**American Journal of Renewable and Sustainable Energy**
Vol. 3, No. 3, 2017, pp. 15-26
http://www.aiscience.org/journal/ajrse
ISSN: 2381-7437 (Print); ISSN: 2381-7445 (Online)

# Technical Feasibility of Proposed Aku-Dam Small Hydropower Project

**Obinna Ajala CHINYERE[1, *], Emmanuel Adewale AJANI[1], Emmanuel Osiewundo OJO[1], Fidelia Ifeyinwa MADUKA[1], Nkiru Rosemary OBASIH[2], Edward Udoka MAFIANA[1]**

[1]Department of Engineering Infrastructure, Renewable Energy (Small Hydropower) Unit, National Agency for Science and Engineering Infrastructure (NASENI), Idu, Abuja, Nigeria
[2]Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria

## Abstract

Proper feasibility analysis is key to the success and sustainability of Small Hydropower projects (SHP) as the feasibility studies serves as a guide wither such projects should be embarked upon, as well as a preventive tool against such projects failure, breakdown or even abandonment. The Technical Analysis of Aku (SHP) project was investigated. In appraising the technical analysis, the flow, head and power to be generated were considered. The Aku river flow was measured during the peak of dry season using velocity area method to estimate a dry season flow of 2.75m$^3$/s, while the head of the river 7.9m was gotten using a digital altimeter, producing an estimated run-off power of 152.1kW from calculation. A Load estimate of 639.013kW of Aku surrounding villages was gotten using the National Centre for Energy Efficiency and Conservation(NCEEC) standard which was a far cry from the run-off generation capacity of 152.1kW, hence the adoption of the dam-toe scheme, to meet the power requirement of Aku load demand. The flow duration curve shows that the flow of 0-3m$^3$/s is available 97% of the year, while 5m$^3$/s the approximate design flow for the dam-toe model is available 85% of the year. The penstock economic diameter and length of 2.58m and 127m respectively will be suitable for the scheme from calculation, while the use of charts and tables guided the selection of two units of Kaplan turbine of 350kW each for the implementation of the scheme.

## Keywords

Technical, Feasibility, Aku-Dam, Small Hydropower

Received: March 24, 2017 / Accepted: April 19, 2017 / Published online: August 8, 2017

## 1. Introduction

The standard of living of a given country can be directly related to the *per capita* energy consumption. No country in modern times has succeeded in substantially reducing poverty without adequately increasing the provision and use of energy to make material progress [15]. Energy and poverty reduction are not only closely connected with each other, but also with the socioeconomic development, which involves productivity, income growth, education, and health [11].

Nigeria is a country where more than half of the population are living in remote and isolated rural communities without access to electricity and are using fuel wood, crop residues, etc. in meeting their energy needs [6]. This has resulted in deforestation and other environmental consequences e.g. sicknesses resulting from the in-door air pollution. In most cases the rural areas are far away from the national grid because of bad terrain and not so good access roads. Therefore, it is

---

* Corresponding author
E-mail address: obixi@yahoo.co.uk (O. A. CHINYERE), ajaniae@yahoo.com (E. A. AJANI), emmacyosy13@gmail.com (E. O. OJO), fidesmind200@yahoo.com (F. I. MADUKA), rovian2003@yahoo.com (N. R. OBASIH), mafianaedwardudoka@yahoo.com (E. U. MAFIANA)

unlikely that full rural electrification would be achieved through grid extension. But, in these same locations, there is abundant flowing water such as rivers, streams, waterfalls, irrigation canals, dams, that in some cases can be easily exploited using SHP technologies [6]. The Council for Renewable Energy of Nigeria estimates that power outages brought about a loss of 126 billion naira (US$ 984.38 million) annual [5].

The recent world's energy crisis is due to two reasons: the rapid population growth and the increase in the living standard of whole societies. The *per capita* energy consumption is a measure of the *per capita* income as well as a measure of the prosperity of a nation [14]. Sequel to this power crisis, Countries all around the world are trying to supply their increasing demands for electricity with clean energy technologies. Opportunities thrive in small hydropower (SHP) schemes development as a viable source of energy for electricity generation.

Inspite of abundance water resources that abound in all states and local government areas in Nigeria, hydropower remains an underutilized resources for electric power generation in Nigeria. Hydropower, a renewable and mature energy source utilizes water from higher to lower altitude to generate power [16]. HydroPower is one of the proven, predictable and cost effective sources of renewable energy. It is a renewable energy source suitable for rural electrification in developing countries like Nigeria. It is a proven technology that can be connected to the main grid, used as a stand- alone/ off-grid mode. Once constructed, Hydro plants require little maintenance over their useful life, which can be well over 50 years [7]. Hydropower system comprises of hydro source, diversion/storage system, water conductor system (channel/tunnel/house) Power house building, generating and control equipment [16].

Small hydro power scheme is defined as any hydro power installation rated between 100KW to 30 MW [3], however a common practice to refer to all hydro station with 30MW and below as Small Hydropower. 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 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 season, and very low discharges in dry season.

This work will address the technical feasibility of Aku SHP plant, taking advantage of the presence of an abandon Dam in the area. Basic objectives in mind to be achieved are to access key technical characteristics of the Aku River in terms of head, flow, river characteristics over a period of atleast twenty years flow data, and power to be generated, to carry out a load survey analysis of the energy demand of Aku Community and its environs, to determine the type of scheme to be implemented, energy generation, economic size of the penstock and type of turbine to be selected.

