Conceptual Design of a Simplified Decentralized Pico Hydropower with Provision for Recycling Water

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***Abstract*—The energy crisis is global with various approaches being adopted by various regions of the world to tackle their peculiar situations. The summary of all the approaches to the energy crisis is the development of smaller, smarter, decentralized systems and more efficient utilization of existing ones. These are less expensive, more environmentally benign and concede the control to the end user thereby reducing the exposure to influence of outsiders especially with the proliferation of insurgent activities in Nigeria. Nigeria has several proposals and/or projections as well as rural electrification programs which have been incapacitated by many issues including poor planning and lack of the political will. The National Energy Policy provides for the exploitation of technologies that can ensure access to power for the populace but current efforts have not shown any particular interest in pico hydropower technology. Also, there is apparent inability to enforce environmental laws despite all the perceived and realistic global warming effects related to the predominant utilization of fossil and biomass energy sources. This paper presents a design of a simple decentralized self-powering pico hydropower system which uses the basic principle of a pumped storage hydro system that can contribute immensely towards increased access to power by the teeming populace in the rural areas in Nigeria if implemented.**

Keywords—Conceptual design, energy crisis, pico hydro technology, recycling water, pumped storage hydro, rural electrification, decentralized system

I. INTRODUCTION

To prevent disastrous global consequences, it would increasingly be impossible to engage in large-scale energy-related activities without insuring their sustainability [1 – 3]. This also applies to developing countries in which there is a perceived priority of energy development and use and electricity generation over their impact on the environment, society, and indeed on the energy resources themselves [4, 5].

Access to electricity is a prime key to development as it provides light, heat and power for productive uses and communication. A vast majority of the people in developing countries, especially in rural areas, do not have access to electricity [6 – 8]. This number keeps increasing despite the rural electrification programs because they are not sufficient to cope with the population growth or the political will in some of the places is not strong enough or absent [9]. Moreover, despite the fact that about 80% of the world's population lives in developing countries, they consume only about 20% of the global commercial energy [10, 11]. According to the World Bank, most of the world's poor people spend more than 12% of their total income on energy, which is more than four times what a middle-income family in the developed world spends [12, 13]. A recent study on access to energy and consumption patterns among Nigerian households indicated that about 40% had access to the national grid with more than 45% not having access to any form of electricity. More than 6% have supported their access to the grid with self-diesel generators and more than 3% completely relied on self-generator. Also, about 1.1% of households have access to the rural electrification programs while more than three-quarters of Nigerians still depend on firewood as their cooking fuel with about 20% relying on kerosene. This is not surprising given the low access to the modern form of energy (electricity) and low reliability of electricity services in Nigeria. These findings show the urgent need for efforts for further developments of the overall Nigerian electricity sector as well as rural electrification programs to ensure rapid economic development [14 – 19].

Population growth makes the challenge even harder. The energy revolution will require moving from electricity systems based on large-scale fossil fuels, large hydro and nuclear fission plants to the ones based on new renewable sources and massive improvements in the efficiency of production, transportation, storage and use energy. Some research and development sectors visualize that power systems of the coming decades could consist of autonomous self-supplying energy systems with a high penetration of renewable sources. Generally, some researches are focused on decentralized and hybrid energy systems. Many PV-hybrid systems have been proposed in the past for electrification of remote areas or grid connected sites, but the vast majority had been based on PV-diesel or PV-wind systems. Many tools are also available for sizing and simulation of PV-hybrid systems. However, fewer include hydro resources. More recent approaches have adopted the PV-hybrid system including a hydro resource from an equatorial area [20 – 27].

The liberalization of the electricity market and environmental issues such as the consequences of the continued release of huge amounts of greenhouse gases on the environment, caused by the combustion of fossil fuel, gives the impetus for the development and implementation of such systems [28, 29]. Environmental concerns have continued to drive the search for cleaner technologies as well as higher energy conversion efficiencies [30]. Besides, fossil fuel reserves tend towards exhaustion in the near future not to mention the volatile nature of the oil industry as shown by youth restiveness in the Niger Delta in Nigeria and the instabilities in the Gulf region [31, 32]. Within this scenario, renewable energies must be used as a key tool in the contribution towards sustainable development in the less developed regions of the world [33, 34]. Furthermore, the substitution of conventional sources of energy such as traditional biomass for cooking, diesel and petrol generators, kerosene lamps and biomass stoves with renewable energies like small hydro power (SHP) can help decrease CO_2 emissions thereby contributing to climate change mitigation. It will also contribute to poverty alleviation and economic development by supplying electricity needs for lighting, water pumping and operating small workshops [36].

