (kWh per year)

$Capex_t$ is the total capital or investment costs at t years (₦ per year t)

$Opex_t$ is the total operating including maintenance costs at *t* years (₦ per year t).

3. Results and Discussion

This section presents the results and discussion in both tabular and graphical forms for the hydro power plant at the main campus of the University. Also included were River *Wuye* run-off, head and flow rate at *Giri* region as well as the hydropower plant capacity, the layout and the energy unit cost.

3.1. Electricity Demand of the University of Abuja

The main campus of the University is on a land space of over 11, 800 hectares. The presently occupied area was less than eight hectares having over 12 distinct building complexes with a centralized electricity supply meter. There were sub-meters at specific points of service, that record energy consumed at faculties/research buildings with energy intensive equipment as shown in Table 1. The sub-meters were in two parts, one to record power into the buildings and the other measures demand from the equipment. The equipment was separated by their kilowatts particularly for electric motors, lightings, appliances and electronic devices. This division was similar to the work by Menezes *et al*. (2014). Laboratories, workshops, and hospital consumes large quantities of energy, often two to three times more than the faculties with offices and classrooms only as shown in Table 1.

Table 1. Estimated Electrical Energy Consumption in University of Abuja as at August, 2015

S/N	Faculties/units	Motor Pump	Heat. Weld	Air con	Fridge freeze.	Comp. laptop	copiers, printers	Lamp Bulbs	Fan TV	Halogen	Total load
	kW	1-10	1- 5	1-5	0.1-0.4	0.050-0.3	0.2-0.4	0.040-0.2	0.040-0.3	1.2-2	kW
1	Agriculture/ Farm	9	7	20	16	47	13	120	66	10	450
2	Arts	2		37	19	67	17	156	81	8	450
3	Health/clinic	6	6	46	31	60	21	170	97	13	900
4	Education	2		38	32	72	19	178	82	12	450
5	Management Sciences	2		27	19	67	17	156	81	13	450
6	Engineering /workshops	25	14	30	16	56	12	130	75	14	900
7	Law	2		21	19	67	17	156	81	9	450
8	Social Sciences	2		23	16	64	23	172	56	8	450
9	Sciences	4	3	30	17	59	17	173	63	11	450
10	Veterinary Medicine	2	6	26	31	60	21	89	67	13	450
11	Post graduate			10	6	12	6	34	12	8	
12	Senate building	9	5	67	56	93	45	220	87	18	900
13	Mini-hostels	3	78			79		320	289	22	900
14	Main-hostels	3	67			121		350	312	25	1080
15	Staff Quarter	8	16	12	16	14	34	45	28	12	1440
16	Mini campus (Academic)										4050
17	Water pump station/street	3									360
18	Others										450
	Total										**14580**

The University of Abuja average monthly peak and base loads, in 2015, were about 883 kW and 667 kW, respectively as shown in Figure 5. These peak and base loads are from one energized 7.5 MVA/33 kV/11 kV injection substation with over twenty distribution transformers of 11 kV/414 V at capacities of 1000 kVA, 500 kVA and 300 kVA. The University had three 7.5 MVA/33 kV/11 kV injection substations, which is sufficient to meet future demand, but will need additional distribution transformer substations.

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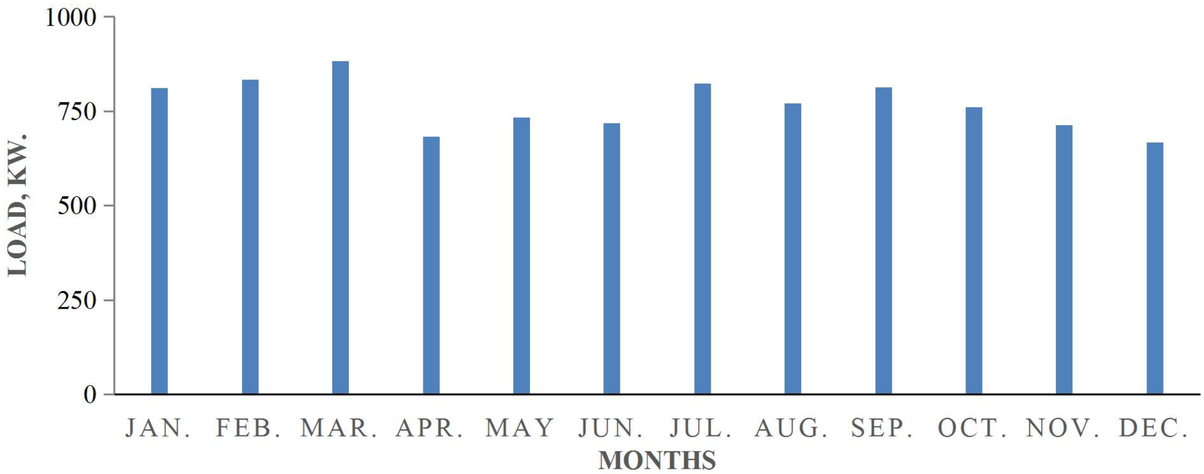