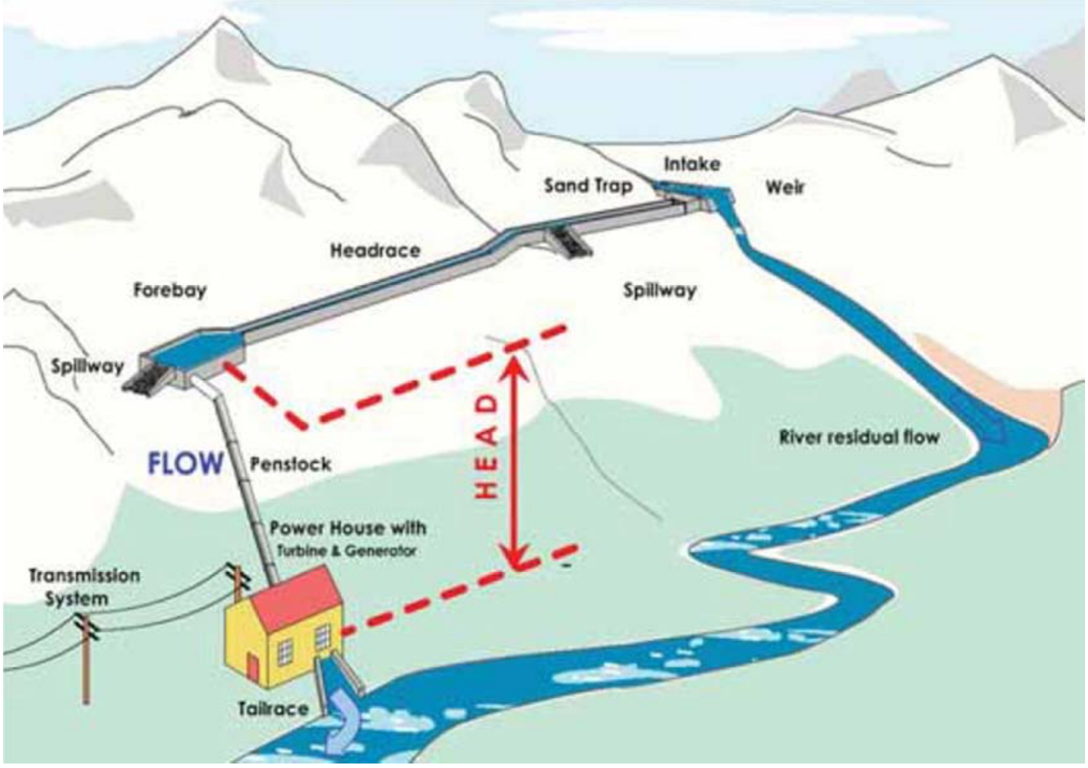


**Figure 1.** Typical arrangement of a Run-off Scheme [10].

# 2. Materials and Methodology

## 2.1. Study Location

River Aku also known as Eze Aku (Onuaku) is located in Uturu in Isuikwato Local Government Area of Abia State, Nigeria. It lies on coordinates 5°54'0" N and 7°33'0" E in DMS (Degrees Minutes Seconds) or 5.9 and 7.55 (in decimal degrees). The area is extensively a low-lying terrain of about 50 – 135m above sea level. The area is generally a level, gentle undulating plain with minor local topographic features of sand ridges and isolated intrusive of igneous origin. The Aku River is an all season river with the highest / full discharge during the rainy season. It flows south easterly and empties into Ivo River. Other rivers within the vicinity are Nwaomaiyi, Ikwa and Akwukwo which all empty into Ivo River.

## 2.2. Materials

The following materials/ instruments were used in accomplishing the objectives of this study. They include:

a) Contour/ topographic Map of Okigwe district to site Aku proposed site

b) Geographical Positioning System

c) Digital Altimeter (+/-1m to +/-5m)

d) Pink Ponk

e) 3.5m/ 12ft Measuring tape

f) 10mm Rubber Rope

g) Stop watch

h) Laptop Computer

i) Cutlass

j) Secondary data from magazines, textbooks, publications etc.

## 2.3. Methodology and Technical Characteristics of the River

The following are the procedures followed for different parts of this work.

The European Small Hydro power Standards (ESHA) was adopted for measurements of the stream characteristics due to their long years of experience and expertise on SHP installation.

**(i) Discharge**: The flow or discharge were gotten using velocity area method due to ease, and reasonable level of precision as shown in figure 2

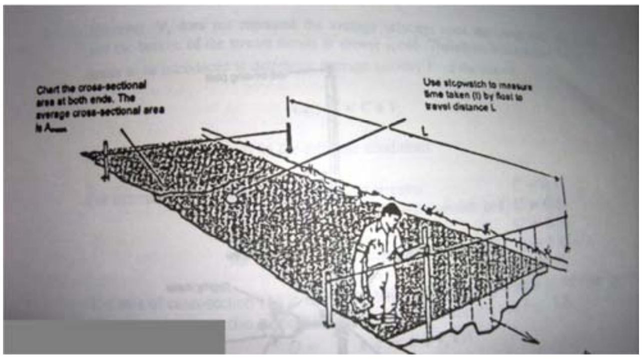


**Figure 2.** Flow measurements by velocity area method [1].

Measurement were taken from the upstream section of the Stream, at five different point of the stream, after which the average of the data is taken to calculate the flow, using [2]

$$Q = Avc \tag{1}$$

Where Q = discharge in $m^3/s$

A = cross-sectional area in $m^2$

$$A = (4d_1 + 2d_2 + 4d_3 + \ldots\ldots\ldots + 4d_n)\frac{w}{3} \tag{2}$$

v = Average velocity of flow in m/s

v = distance travelled/ time

c = correction factor which ranges from 0.25-0.85 [2]

(0.85- for smooth rectangular channel and bed, 0.75- for deep slow moving stream,

0.45-for quick turbulent stream, 0.25- for shallow rocky stream)

**(ii) Flow Duration Curve (FDC):** This is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest. They are used to show power equivalent of the flow that can be superimposed onto it, so that it is possible to read off the amount of time of the year that certain power levels can be obtained.

**(iii) Head**: Using an Altimeter (altitude meter) and a contour map of the site, the estimated gross head H, of the terrain were gotten, but if need arises for the deployment of the existing dam, data gotten from the depths of the dam will act as the head of the scheme, thus overriding the readings gotten from the altimeter.

**(iv) Power**: The objective of a hydropower scheme is to convert the potential energy of a mass of water, flowing in a stream (Q) with a certain fall (termed the HEAD), into electric energy at the lower end of the scheme, where the power house is located.

Hence, the power to be produced were gotten using a hydro power equation that has a relationship between flow and the head [7]

$$P = \eta \rho g Q H \tag{3}$$

where;

P is the power in watts

$\eta$ is the general efficiency of the plant

$\rho$ is the density of water in $kg/m^3$

g is the gravitational acceleration in $m/s^2$

Q is the discharge, passing through the turbine in $m^3/s$

H is the gross head of the water in m (elevation differences between the fore bay and the tail water)

$$P = 7QH \quad \text{where } \eta\rho g = 7 \text{ [7]} \tag{4}$$

**(v) Load Survey Analysis**: Energy demand of the surrounding villages were considered by counting the number of houses, social centers, cottage industries, religious center to ascertain their load requirement. The NCEEC standard energy efficient applicant ratings for Fan 25W, TV set 20W, DVD 10W, etc, were adopted. Also the use of 10-15% of the total load is provided for future expansions. The power demand is also a function of the technical viability of the scheme. If the power demand of the community is higher than the available stream power, the scheme will not be technically viable. But this challenge can be solved, by constructing a dam, which is very expensive to build. The power demand is gotten by taken a census of the load demand analysis of each household, commercial and social outfits etc., multiplied by their respective diversity factor of 0.65, 0.7 and 0.65 to ascertain their power requirement [12]. The diversity factor occurs in an operating system because all loads connected to the system are not operating simultaneously or are not simultaneously operating at their maximum rating.

**(vi) Penstock Sizing**: The pipe that carries water under pressure to the turbine is a major part of technical concern as it constitutes a major expense in the total Small-Hydro budget. The length the penstock can be determined using Pythagoras theorem.