II. HYDROPOWER

Hydropower is a renewable, economic, non - polluting and environmentally benign source of energy. Hydro power stations have inherent ability for instantaneous starting, stopping, load variations etc, and help in improving reliability of power system [36, 37]. Hydro stations are the best choice for meeting the peak demand. The generation cost is not only inflation free but reduces with time. Hydroelectric projects have long useful life extending over 50 years and help in conserving scarce fossil fuels. They also help in opening of avenues for development of remote and backward areas [38 – 42].

The hydropower potential of Nigeria is very high and hydropower currently accounts for about 29% of the total electrical power supply. The first hydropower supply station in Nigeria is at Kainji on the River Niger where the installed capacity is 836MW with provisions for expansion to 1156 MW. A second hydropower station on the Niger is at Jebba with an installed capacity of 540 MW. It has been estimated since the 1990s that for Rivers Kaduna, Benue and Cross River (at Shiroro, Makurdi and Ikom, respectively) the total capacity stands at about 4,650 MW. Only the Shiroro site has been exploited till date. Estimates for the rivers on the Mambila Plateau are put at 2,330MW. The overall hydropower resource potentially exploitable in Nigeria is in excess of 11,000MW. The foregoing assessment is for large hydro schemes which have predominantly been the class of schemes in use prior to the oil crisis of 1973 [43 – 45].

Hydroelectric power plants despite having many advantages over other energy sources, has potential environmental impacts that are negative [46, 47]. Since it depends on the hydrological cycle, hydropower is not a reliable source of energy. Also, global climate change will increase rainfall variability and unpredictability, making hydropower production more undependable. Increased flooding due to global warming also poses a major hazard to the safety of dams. In addition, all reservoirs lose storage capacity to sedimentation which can in many cases seriously diminish the capacity of dams to generate power. Hydropower projects alter the habitats of aquatic organisms and affected them directly. Several millions of people have been forcibly evicted from their homes to make way for dams losing their land, livelihoods and access to natural resources and enduring irreparable harm to their cultures and communities [48 – 52]. Further, growing evidence suggests that reservoirs emit significant quantities of greenhouse gases especially in the lowland tropics. Also, there is growing evidence that hydropower is often falsely promoted as cheap and reliable, are prone to cost overruns and often do not produce as much power as predicted [53, 54]. The foregoing demerits are more directly applicable to large hydropower schemes.

Future plans for new hydroelectric plants, however, will need to consider three major factors. Private capital may not favor hydropower, since such facilities do not have short repayment periods and high returns. Such investments are best suited for public investment, which have to compete for other social services. Secondly, there is growing evidence that hydroelectric plants based on large dams are not environmentally neutral. Thirdly, potential declining river flows due to climate change impacts may lead to declining hydropower production, which in turn, will have an impact on the financial viability of such schemes. Large hydro schemes in several developing countries could play a major role in providing an alternative electricity source [51 – 59].

A. Pico Hydropower

There have been growing interests in research and development into pico-hydro systems especially in Asian countries. This could have largely been as a result of the need to diversify from fossil fuels such as coal, the necessity of off-grid options for better access to rural communities and the natural obstacle which the topography imposes against large scale developments. Implementation is highly advanced leading to significant commercial activities [60 – 67].

Emphases have however been on the application where water is flowing. At the recent International Hydropower Association (IHA) World Congress tagged IHA 2011 which played host to around 500 delegates from 71 countries, discussions were intensive and included many different perspectives.

Priorities focused on the need for strategic approaches, and a broader engagement when it comes to energy and water planning. There is also growing interest in the use of pumps as turbines (PATs). This basically involves the use of centrifugal pumps working in the reverse mode [68 – 70].

The basic power equations associated with the system are shown in equations 1 and 2 below.

$$P_{in} = H \times Q \times g \quad (1)$$

$$P_{out} = H \times Q \times g \times \eta \quad (2)$$

where P_{in} = Input power (Hydro power), P_{out} = Output power (Generator output), H = Head (meter), Q = Water flow rate (m/s), g = gravity (9.81 m/s^2) and η = efficiency [71, 72]. According to [73], water flow available is normally more than that needed since the flows for pico-hydro are small. Also, they gave 50% efficiency to estimate the potential output power as a rule of the thumb. This takes care of the losses in the pipe (or penstock) and in the generator.