Figure 5: Average monthly load profile at University of Abuja, 2015

3.2 River Run-Off and Hydrology of *Giri*, Abuja.

The data obtained from NIMET weather stations were computed from January to December, 2015, as shown in Table 2. The rainfall season spans from April to November, with 60% between months of July and September, yearly. Hence, the excess river flows will be useful for storage in the proposed dam for the hydropower plant. In Table 2, it was observed that *Giri* area had an average mean temperature of 27.3^oC while the rainfall was approximately 1,460 mm annually with river run-off of 1,330 mm in catchment area of over 30 km^2. River *Wuye* at *Giri* will require little modification to the landscape and no resettlement as the river course is within the University and guided her master plan. The likely changes to the landscape and river flow regime will have little effects to the habitats and ecosystem in the life of the hydro power plant.

Table 2: Rainfall and temperature prediction in *Giri*, Abuja (NIMET, 2016).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	0	0	20	60	140	220	260	300	300	140	20	0
Temp (^oC)	27.6	29.3	30.2	28.9	27.3	26.0	25.1	25.2	24.9	26.3	26.9	26.7

During the study, River *Wuye*, was noticed to have annual pronounced wakes and eddies from May to October, caused by boulders on the bed along river course. This scenario is similar to report of some rivers classified as suitable for hydropower by Abebe (2014). It is generally appreciated that bedrock on river course with consolidated banks enhances earth dam as reported by Rajput (2012). The proposed dam at *Giri*, has aforementioned attributes. The specifications of proposed earth dam were estimated to have height of 10 m, maximum dam core height of 8.0 m, and dam lenth length of 120 m with accessories such as spillway for intake capacity of 4, 000 m^3 (FMWR, 2014). The river when dammed for the hydropower plant, will generate electricity as well as provide water for the University. Furthermore, the addition of a matching water treatment plant on the proposed dam of 4,000 m^3 storage capacity, will have a flow rate that will exceed, 50 m^3/h, previously obtained in the package treatment plant for the University Staff Quarters at *Giri*, Abuja, as reported by Dikedi (2012). The water stored in the dam will be regulated to sustain the energy generation and to regulate flood. Strong seasonal flow variations with strong peaks during rainy season will require reinforced construction works to protect dam structures and installations. Apart from flooding that requires control, excessive sand affects turbine systems with resultant high wear rates and maintenance costs of the hydropower plant, hence periodic desilting of the dam will be necessary. Thereafter, when the river flow is low, wind and solar power plants could be deployed fully to take over from the hydropower plant as base load (Hussein *et al.,* 2016).

3.3 The Characteristics of the Proposed Hydropower Plant.

River *Wuye* at *Giri* does not dry completely even during dry season but it has minimum flow during the period of November to April yearly. The specifications of the hydropower plant on River *Wuye* at *Giri*, Abuja, includes river cross-sectional area of 16.9 m^2. The river speed of 0.86 m/s was an average taken during the year. Based on the flow rate of 14.5 m^3/s, gross head of 11 m, head losses of 1m, overall efficiency of 0.6, net head of 10 m, theoretical power of 1.4 MW and actual power of 855 kW obtained from the computation on River *Wuye* at *Giri,* Abuja. A horizontal tabular turbine for the mini-hydro power plant at 855 kW, was selected. River *Wuye* at *Giri* has similar characteristics to some of the rivers in neighboring Niger State, earlier reported by Rufai *et al.* (2012). These rivers in Niger State have flow rates that were found in the ranges of 13 m^3/s to 18 m^3/s except River *Swashi* calculated to have a flow rate at 6 m^3/s as reported by Rufai *et al.* (2012). Similarly, some of the dam heights range from 17- 100 m and the lengths range from 100- 2000 m as reported by Rufai *et al.* (2012). There are several hydropower potentials in Nigeria, with heads ranging from 1.5 to 72 m that are expected to power turbo or Kaplan turbines as suggested in the work of Adejumobi *et al.* (2013). In addition, there are some small hydropower plants that have been completed in some locations in Nigeria. These include two hydropower plants of 200 kW each in Taraba State, two hydropower plants of 75 kW each at *Waya* dam in Bauchi State and a hydro power plant of 30 kW at Ezioha-Mboro dam, Enugu State as reported by UNIDO (2010).