The economic diameter of a penstock is given by [8]

$$D_e = C_1\, C_2\, Q_0^{0.43}\, H_0^{0.1} \tag{5}$$

where

$D_e$-Economic Diameter

$C_1$-Energy Cost Coefficient (1.2 - where energy cost is low; 1.3 – where energy cost is high or where there exist no alternative source)

$C_2$-Penstock material coefficient (1.0 for steel; 1.05 – 1.1 for wood; 0.9-0.95 for plastics)

$Q_0$-Design Discharge

$H_0$-Design Head of Plant

**(vii) Turbine Selection**: Standard Tables and chart were used to recommend the type of turbine either to be purchased or locally design for the project. They also provide a guide of the number of turbines to be selected due to flow variation.

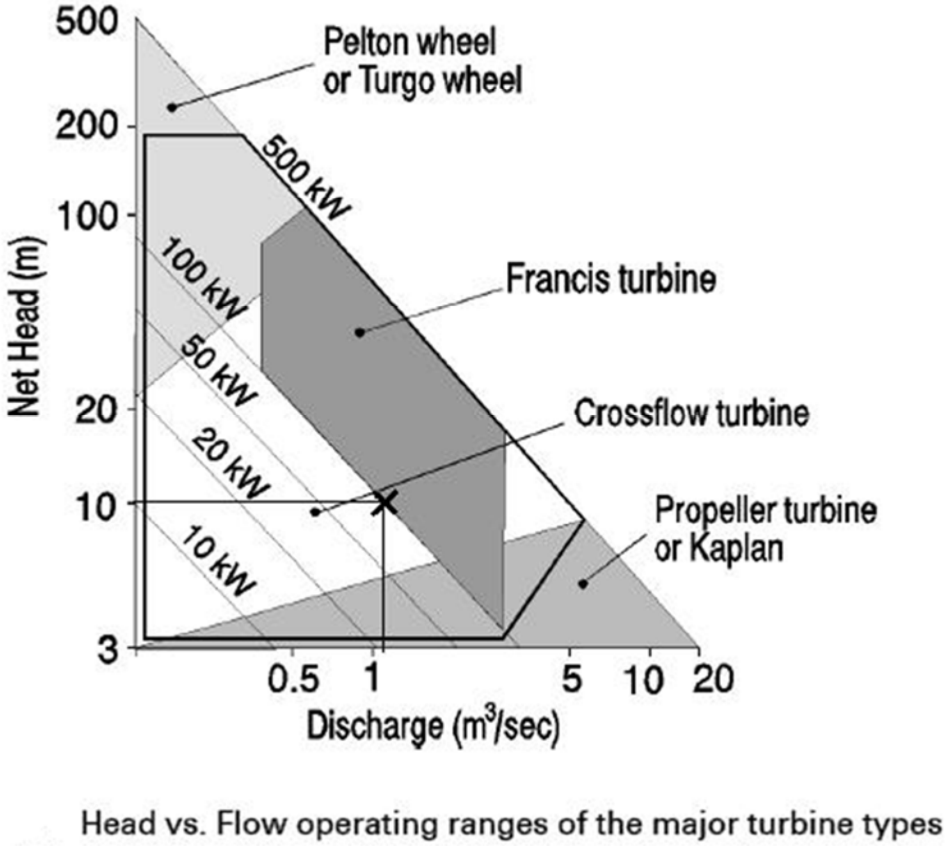
Tables and charts are used to project the type of turbine to be used for a small hydropower plant, Tables 1, 2, 3 and figures 3, 4 and 5 show the selection of turbines based on head, while Table 1 specifies the recommended turbine to use due to head variation at peak periods. The chart in figure 3 gives a relationship between the available head and flow for a particular scheme and the type of turbine that will favour the scheme, while figure 4, gives further relationship between hydraulic power, head and flow and the turbine to be selected. Also the chart in figure 5 gives relative characteristics between how the Kaplan and the Francis turbine will react to load variation due to lean period of flow. The chart in Figure 5, shows that the Francis turbine will show a sharp decline in efficiency due to load variation, while the Kaplan will show no appreciable load variation effect, making the Kaplan type of turbine best for varying load conditions.

**Table 1.** Turbine selection by head application [13].

| S/No | Type of Turbine | Head Application (m) | |
|---|---|---|---|
| Impulse | | Minimum | Maximum |
| 1 | Pelton wheel | 100 | 500 |
| 2 | Turgo Impulse (inclined pelton) | 40 | 200 |
| 3 | Cross flow | 1 | 200 |
| Reaction (Francis, mixed flow) | | | |
| 4 | Francis horizontal, vertical | 10 | 250 |
| Reaction (Axial flow) | | | |
| 5 | Vertical Kaplan (adjustable blade propeller) | 16 | 40 |
| 6 | Horizontal Kaplan (with adjustable blades and adjustable gates) | 2 | 25 |
| | Bulb | 2 | 25 |

**Table 2.** Turbine Selection by Acceptable flow and head variation [9].

| Turbine type | Acceptance of Q variation | Acceptance of H variation |
|---|---|---|
| Pelton 1 jet | 20% Qmax | Low |
| Pelton multi-jet | 10% Qmax | Low |
| Francis | 50% Qmax | Low |
| Kaplan double regulated | 20% Qmax | High |
| Kaplan single regulated | 50% Qmax | Medium |
| Cross-flow | 20% Qmax | Medium |
| Propeller | 20Qmax | Low |