To determine the head, gross (static) head and net (dynamic) head must be considered. Gross head is the vertical distance between the top of the penstock and the point where the water hits the turbine. Net head is gross head minus the pressure or head losses due to friction and turbulence in the penstock. Head losses depend on the type, diameter, and length of the penstock piping, and the number of bends or elbows [74]. Gross head can be used to estimate power availability and determine general feasibility, but net head is used to calculate the actual power available. According to [72], there are many methods of head measurement. One of the simplest and most practical methods for head measurement is by using a water-filled tube and calibrated pressure gauge. Through this method, the pressure gauge reading in psi can be converted to head in meters using equation 3 [72].

$$H = 0.704p \quad (3)$$

where, H = Head (meters) and p = Pressure (psi). The water pressure represents the net head of the system that is useful to calculate the actual power available.

The most simple of flow measurement for small streams is the bucket method [72]. In this method, water is allowed to flow into a bucket or barrel and the time it takes for the container to fill recorded. The volume of the container is known and the flow rate is simply obtained by dividing this volume by the filling time.

As concerns about global warming grow, societies are increasingly turning to the use of intermittent renewable energy resources, where energy storage becomes more and more important. There has been a renewed commercial and technical interest in pumped hydro energy storage (PHES) recently with the advent of increased variable renewable energy generation and the development of liberalized electricity markets. The introduction of pumped hydro storage (PHS) systems in isolated electrical grids, such as those found in island regions, appears to be a promising solution that is able to face both the high electricity production cost and the continuously increasing power demand encountered in these areas [75, 76].

B. *Pumped Hydropower*

Attention is also currently being given to the pumped-storage hydropower system to supply high peak demands by moving water between reservoirs at different elevations [77, 78]. Pumped-hydro energy storage is the most established technology for utility-scale electricity storage and have continued to be deployed globally. Pumped-storage plants are particularly well suited to peaks in electricity demand. During off-peak hours, such as the early morning hours, excess electricity produced by conventional power plants is used to pump water from lower to higher-level reservoirs. During periods of highest demand, the water is released from the upper reservoir through turbines to generate electricity. The combined use of pumped storage facilities with other types of electricity generation creates large cost savings through the more efficient use of base-load plants [75, 79 – 81].

Pumped-storage facilities have some distinctive features which include:

(i)Greater output can be obtained with smaller reservoirs in comparison with conventional hydropower.

(ii)They use the water stored in the reservoirs repeatedly and do not need large natural inflow to the reservoirs.

(iii)While conventional hydropower can only generate power, pumped storage can absorb power when the system has an excess. Pumped storage thus has greater capability of load leveling than conventional hydropower [82].

The ancillary services provided by pumped storage include:

(i)Frequency control due to its quick load following operation;

(ii)Load leveling to enable large thermal or nuclear power to operate at constant output;

(iii)Reserve operation to cope with sudden changes in power demand or system failure; and

(iv)Stand-by capacity to prepare for the unexpected failure of other plants or systems [75, 83 – 86].

The role of pumped-storage plants as reserve generators is important in enhancing the reliability of a given power system, but also valuable from an environmental viewpoint as they can contribute to slowing down GHG emissions. In fact, the cycle efficiency of pumped storage in the energy reproduction process is about 70-75% and this often misleads people to suppose that pumped storage would increase GHG emissions. Yet, without pumped storage in the system, many thermal power plants operate at their partial load as reserve generators to cope with unexpected increases in power demand or sudden loss of generating power caused by system failures. Such reserve operation compels thermal power plants to operate at lower efficiency and results in an increase of both fuel consumption and GHG emissions [87, 88].

The use of underground reservoirs as lower dams has been investigated. Salt mines could be used, although ongoing and unwanted dissolution of salt could be a problem. If they prove affordable, underground systems might greatly expand the number of pumped storage sites because saturated brine is about 20% more dense than fresh water [79]. Fig. 1 shows a pumped hydro plant.