3.4 Plant Layout and Economic Analysis of the Hydro Power Plant

The plant layout for the placement of components that constitute the hydropower plant on the river course, is shown in Figure 6. The components of the hydropower plant are numbered from 1 to 14 on the drawing with their description in the attached legend. From Figure 6, River *wuye* flows from *Suleja* to *Giri,* where the hydropower plant will be located and, then towards *Gwagwalada*, on its journey to River *Usuma* and onwards to River *Gurara* in Kaduna State. The layout depends on size of civil works, dimension of runner diameter of turbine and turbine-generator system. The layout have effects on overall cost of the hydro power plant as stated by Singal and Saini (2007).

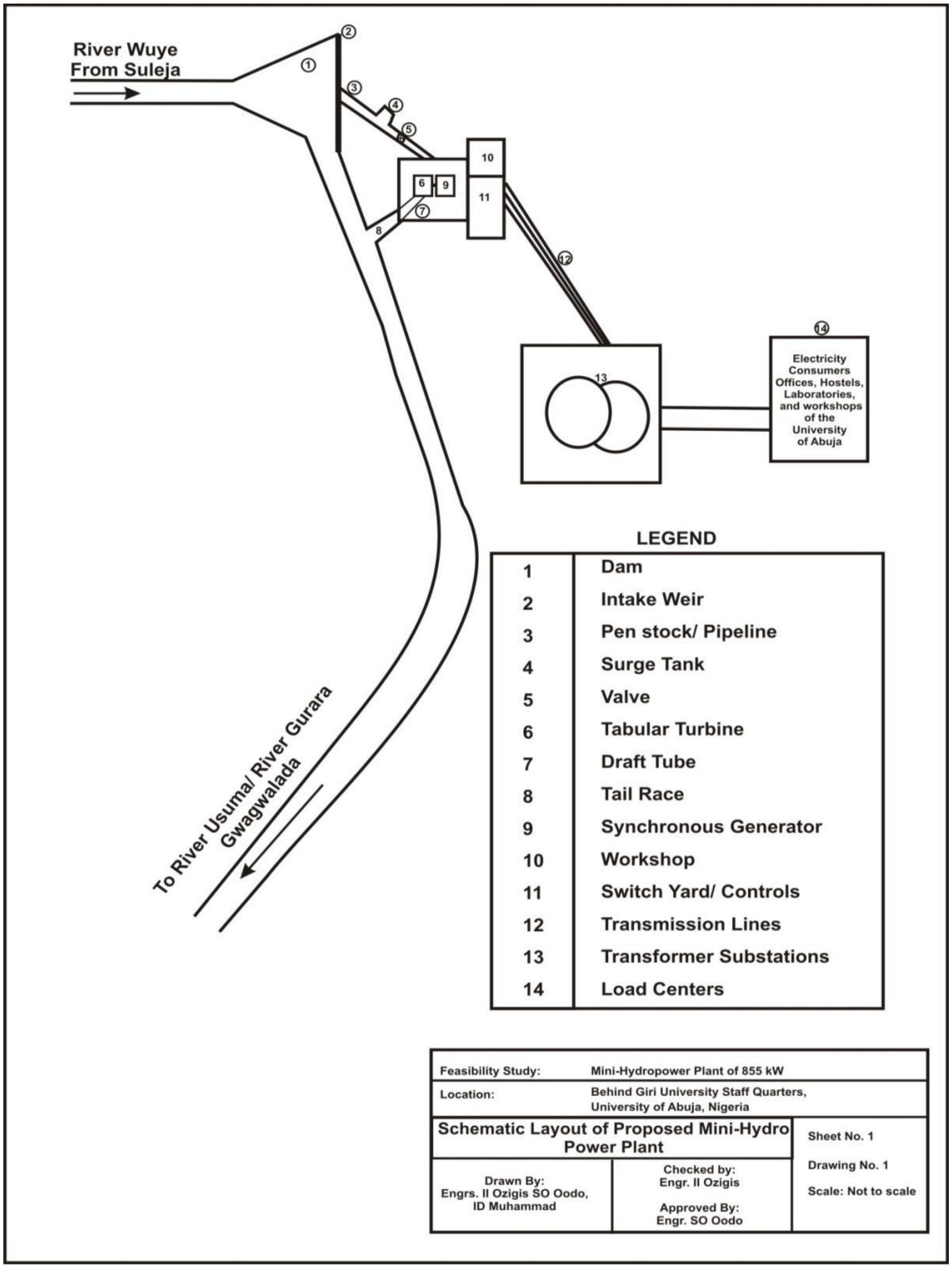

Figure 6: Schematic layout of the proposed hydro power plant at *Giri*, Abuja, Nigeria

The estimated cost for the hydropower plant of 855 kW was at ₦78.5 Million as shown in Table 3. The low cost for the hydropower plant at ₦93,960/kW ($261/kW at conversion rate of US$1= N360.00), arose due to the intended use of labour and materials for the construction. The local materials include laterite, clay, aggregates and boulders obtainable from the University land and source procurement from off-shore of a refurbished turbine-generator instead of a new turbine generator sets. Similarly, UNIDO (2010) reported that the cost of the hydro power plant per kW ranges from ₦93, 960.00 to ₦720, 000.00 ($261-$2000)/kW in some African countries. However, Johnson *et al.* (2012) stated that some small hydropower plant total project costs can be up to $2,000/kW or more, depending on specific site characteristics. Compared to Johnson *et al.* (2012)'s work, with reasonable interpolations, the cost of the hydropower plant with a new set of turbine-generator and pipeline system could be up to ₦600 million ($1.7 million) for hydropower plant at 855 kW. In Table 4, the estimate for the hydropower plant shows that the cost of equipment installation is half the equipment cost while earth dam and pipeline costs are equal to equipment cost. The cost estimates for some small hydropower plants reported by Johnson *et al.* (2012), has similar trend. According to UNIDO (2010), it should be appreciated that as power increases, the overall cost also increases due to extra cost as a result of the addition of electric poles, step-up and step-down transformers, transmission lines, particularly when distances are over 100 m.