Head vs. Flow operating ranges of the major turbine types

**Figure 3.** Head verses Flow operating ranges of major turbine types [9].

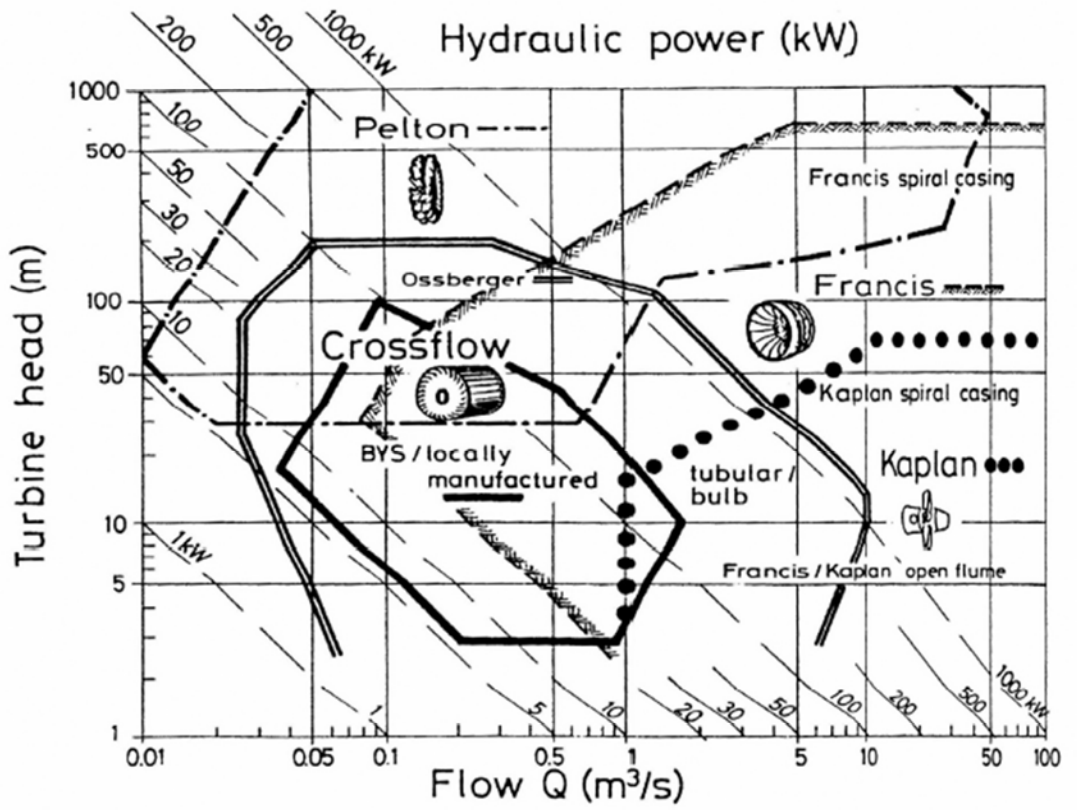


**Figure4.** Hydraulic Power verses Flow for different Types of Turbine [13].

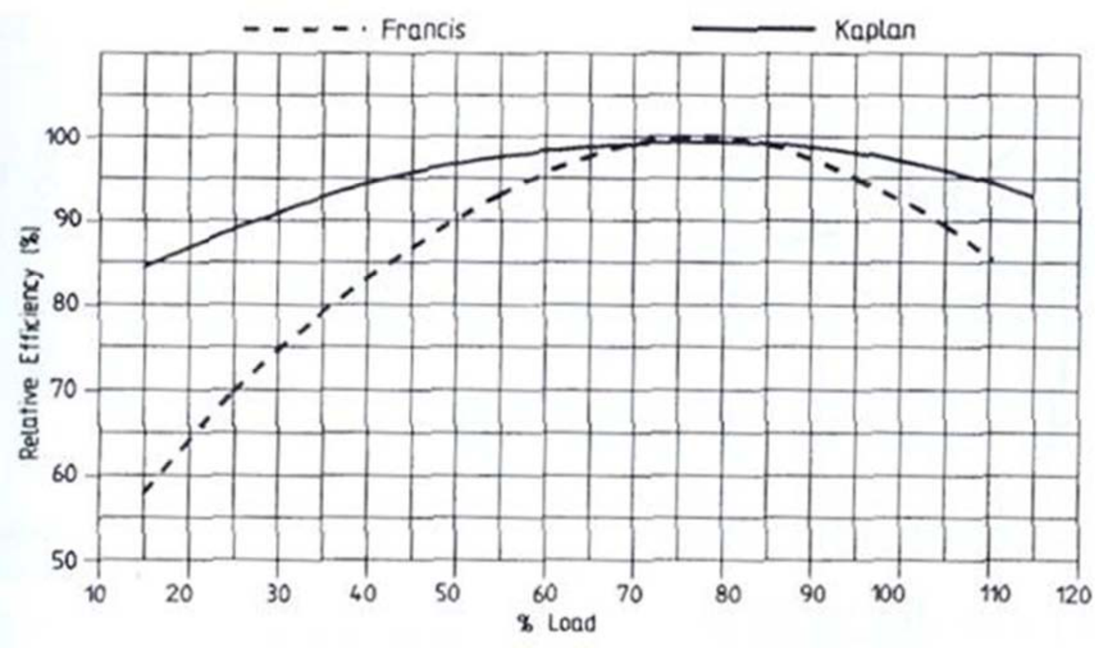


**Figure5.** Francis verses Kaplan application based on load variation [9].

**Table 3.** Specific speed for various types of turbines [4].

| Type of Runner | Specific speed ($N_s$) |
|---|---|
| Pelton | 12-30 |
| Turgo | 20-70 |
| Cross-flow | 20-80 |
| Francis | 80-400 |
| Propeller and kaplan | 340-1000 |

# 3. Results and Discussion

## 3.1. Results of the Study

### 3.1.1. Technical characteristics of Aku River

**a) Cross-sectional area**: from Equation (2), the Cross-sectional area is calculated. First the river bed is assumed to have semicircular base or parabolic shape, for reasons of its ability to retain water as well as having different depths across the cross-section. As shown in Figure 6 and Figure 7

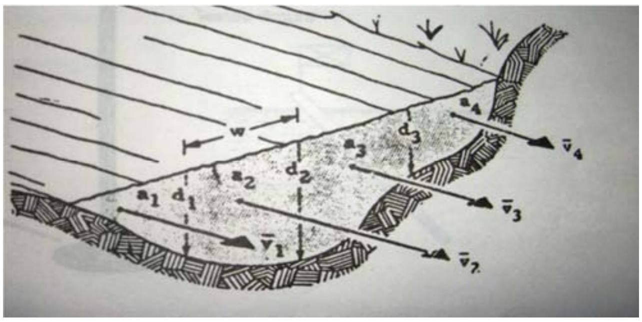


**Figure 6.** Discharge equals the sum of the discharge through each partial area [2].

Source: MHP Source book.

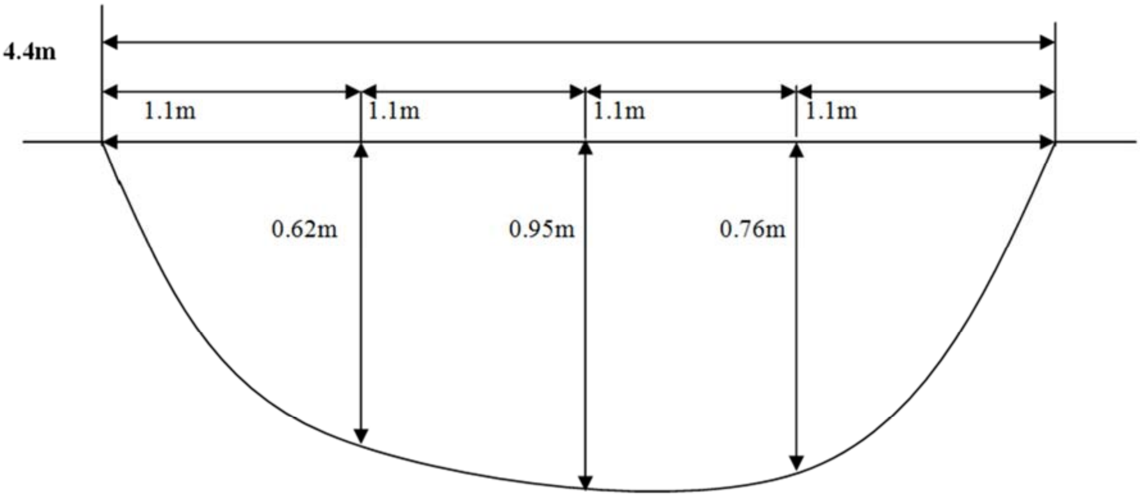


**Figure 7.** Sketch of Discharge equals the sum of the discharge through each partial area.

Since the difference in depth across the cross-section does not vary much, the section is divided into three equal part of 1.1m as shown in Figure 7. From Equation (2), we have that the Area A is given as:

$$A= (4d_1 + 2d_2 + 4d_3 + \ldots\ldots\ldots + 4d_n)\frac{w}{3}$$

$$A= [4(0.76) + 2(0.95) + 4(0.62)]\frac{1.1}{3}$$

Hence the cross-sectional Area = $2.75m^2$

**b). Velocity of flow**

$V_s = \frac{\text{Distance}}{\text{time}}$ where $V_s$ is the surface velocity

Hence the average stream velocity becomes

$$V = Cv_s$$

A minimum of five readings is taken to get the meantime it takes to cover a defined distance of 10m as shown in Table 4.