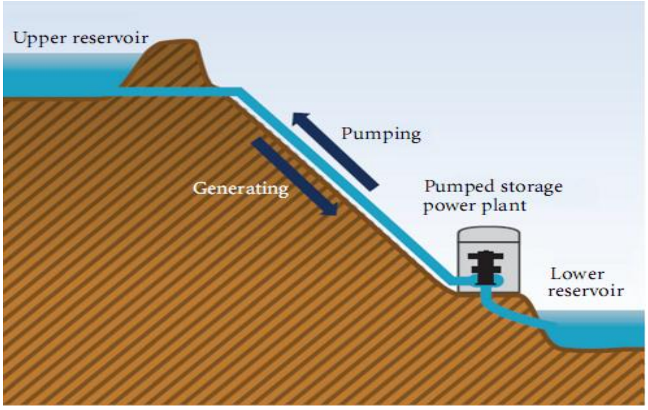

Fig. 1: Schematic view of a typical Pumped-Storage Hydro Power Plant [89]

III. DESIGN OF THE MAIN COMPONENTS

A. *Penstock Design and Selection*

Penstock diameter, length, and routing all affect efficiency, and in practice, there are guidelines for matching the size of the penstock to the design flow of the system. Generally, the available horsepower considerably reduces with reducing penstock diameter due to friction even if it can carry all the available water. Penstocks can either be installed above or below ground. The procedure for penstock design and selection presented by [90] which approximates the general procedure includes selecting the material for the penstock pipe, determination of its diameter, computation of the total head loss, consideration of the surge head (water hammer), computation of thickness and the factor of safety as a precaution. The most important design parameter in this selection is that the velocity of the water should be in between 2.5 m/s to 3.5 m/s. If the velocity is lower or higher it can cause loss in the power output and thus be uneconomical in the longer run. The American Society of Mechanical Engineers (ASME) code has a provision for this. [90] presented in tabular form the various possibilities of penstock materials that have been used especially in Nepal based on some general factors as shown in Table 1. The table also includes inputs from [91]. The choice material is dependent on the dominant desirable factor(s). The higher the number of asterisks the more desirable the factor concerned.

According to [90, 91], PVC is lighter, has better friction characteristics and is cheaper that steel apart from the subjective factor of being more readily available in the required sizes. Their pressure characteristics are similar. For this design, PVC pipe is selected as the penstock. [74] presented an analysis for the optimum penstock diameter considering cost and effect of slope with the aim of achieving the condition that head loss $h = {}^{H_g}/_{3}$, where H_g is the gross head of the system and it is implied that the turbine head $H = {}^{H_g}/_{3}$. The optimum penstock diameter is expressed as

$$D_{opt} = \left[\frac{fQ^2}{2g\left(\frac{\pi}{4}\right)^2\left(\frac{h}{H_g}\right)S}\right]^{1/5} \quad (4)$$

where $f =$ friction factor determined by the surface roughness of the penstock material, $S =$ penstock slope $= {}^{H_g}/_{L}$, $L =$ length of penstock and $Q =$ optimum discharge. For this concept, $S \cong 1$, which implies that the penstock is approximately vertical.

The approximate wall thickness selected for a penstock is generally a function of the tensile strength of the material, pipe diameter and the operating pressures. The operating pressure at any point along a penstock results from the local head of water above that point as well as from surge pressures arising from rapid changes of flow in the penstock. The minimum pipe thickness required to safely handle a given pressure is given as

$$t = 5.0 \times 10^3 \frac{pD}{\sigma} \quad (5)$$

where $t =$ pipe thickness, $p =$ water pressure, $D =$ internal pipe diameter and $\sigma =$ design stress of the material (N/m^2) $= UTS/Safety\,factor$. The equation considers only the pipe thickness required to handle the working pressures so that thin-walled pipes can be used for low head schemes. For uncoated steel pipes however, the minimum thickness for low-pressure applications is specified by the need for stiffness, corrosion protection and strength.

When a hydropower plant is operated, sudden flow changes can occur which produces a corresponding kinetic energy change of water giving rise to pressure surges in the penstock, commonly called water hammer. The critical time is used to indicate under what circumstances water hammer pressure should be considered and is defined as

$$T_c = \frac{2L}{a} \ (s) \quad (6)$$

where $a =$ wave velocity in the penstock expressed as

$$a = \frac{1400}{\sqrt{\left(1+\frac{KD}{Et}\right)}} \quad (7)$$

where K = bulk Modulus for water, E = the value of Young´s Modulus, D = pipe diameter (mm), t = the wall thickness (mm). The critical or highest possible pressure in the pipeline occurs when the flow in the pipe is stopped suddenly. This causes a pressure wave to move back and forth in the pipeline thereby producing a pressure of very high magnitude. If the stoppage occurs within the critical time $2L/_a$ (s) then the surge pressure may be given as

$$p_s = \frac{a\Delta V}{g} \quad (8)$$

where Δv = change in velocity in the pipe. If uniform stoppage (by valve closure for instance) takes place relatively slowly, maximum pressure will be experienced at the valve with the pressure rise decreasing to zero uniformly along the length of the penstock. For such a case the value of pressure is estimated as