Table 3: Estimate of minimum costs of components and project worth of the hydro power plant

S/N	Description (*UNIDO, 2010)	% of Total	Cost (₦)
1	Project development, engineering, environmental, social, licenses, permits and legal costs	7.2	5,784,178.00
2	Civil Works(acess road, intake, weir, tailrace, pipelines, power house)	46.3	37,167,900.00
3	Electro-mechanical equipment (Turbine, governor, valves, generator, controllors, hydraulic structures)	31	24,904,098.00
4	Other equipment and non-equipment (workshop, tools)	1.3	1,044,365.00
5	Grid connection (switchyard, transmission lines, transformers, and installation)	4.2	3,401, 679.00
	Sub-total (1-5)		**72,302, 220.00**
6	Contingencies @10% of above sub-total	10	8,033,580.00
	Total project cost		**₦80,335,800.00**
	Project unit worth		**₦93,960.00/kW**

Levelized cost of unit energy are affected by discount rate as shown in Figure 7. The computation of LCOE on spreadsheets used the assumptions on Table 4. At the same discount rate, the LCOE was higher for the solar PV power plant on account of high operating costs and lower capacity factor when compared to hydropower plant of similar name plate capacity as shown in Figure 7. The LCOE for the hydro power plant ranges from ₦24.79 to ₦50.14/kWh while LCOE for solar PV power plant ranges from ₦70.74 to ₦118.58 kW/h, as against tarrif rate of ₦29.81/kWh by the Abuja Electricity Distribution Company, Abuja, in November, 2017. According to UNIDO (2010), electricity unit cost in East and Southern Africa is within the range of US cents 3.1 - 20/kWh (₦11- ₦72/kWh). However, in most countries, the hydro and solar power plant's energy unit cost were generally in the range of US cents 5 - 10/kWh and US cents 40 - 60/kWh respectively, as separately reported by UNIDO (2010) and Sener and Aytal, (2017). Similarly, Operating and maintenance costs of hydro and solar power plants were reported to be about $14.13/kW and $13.08/kW per annum, respectively, by IRENA (2012).