**Table 4.** Site Result of time taken to cover a distance of 10m.

| Distance (m) | Time (s) |
|---|---|
| 10m | 8.40 |
| 10m | 8.30 |
| 10m | 8.42 |
| 10m | 8.40 |
| 10m | 8.50 |

$$\text{Mean time} = \frac{8.4+8.3+8.42+8.40+8.5}{5} = 8.4s$$

$$\text{Hence } v_s = \frac{\text{distance}}{\text{time}} = \frac{10}{8.4}$$

$v_s = 1.2m/s$

But average velocity $V = Cv_s$

Where C = 0.85 for a smooth bed river

$V = 0.85*1.2$

$V = 1.0m/s$

**c) Stream Discharge**: from Equation (1), the river discharge is calculated. We have that the cross-sectional area A, and the average velocity of flow V, is $2.75m^2$ and 1.0m/s respectively.

$$Q = AV$$

Substituting the value of A and V in the equation

$$Q = 2.75 * 1.0$$

$$= 2.75m^3/s$$

**d) Head Measurement**: The use of the digital altimeter measured the difference in the proposed location of the power house and forebay at the site. The difference between the two distances gives the gross head of 7.9m

**e) Calculation of Estimated Power the Stream can generate**: using Equation 4, the Estimated Power is calculated.

$$\text{Power} = Q*H*7$$

Substituting the value of Q and H in the equation, we have

$$\text{Power} = 2.75*7.9*7$$

$$= 152.1kW \text{ approx.}$$

### 3.1.2. Load Survey Analysis

The National Centre for Energy Efficiency and Conservation (NCEEC) standard for load survey was adopted by the assistance of independent energy consultant. The detailed summary of energy consumption pattern which shows the estimated power demand of the people to be 639.013kW is shown in the Table 5, 6, 7 and 8 respectively.

**Table 5.** Domestic load estimate for Aku SHP; current and future (20 years period).

| Class | Quantity | Locations Description | Appliances (Wattage) | | | | | Total (Watt) |
|---|---|---|---|---|---|---|---|---|
| Domestic | 100 | Village | Lights | Fans (Ceiling & Table) | Radio | Fridges | Others (Iron, Video TVetc) | |
| | | Currently connected households | 15,000 | 7,125 | 2,000 | 10,000 | 12,875 | 47,000 |
| | | | Total domestic (current) | | | | | 47,000 |
| | | Future Connections | | | | | | |
| | 70 | Acha | 10,500 | 5,250 | 3,500 | 10,000 | 9,700 | 38,950 |
| | 55 | igbogolo | 8,250 | 4,125 | 2,750 | 8,600 | 8,200 | 31,925 |
| | 120 | Projected New houses and appliances for 20 year period for Aku, Acha and Igbogolo | 30,000 | 22,000 | 4,500 | 17,875 | 13,625 | 88,000 |
| | | | Total domestic (Future) | | | | | 158,875 |
| | | | Total domestic (current and future) | | | | | 205,875 |
| | Applying diversity factor of 0.65 = 205,875 * 0.65=133,818.75 | | | | | | | |

**Table 6.** Commercial load estimate for Aku SHP; current and future (20 years period).

| **Class: Commercial** | | **Appliances (Wattage)** | | | | | |
|---|---|---|---|---|---|---|---|
| **Quantity** | **Description** | **Lights** | **Fans (Ceiling & Industrial)** | **Others(Radio,Video,Tv, computer etc)** | **Fridges, freezers & Air conditioners** | **Machineries (welding machine, stone & sewing machinesetc)** | **Total (Watt)** |
| 30 | Currently connected shops | 900 | 1,500 | 400 | 12,000 | 8,700 | 23,500 |
| 2 | Poultry farm | 6,500 | - | - | - | - | 6,500 |
| 3 | Factories | 9,450 | 5,500 | - | 7,460 | 423,367 | 445,777 |
| 1 | Commercial banks | 375 | - | 3,200 | 10,500 | 1,500 | 15,575 |
| | | | | Total commercial (current) | | | 491,352 |
| | Future Connections | | | | | | |
| 1 | Guest house | 400 | 1,100 | 2,200 | 9,800 | 1,750 | 15,250 |
| 1 | Trade Stores | 480 | 1,280 | 560 | 7,400 | 850 | 10,570 |
| | Other business expansions | | | | | | 77,575 |
| | | Total commercial (Future) | | | | | 103,395 |
| | | Total commercial (current and future) | | | | | 594,747 |
| Applying diversity factor of 0.7 = 594,747*0.7 = 416,322.9 | | | | | | | |

**Table 7.** Government load estimate for Aku SHP; current and future (20 years period).

| **Class: Government** | | **Appliances (Wattage per unit)** | | | | | |
|---|---|---|---|---|---|---|---|
| **Quantity** | **Description** | **Lights** | **Fans(Ceiling)** | **Computers, Photo-copier,Printer** | **Fridges, & Air conditioners** | **Other appliances.** | **Total (Watt)** |
| 5 | Government Offices | 14,000 | 8,000 | 3,300 | 13,500 | - | 38,800 |
| 1 | General Hospital | 3,800 | 2,800 | 10,200 | 17,000 | 15,400 | 49,200 |
| 3 | Schools | 1,700 | 1,200 | 1,800 | - | 500 | 5,200 |
| | | | | Total (current) | | | 93,200 |
| | Future Connections | | | | | | |
| | General expansions | | | | | | 13,980 |
| | | | | Total (Future) | | | 13,980 |
| | | | | Total (current and future) | | | 107,180 |
| Applying diversity factor of 0.6 = 107,180*0.6 = 64,308 | | | | | | | |