$$p_s = \frac{K}{2} \pm \sqrt{K + \frac{K^2}{4}} \quad (9)$$

where

$$K = \left[\frac{L\Delta V}{gH_gT}\right]^2 \quad (10)$$

and T = time for valve closure in seconds with the positive sign for an opening valve. If the closing time is long enough and the value of K is significantly less than 1.0, the equation for the pressure becomes

$$p_s = H\sqrt{K} = \frac{L\Delta V}{gT} \quad (11)$$

Penstock efficiency can be computed from the expression [92]

$$\eta_{pen} = \frac{H_n}{H_g} \times 100\% \quad (12)$$

where H_n and H_g are the respective net and overall available head,

As a precaution the safety factor (SF) of the penstock pipes can be computed using the equation given by [90] as

$$SF = \left|t_{effective} \times UTS\right| \times \left|5h_{total} \times 10^3 \times D\right| \quad (13)$$

The associated frictional losses can be estimated using the expression given by [93] for pipes of diameter greater than 5cm and flow velocity below 3m/s as

$$H_f = \frac{6.87L}{D^{1.165}}\left[\frac{V}{C}\right]^{1.85} = \frac{89.283L}{D^{4.865}}\left[\frac{Q}{\pi C}\right]^{1.85} \quad (14)$$

where L = length of penstock, D = diameter of penstock, C = Hazan-William Coefficient which lies between 135 – 140 for plastic pipes and V = flow velocity given by $V = 4Q/_{\pi D^2}$. An average value of $C = 137.5$ can be used for obtaining H_f . The turbulence losses were estimated with the expression given as

$$H_t = \sum K_i\left[\frac{V^2}{2g}\right] = \sum K_i\left[\frac{4Q^2}{(\pi g)^2 D_p^4}\right] \quad (15)$$

where K = loss coefficient associated with entry of flow into the penstock, valves, elbows, bends and penstock area reduction resulting from the use of reducers. Values for K for pipe entry, the gate valve and the 90^0 elbow that will be used are given by [94] as 0.5, 0.25 and 0.9 respectively. For change in penstock dimensions, K values can be obtained using an expression given by [93] as

$$K_c = 0.42\left[1 - \left(\frac{d}{D}\right)^2\right] \quad (16)$$

where d = smaller inner diameter and D = the larger inner diameter. The net head available can then be computed using the expression

$$H_n = H - H_L \quad (17)$$

where H = total height of the water surface above the plain of the turbine shaft and $H_L = H_f + H_t$.

B. Determination of System Discharge, Q

The theoretical value of the system discharge Q_t can be computed for the penstock diameter obtained from the previous section. The discharge is expressed as

$$Q_t = \frac{\pi D_P^2\sqrt{2gH}}{4} \quad (18)$$

where D_P = penstock diameter (m) and H = available head (m). For this concept, $H \cong$ the height of the water surface above the plane of the turbine. The system discharge can also be estimated in terms of the volume of the water in the overhead reservoir by timing the discharging of the water from the overhead reservoir. This estimate can be computed from the expression

$$Q_e = \frac{Volume\ of\ water\ discharged}{t} \quad (19)$$

where t = time taken to discharge some water from the tank.

An electric water pump of capacity 1.0hp is selected as appropriate for this design. This is to ensure that the system is self-running. In order to achieve this, the capacity of the pump must be the minimum required obviously. For this system, the target power output is approximately 2.5kW.

TABLE 1: COMPARISON OF PENSTOCK MATERIALS

Material	Friction Lost	Weight	Corrosion	Cost	Jointing	Pressures
Mild Steel	***	***	***	****	****	*****
HDPE	*****	*****	*****	**	**	*****
uPVC	*****	*****	****	****	****	*****
Concrete	*	*	*****	***	***	*
Ductile Iron	****	*	****	**	*****	****

HDPE= High Density Polyethylene; uPVC = Unplastified Polyvinyl Chloride

* = Poor and ***** = Excellent (Sources: [90, 91])

C. Turbine Design

The design procedure for a single nozzle Pelton turbine resembling a propeller turbine was adopted. This was because a propeller turbine allows for the generators to be directly driven thereby avoiding transmissions and the attendant losses. Also, the runners involve a relatively lower number of fixed blades, therefore simplifying the manufacturing process and reducing the potential for inconsistent blade construction and orientation. Furthermore, the Pelton turbine can be mounted vertically or horizontally [72, 73, 95 – 99].