Table 4: Assumptions for the Economic Analysis of the Hydropower Plant

S/N	Hydro. Model Direct Inputs	Value	Description and/or Justification
1	Capex: Capital Cost (₦)	347,950,000.00	*Corbetti Model*
2	Opex: Operations Cost (₦/year)	22,555,000.00	*6.5% of pfront Investment per year*
3	E: Electricity Production (kWh/year)	3,471,984.00	*Actual Electricity Generated based on NC, CF and Hrs/Year*
4	r: Discount Rate (%)	10.00	*Discount Rate approximated by WACC for business project*
5	n: Lifetime (years)	60.00	*Average Lifetime of a small hydro Power Plant*
6	Tarrif Rate (₦/kWh)	29.81	Abuja Electricity Distribution Company, Abuja, in November, 2017
	Hydro. Model Indirect Inputs	Value	Description and or Justification
7	Nameplate Capacity (kW)	855.00	*Corbetti Model & Basis of Comparison*
8	Capacity Factor (%)	47.00	*Average Capacity Factor of small hydro power plant in Africa according to UNIDO (2010)*

Note average capital cost of small hydro power plant from UNIDO (2010).

$$Capital\ cost = \left(\frac{Maximum\ cost + Minimum\ cost}{2}\right) = \frac{(N615,600,000 + N80,300,000)}{2} = N347.95\ Million$$

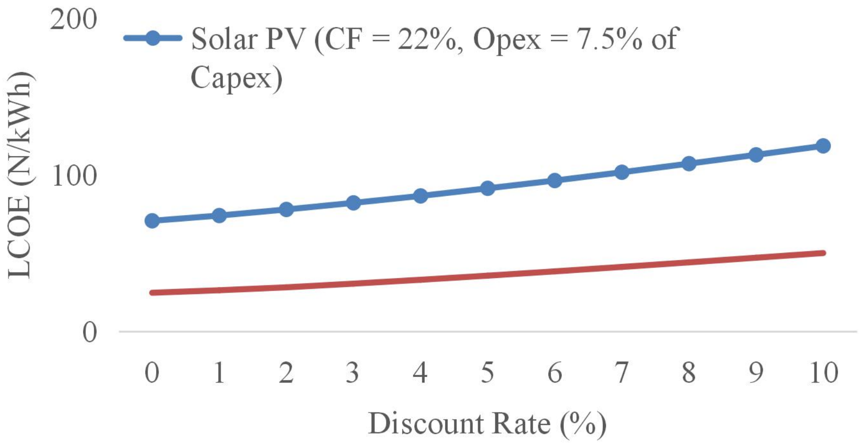

Figure 7: Effect of Discount rate on LCOE in Hydro Power Plant and Solar PV Power Plant

4 Conclusion

From the investigations carried out on the feasibility of a mini-hydropower plant on River *Wuye* at *Giri*, for main campus of the University of Abuja, the following conclusions were drawn:

The electricity demand at the University of Abuja, were determined to have base and peak loads of 667 kW and 883 kW, respectively, during the period of study.The run-off from rain records was 1330 mm, with the estimated dam height, maximum core height, dam length and reservoir at 10 m, 8 m, 120 m and 4,000 m^3, respectively. Based on the flow rate of 14.5 m^3/s, maximum head of 10 m and the layout, a horizontal tabular turbine for the mini-hydro power plant at 855 kW, was selected.The cost of the hydro power plant ranges from ₦80.3 million to ₦615.6 million equivalent to ₦93,960/kW- ₦720,000/kW or ($261/kW-$2000/kW), depending on refurbished or new turbine and generator system as well as the extent of associated civil works.The electricity energy unit cost for the hydropower plant was ₦24.74- ₦50.14/kWh at maximum discount rate of 10%.

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