**Table 8.** Other load estimate for Aku SHP; current and future (20 years period).

| **Class: Others** | | **Appliances (Wattage per unit)** | | | | | |
|---|---|---|---|---|---|---|---|
| **Quantity** | **Description** | **Lights** | **Fans (Ceiling)** | **Computers, Photo-copier, Printer** | **Fridges, & Air conditioners** | **Other appliances. (Public address system, Bands etc)** | **Total (Watt)** |
| 7 | Churches | 4,600 | 7,100 | - | - | 19,200 | 30,900 |
| 1 | Town Hall | 400 | 1,800 | - | - | 2,500 | 4,700 |
| | | | | Total (current) | | | 35,600 |
| | Future Connections | | | | | | |
| | General expansions | | | | | | 5,340 |
| | | | | Total (Future) | | | 5,340 |
| | | | | Total (current and future) | | | 40,940 |
| Applying diversity factor of 0.6 = 40,940*0.6 = 24,564 | | | | | | | |

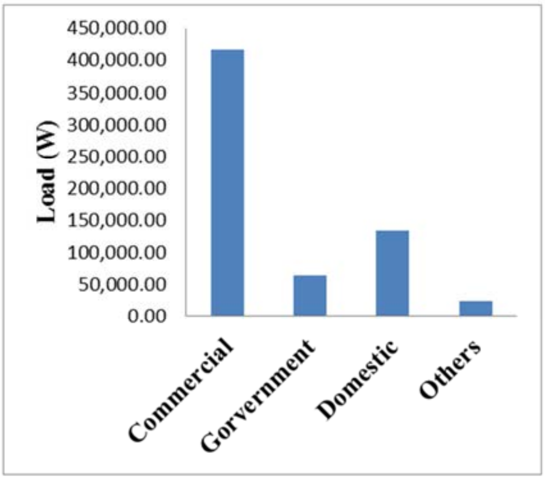


**Figure 8.** Load Survey Distribution Chart.

$$\text{Grand Total} = 133{,}818.75 + 416{,}322.9 + 64{,}308 + 24{,}564 = 639{,}013.65\text{W}$$

$$\text{Grand total in kW} = \frac{639{,}013.65}{1000} = 639.013\text{kW}$$

### 3.1.3. Scheme Type to Be Adopted, Energy Generation, Economic Size of Penstock and Turbine Selection

**a) Scheme Type and FDC**: The power of152.1kW generated as result of the dry season flow (Q) cannot meet the energy demand of the Aku and its immediate surrounding communities whose energy demand from load survey conducted was roughly 700kW; as a result of this the adoption of the rehabilitation of the existing dam used once in the area for rice irrigation is proposed if the Aku Small hydropower plant stands a chance to be technically viable.

Table 9 and figure 9 and 10 shows a summary flow data, flow duration curve and power duration curve for a period of twenty years respectively.

Assume that approximately 700kW Peak power is needed to provide for the electric power need of Aku village if the existing dam with Area of 3,142,500m$^2$, depth (Head) 21m and with a free board of 2m from site measurements. From Equation (4), Power (P) is given as:

$$P= 7QHg$$

$$Q=P/7Hg = 700/ 7 X 21$$

Q = 4.76m$^3$/s =5m$^3$/s approx. This would be the design flow of the turbine.

**Table 9.** Summary of Flow data over a period of 20 years.

| Months of available flow | Mean flow (m$^3$/s) | Available power (kW) | % Exceedence |
|---|---|---|---|
| 12 | 2.6 | 382.20 | 100.00 |
| 11 | 4.6 | 676.20 | 91.67 |
| 10 | 6.1 | 896.70 | 83.33 |
| 9 | 8.2 | 1205.40 | 75.00 |
| 8 | 9.6 | 1411.20 | 66.67 |
| 7 | 12.0 | 1764.00 | 58.33 |
| 6 | 13.4 | 1969.80 | 50.00 |
| 5 | 16.3 | 2396.10 | 41.67 |
| 4 | 18.2 | 2675.40 | 33.33 |
| 3 | 20.0 | 2940.00 | 25.00 |
| 2 | 21.8 | 3204.60 | 16.67 |
| 1 | 24.0 | 3528.00 | 8.33 |

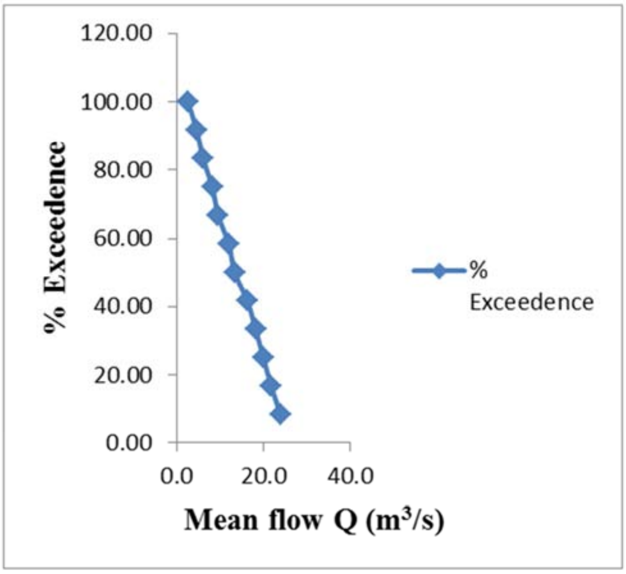


**Figure 9.** Flow Duration Curve.

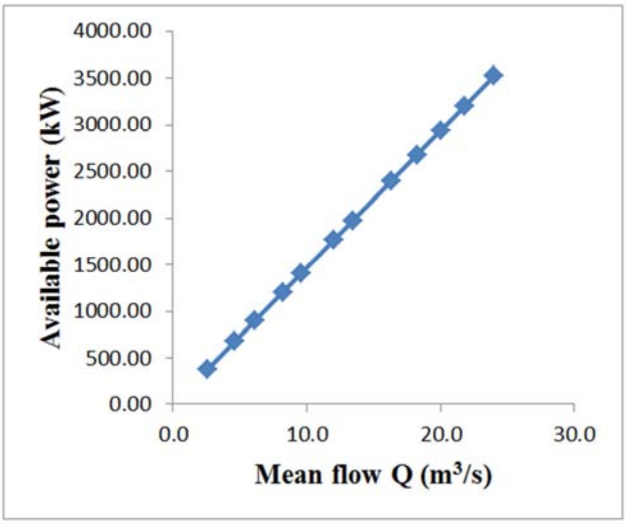


**Figure 10.** Power Duration Curve (PDC).

**b) Energy Generation**: The power generation from project can be all year round. Considering the two regimes of flow, lean and moderate, indicated in the hydrological analysis.

**i) Moderate Flow**

$$Q = 4.76m^3/s$$

$$H = 21m$$

Capacity = 4.76 x 21 x7 = 700kW approx.