The approach presented by [61] was used in this work in order to obtain the base turbine runner diameters which can be scaled as appropriate to enhance manufacturability and application for the study [100, 101]. The values of Q_t computed using equation 17 are substituted into the expressions for the turbine parameters.

According to [61], the specific speed of the turbine is given by

$$n = 31\left[H\frac{Q_t}{j}\right]^{0.5} \tag{20}$$

where $j = 1 - 6$ is the number of nozzles. For simplicity and ease of manufacture, $j = 1$ was used for this concept.

The runner diameter can be computed from the expression

$$D_T = \frac{49.4H^{0.5}j^{0.02}}{n} \tag{21}$$

with D_T being in metres. The value of D_T obtained can be appropriately scaled to get the desired result.

The hub diameter and hence, blade height or cup length was found from the expression given by [90] as

$$\frac{D_h}{D_T} = 0.55 \tag{22}$$

where D_h is the hub diameter and the blade height is found from the expression

$$h = \frac{D_T - D_h}{2} \tag{23}$$

The number of blades can be selected from the chart of parameters for sizing turbines by [96]. The parameters of importance here are the available head and discharge or flow rate. Fig. 2 shows the working drawings of the blades. The blades will be made of cast aluminum and welded to the hub using gas welding. The runner assembly will then be coupled to the shaft. Appropriate bearings and adapted seals will be selected for mounting the runner in order to facilitate optimal rotation and to prevent/minimize leakages. The assembly will then be mounted in a casing made of sheet steel and externally reinforced to overcome buckling under pressure having a convenient annulus or flow area (A) satisfying the condition in the expression below.

$$A = \pi D_m h_b \tag{24}$$

where $D_m =$ runner mean diameter such that $D_h < D_m < D_T$, and $h_b =$ blade height.

The casing cover will be secured in position on a gasket with several M13 and M14 bolts and nuts used as the fasteners. The support of the turbine will be made of a combination of 5mm u-channel and 4mm angle iron with provisions for four M20 foundation bolts.

The alternator will be mounted such that it can be coupled to the turbine using a belt drive. The diameters of the driving (D_1) and driven (D_2) pulleys will be fixed based on the minimum rotational speed requirement of the alternator using the expression below in order to magnify the rotational speed of the turbine shaft.

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \tag{25}$$

where N_1 and N_2 are the respective rotational speeds of the driving and driven pulleys in rpm.

The tailrace will consist of a duct conveniently slanted in order to enhance discharge of water from the turbine into the ground reservoir. Fig. 3 shows an exploded view of the turbine which was drawn using *Autodesk* Inventor.

A simple nozzle will be fabricated in the form of a tapering pipe to facilitate the creation of a jet of water from the penstock unto the turbine.

D. Description of the System

A schematic diagram of the set-up is shown in the fig. 4. It will have a reservoir mounted overhead and a concrete underground reservoir into which water will be discharge downstream of the turbine. The arrangement will be such that the overhead reservoir (1) delivers water to the turbine (3) through the penstock (2). The nozzle will cause flow acceleration at the exit of the penstock. Water from the nozzles impinges on the turbine blades when the outlet valve of the overhead reservoir is opened. The whole turbine assembly will be mounted horizontally with the tailrace conveniently inclined such that flow from within the turbine casing is enhanced. The water exits from the turbine into the ground reservoir (6). The water will then be re-circulated into the overhead reservoir by the electric pump (5). The potential energy of the water will be converted to rotational kinetic energy which produces a torque on the alternator (4) which is linked to the turbine using a convenient belt drive which is acceptable in current practice for micro hydro power schemes and on the same horizontal plane [96]. A potential difference which can be measured is then produced. A means of storing the energy can then be linked to the alternator

The fluid power (P_f) available for each operation can be computed using equation 2. The shaft power,P_s, was computed from first principles from

$$P_s = \omega T = \frac{\pi\rho g Q N D_T}{60} \tag{26}$$

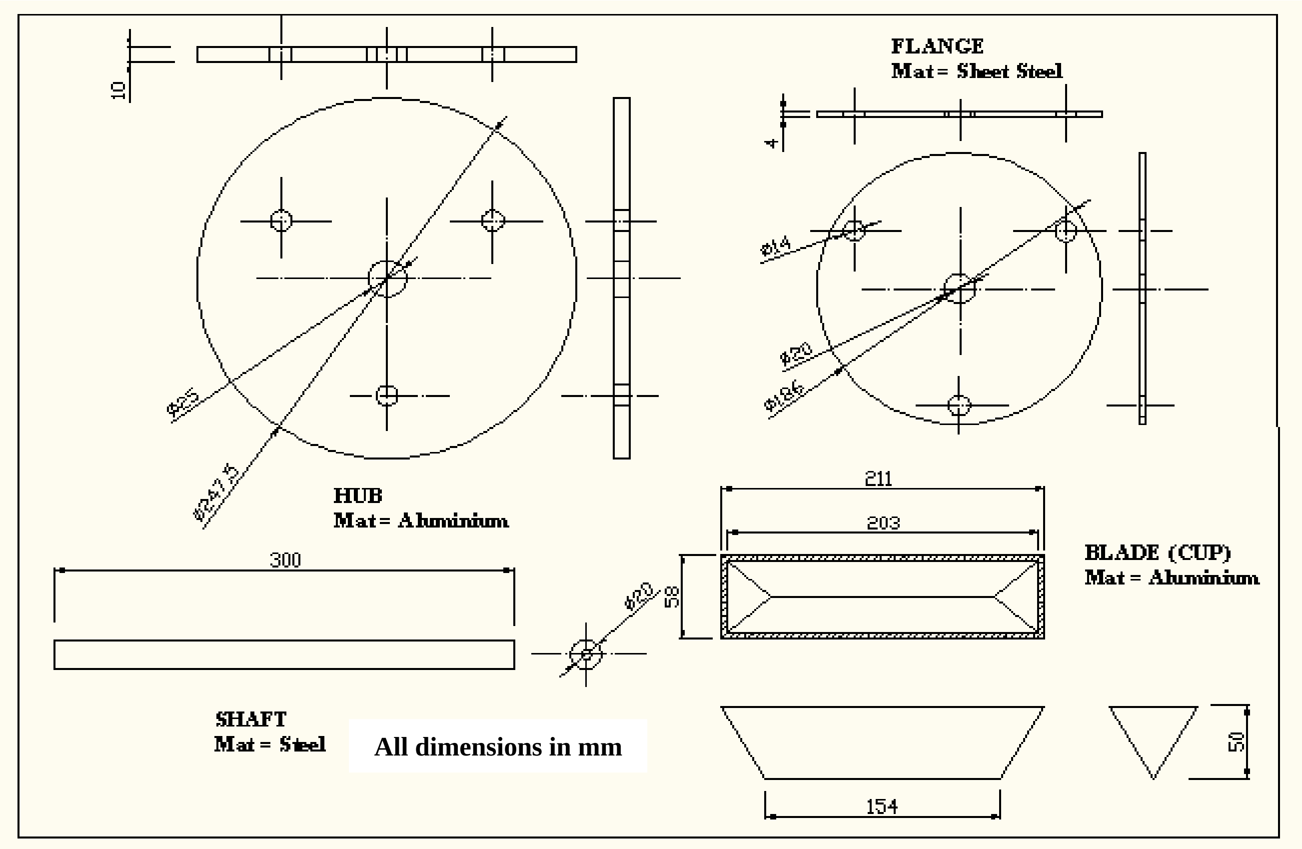

Fig. 2: Working Drawings for the Turbine Blades

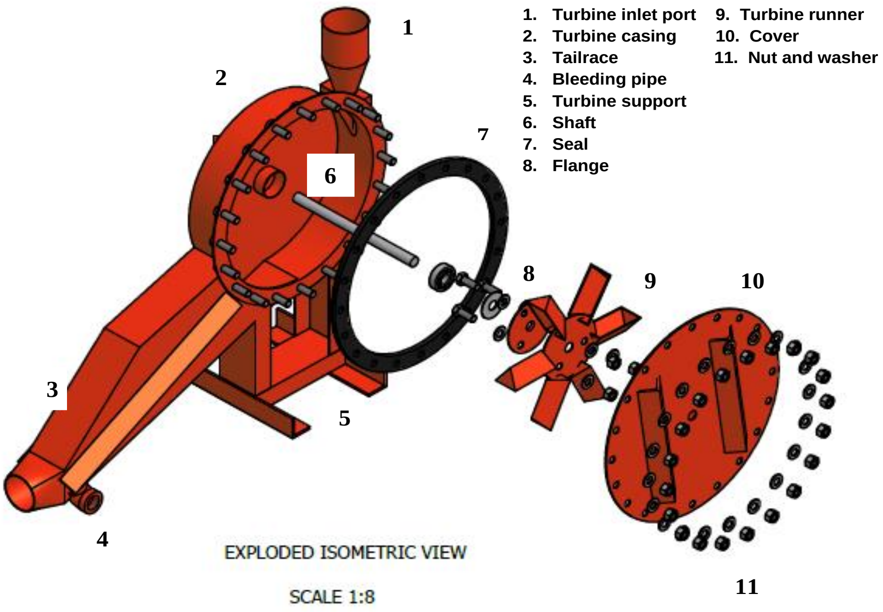

Fig. 3: Exploded View of the Turbine

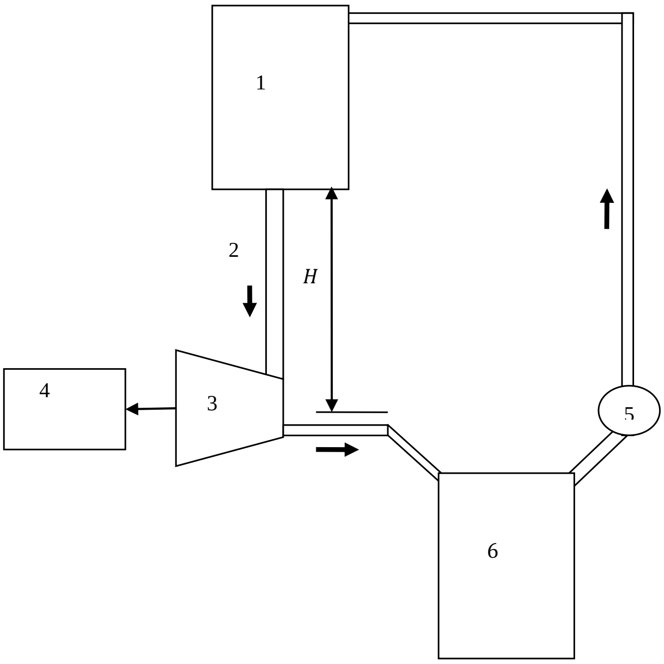

Fig. 4: Schematic Diagram of the System

where $\omega =$ the angular velocity and $T =$ torque. The efficiency of the system for each operation can determined using the expression below [71].

$$Efficiency, \eta = \frac{P_s}{P_f} \quad (27)$$

CONCLUSION

This work presents the design a simple pico-hydro system which utilises a recycled water source. It will be a variation of one of the methods of the pumped-storage method hydro power generation which is currently mainly used to handle variation in demand. Work has been done in the area of designing a proposed system which will utilise water supplied from the mains to residential buildings. Apart from the problems of variation of pressure at various points which the proposed system will have to address, it will be difficult to implement it in Nigerian locations because water from the mains is generally not available or grossly intermittent where available. Hopefully, this system will bring the hydro system to the point of application and particularly where naturally flowing water is not available thereby bringing to bear the advantages of SHP mentioned already. Particularly, the uncertainty of rainfall which is a major problem with conventional hydro systems will not adversely affect the use of this system.

The natural tendencies of emissions from dams of conventional hydropower systems will be absent to a large extent as well the adverse effects of such systems on aquatic life. The turbine will not be exposed to silt and sediments which are common place in conventional systems. Like is the case with gasoline and diesel generators, the end user will be able to have more control over the power system but in this case, the emission of greenhouse gases associated with the utilization of fossil fuel for power generation will be greatly reduced. The expected challenges will likely revolve around maintenance of the water recycling circuit as well as the design and/or selection of the appropriate turbine.

Ultimately, the system could be strategically implemented in collaboration with relevant and willing agencies such as UNIDO, the Energy Commission of Nigeria, and the States and Local Government Councils as well as small and medium scale enterprises. This may contribute to the mitigation of the effect(s) of current energy utilization pattern/practices on the environment, concede control to the end user thereby reducing access by potentially retrogressive agents and of course enhance better economic considerations.

The MDGs as well as Nigeria's vision 20 – 20 – 20 objectives will be enhanced on a general note. Farms and small and medium scale enterprises could be offered an ultimately cheaper and cleaner energy option over which more control could be had. Rural locations, particularly those without the naturally flowing water, can also have access to this energy option which will in the long run justify the relatively higher initial cost. The adverse effect of the use of other energy sources on the environment will reduce. The predominant situation in which saboteurs hold a whole region to ransom for some reason simply because access to the output of the centralized systems is within their immediate reach and/or control will be limited. An opportunity will be created for employment depending on the level of the success of the study.

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