But the operating time of the turbine = 24hours

Energy Produced at Moderate flow regime between March and October; a period of 8months which is equal to 240days

Energy produced = 700 x 24 x 240

Energy Produced = 4,032,000kWh

Expected net production = 90% of total energy

Expected net production = 4,032,000 x 0.9

= 3,628,800kWh

**ii) Lean Flow**: The lean flow regime ranges between 0-3m$^3$/s from the month of November to February which is about four months (120 days)

Capacity = 2.5 x21 x 7 =350kW

Energy Produced = 350 x 24 x 120

Energy produced =1, 157, 760, kWh

Expected net production = 90% of Energy produced

Expected net production = 1,157,760 x 0.9

= 1,041,948kWh

Hence Annual Energy produced = Energy at moderate flow + Energy at Lean Flow

= 3,628,800+1,041,948

Annual Energy produced= 4,670,748kWh

**c) Penstock Economic Diameter:** from Equation (5), the Economic Diameter of a Penstock is given by [8]:

$$D_e = C_1\ C_2\ Q_0^{0.43}\ H_0^{0.14}$$

$$D_e = 1.2*0.95*2.5^{0.43}*21^{0.14}$$

$$D_e = 2.5$$

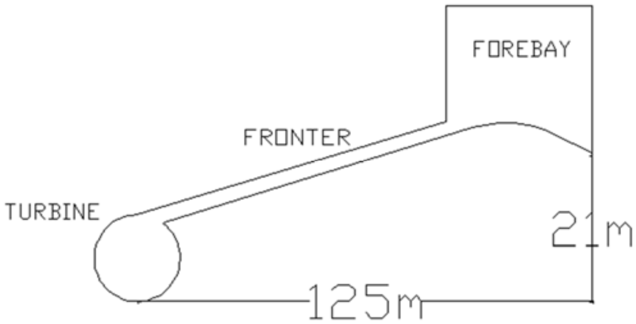


**Figure 11.** Penstock Schematic Arrangement of Aku SHP.

But from the Topographic Map, scaled horizontal distance is 5mm with a scale of 1 to 25,000mm (1m = 1000mm).

Therefore the horizontal distance $=\frac{25{,}000}{1000} * 5 = 125$m (as seen in the Figure 11).

Using Pythagoras Theorem, ie.

$$\text{Length of pipe} = \sqrt{horizontaldistance^2 + hgross^2}$$

$$= \sqrt{125^2 + 21^2}$$

Length of pipe = 126.75m

= 127m approx.

**d). Turbine Selection**

i) **Unit Selection Criteria**: From Table 1, based on a head 21m, the following turbines were selected:

a) Crossflow

b) Horizontal Kaplan

c) Bulb

d) Francis

ii) **Considering Flow and Head of Turbine**: From figure 1, considering a head of 21m and a flow of 2.5m$^3$/s, the following turbines were selected

(1. Francis

(2. Kaplan

(3. Tubular bulb

iii) **Net head verses Discharges:** From Figure 3, considering a flow 2.5m$^3$/s and a head of 21m, the following turbines were selected

1) Francis

2) Kaplan

iv) **Francis verses Kaplan decision**: From Figure 5, the Francis turbine shows a sharp decline in efficiency as the load varies, while the Kaplan turbine shows no appreciable decrease in the efficiency at varying loads, making the Kaplan turbine more viable than the Francis turbine for the Aku SHP project.

Sequel to this advantage of the Kaplan turbine over the Francis turbine, the Kaplan turbine is recommended for the Aku SHP.

Furthermore, to calculate the head loss for a dry period, with a flow Q=5m$^3$/s

And area =3,142,500m$^2$

But 5m$^3$/s = 5*60*60*24*30 = volume of water per month

Volume of water per month = 12,960,000

Head loss =12,960,000/3,142,500

=4.1m appros

% loss of head at dry period = (4.1/21 *100) =19.52%

## 3.2. Discussions

### 3.2.1. Technical Characteristics of Aku in Terms of Flow, Head and Estimated Stream Power

**a) Flow**: The river flow is the fuel that runs the SHP plant. The Aku river flow was measured during the Peak of dry season using the velocity area method of flow measurement to estimate the minimum flow of the river. First the cross-sectional area of the river was calculated by partitioning the river into three different zones since the difference in depth across the cross-section does not vary much to get a cross-sectional area of 2.75m$^2$. The river velocity was measured by taking a length of the stream which is relatively straight and uniform and a tennis ball is placed at the stream where the velocity is required, the time it takes to cover a distance D is recorded. A minimum of five readings is taken to get the meantime it takes to cover a defined distance of 10m and a correction factor was used to multiply the value of the surface velocity to get the average stream velocity of 1.0m/s, since water at the edges and near the bottom of the river moves slower than water at the surface and center of the stream due to roughness of the bed and viscosity of the water. The stream discharge is related to the cross-sectional area and velocity of the river directly, which when multiplied out gives us a final river discharge of 2.75m$^3$/s.

**b) Head:** The river head is the vertical distance through which water falls to the turbine. The head of the Aku SHP was gotten by the aid of a digital Altimeter through field work. The principle of the altimeter is that it measures atmospheric pressure. Atmospheric pressure that changes 9mm head of mercury for every hundred meter changes in elevation. This is achieved by getting the difference in the proposed location of the power house and forebay at the site as shown in figure 11. The difference between the two distances gave the head of 7.9m.

**c) Estimated runoff power potential:** Substituting the value of Q and H in equation 4 considering Losses in penstock, turbine, gear transmission, generator and electricity transmission reduce the final electrical run off power to be 152.1kW, which implies that the system operated at a standard efficiency of 70%. The power of 152.1kW is termed the run-off potential of the Aku SHP project which is subject to the load demand of the Aku community and its surrounding.

### 3.2.2. Load Survey Estimate

The estimated load of the proposed project was gotten to be 639.013kW, which is far bigger than the runoff generation capacity of 152.1kW. Hence for this project to be technically viable the Dam- toe systems were deployed as the only alternative to help raise the water level and storage for more power generation. Also from Figure 8, it was observed that the commercial load has the bulk of the demand of 416,322.9kW due to the high presence of industrial activities going on in the study area, which is a good sign that the project shows a potential to pay for itself. Hence a 700kW turbine is recommended for the Aku SHP project.

### 3.2.3. Scheme Type, FDC, Energy Generation, Economic Size ofPenstock and Turbine Selection

**a) Scheme type:** The power of 152.1kW generated as a result of the dry season flow (Q) cannot meet the energy demand of the Aku and its immediate surrounding communities whose energy demand from load survey conducted was roughly 700kW, as a result of this the adoption of the rehabilitation of the existing dam used once in the area for rice irrigation is proposed if the Aku Small hydropower plant stands a chance to be technically viable. From secondary data gotten from the Local Area Council, the existing dam has a water storage capacity of 12,960,000m$^3$ per month, covering an area of 3,142,500m$^2$ and a dam depth of 21m, with a free board of 2m. Though construction work is intended to be done to excavate the original depth of the dam covered with debris and sand and to work on the dam embankments. Hence the design discharge will now be a function of the available dam depth, load estimate of Aku to get a new design discharge of approximately 5m$^3$/s from calculation.

**b) Flow Duration Curve (FDC):** This is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest. The data used for this plot was gotten from Nigerian Metrological Institute of Aku guauged reading for a period of atleast twenty years to predict the character of the river for a longer period of time. From the FDC curve shown in Figure 9 it was observed that a flow of 5m$^3$/s is available at about 85% of the year while flow of 0-3m$^3$/s is available at about 97% of the year. Hence from the FDC the calculated design flow of 5m$^3$/s can be sustained for full operation of the turbine between the month of March and October and the lean flow regime falls between the months of October and February. From this analysis to avoid total shut down during the peak of the dry season, it is recommended not to operate the scheme with one turbine but with two turbines, with one of the turbines to operate at either with different design flow or the same design flow equally divided (2.5m$^3$/s).

**c) Energy Generation**: The power generation from project can be all year round. Considering the two regimes of flow; lean and moderate. From our calculation earlier the estimated one year record run off flow was 2.75m$^3$/s it is advisable for the purpose of effectiveness and tolerance to use a minimum lean design flow of 2.5m$^3$/s which is almost available 100% of the year from the flow duration curve. Hence a sum of the lean and moderate flow gives an estimated annual generation capacity of 4,670,748kWh all year round will be produced from the Aku SHP if put into use. The energy generation provides a platform for cost and benefit analysis of a project, since it is what customers pay for, at a stipulated tariff rate.

**d) Economic Size of the Penstock**: The Penstock constitutes a major expense in the total micro-hydro budget. Selecting an appropriate type of pipe material and diameter will help minimize head losses due to friction and surge; it will also help reduce cost and sudden failure of the component. From calculation a penstock length of 127m with diameter of 2.58m were used for the Aku SHP project. The material to be employed is uPVC due to the smoothness of the environment, cost, corrosion resistant and smooth internal surface that reduces wall friction losses as compared to the conventional steel material.

**e) Turbine selection:** The power, head and flow data are the primary and most important factor to consider when a turbine type is selected. The selection of the turbine in this study was considered based on charts and tables of head, flow and head of turbine, head verses discharges and efficiencies of different type of turbine as discussed earlier. The vertical Kaplan was not listed as a result of head loss, due to the vertical positioning of the shaft. From Figure3, the Kaplan, Francis and Tubular turbines were selected based on a head of 21m and a flow of 2.5m$^3$/s. Due to the maintenance flexibility, the tubular bulb kind of turbine was not viable for the Aku SHP project, owing to the high man power demands and equipment availability when it breaks down. Figure 4, shows that the Kaplan and Francis turbine were also selected to further verify the decision above. The Kaplan and Francis turbine were compared based on efficiency using figure5, the Francis turbine shows a sharp decline in efficiency as the load varies, while the Kaplan turbine shows no appreciable decrease in the efficiency at varying loads, making the Kaplan turbine more viable than the Francis turbine for the Aku SHP project, were load variation is anticipated. Sequel to this advantage of the Kaplan turbine over the Francis turbine, hence, it is recommended the use of the Kaplan turbine which is more expensive than the Francis turbine, for the Aku SHP project on the ground of site specification demands. For maintenance purposes and water volume reduction at the peak of dry season and to avoid complete shutdown, two unit of turbine of 350kW each are recommended and a flow of 2.5m$^3$/s to run each turbine, because multiple turbines help increase the average efficiency of the plant. This is especially evident where the flow varies significantly. In such situations, one machine can be run at a better efficiency. Some turbines cannot operate at very low part loads. Hence two units of 350kW turbine will be employed with each turbine having a flow of 2.5m$^3$/s. In summary with a dry period head loss of 19.52%, it is paramount to use the Kaplan type of turbine to maintain the efficiency of the turbine at all period of the year.

## 4. Conclusion

The Aku river is technically viable since the flow and head provides both lean and wet period capacity to generate a power of approx. 700kW and an all year energy generation capacity of 4,670,748kWh which is considerably enough for the Aku community and its surrounding, despite adopting the Dam-toe scheme type of SHP plant that demands high flow requirements for the dam and turbine to operate at all season of the year effectively without shutting down totally. With an estimated load of Aku and its surrounding villages to be 639.013kW, a far cry from what is obtained from the natural runoff capacity of 152.1kW makes the project not viable using the runoff river scheme, but viable by adopting the Dam-toe scheme that has the potential to generate 700kW, which is above the estimated load survey carried out, guarantees the viability of the Aku SHP in terms of meeting the power demands of the project and paying for itself comfortably as bulk of the load survey indicates the high presence of businesses having the highest share of 416,322.9kW of the 639.013kW total estimated power capacity. More so the choice of penstock size and turbine type of at least 2 numbers of turbines is ideal for flexible operations and repair since the SHP station is far away from town. It is very rare for both turbines to breakdown at the same time; at least one of them would be operational while repairs are being carried out on the second one. This will guarantee steady supply of power and reduce down time of the plant.

## References

[1] Adam, H., Andy, B., Priyantha, H., & Allen, H., (1993), MH Design Manual: A guide to Small – Scale water power schemes.

[2] Alien, R. (1990), MHP source book: A Practical guide to design and implementation in developing countries.

[3] Ajani, E. (2007), Small Hydropower Development in Nigeria: Hangzou SHP News Vol. 28.

[4] Alternate Hydro- Energy Centre, Indian Institute of Technology (2009), International training course on Small Hydropower Development.

[5] Council for Renewable Energy, Nigeria (CREN). (2009), Nigeria Electricity Crunch, available atwww.renewablenigeria.org, Google Scholar.

[6] Energy Commission of Nigeria (1998), "*World Solar Programme, 1996 – 2005",*Projects of the Government of Nigeria: Project Documents", ECN Abuja Nigeria.

[7] ESHA (1998), Layman's Guide book on how to develop a Small Hydro Site.

[8] HRC Training manual on SHP (2006), Hangzhon Regional Center (HRC) for SHP, Domestically called, National Research Institute for Rural Electrification, China.

[9] http://www.google.com/search?q=tables+charts

[10] Klaus, J., Ekart, H., & Heinz, U. (2009), ASEAN Centre for Energy (ACE): Good and Bad of Mini Hydro Power.

[11] Nnaji, C. and Uzoma, C. (2010), CIA World Factbook, http://www.cia.gov/library/publications/the-world-factbook/geos/ni.html,GoogleScholar.

[12] NCEEC (National Centre for Energy Efficiency and Conservation), (2012), A paper presentation at a 2-day UNDP GEF energy efficiency training workshop on promoting energy efficiency in Nigeria.

[13] Ptentec Indonesia Consulting and engineering, (2009), MHP Training Program Indonesia.

[14] Rai, G. (2004), Non- Conventional Energy Sources. Khanna Publishers, Delhi; Google Scholar.

[15] Rosen, M. (2009), Energy Sustainability: A Pragmatic Approach and illustrations. View Article, Google Scholar.

[16] Singhai, M. and Arun, K. (2015), Optimum Design of a Penstock for Hydropower Projects- International Journal of Energy and Power Engineering (Vol. 4).