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Effect of Penstock Diameter of a Simple Pico Hydro System on Shaft Power

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ABSTRACT

The effect of penstock diameter on shaft power was studied as part of an ongoing development of a simplified pico-hydropower system with water recycling. The speeds of the turbine and alternator shafts and volume of water displaced were measured for each penstock diameter and nozzle area ratio. The shaft power, flow rate and efficiency of the turbine were computed. The mean efficiencies were 0.776 and 0.510 for penstocks diameters 0.0762 and 0.0381 m respectively. Hence, larger penstock diameters with small nozzle area ratios favor optimal system operation. The results show that the system can potentially impact Nigeria's energy mix positively

Introduction

Energy is a critical input parameter for national economic development. In order to achieve United Nations sustainable development goals (SDGs), developing countries will require significantly expanded access to energy [1-7]. About six years ago, the total global energy demand was around 80% fossil energy and the remaining 20% are supplied by nuclear and renewable energy [8-9]. However, CO2 in the atmosphere is increasing as a result of the burning of fossil fuels and over the last few decades, a decline in fossil fuels reserves has been observed world-wide. Also, fossil fuels are not being newly formed at any significant rate, and thus present stocks are ultimately finite. To prevent disastrous global consequences, it would increasingly be impossible to engage in large-scale energy-related activities without ensuring their sustainability [10-15]. 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 [16-18].

Access to electricity is a prime key to. A vast majority of the people in developing countries, especially in rural areas, do not have access to electricity [19-25]. This number keeps increasing despite the rural electrification programmes 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 [26-31]. Studies on access to energy and consumption patterns among Nigerian households have 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 standby generators and while about 3% completely relied on them. Also, about 1.1% of households have access to the rural electrification programmes while more than three-quarters of Nigerians still depend on firewood with about 20% relying on kerosene as cooking fuel. This is not surprising given the low access to electricity and unreliability of electricity services in Nigeria. Hence, there is an urgent need for efforts to further develop the overall Nigerian electricity sector as well as rural electrification programmes to ensure rapid economic development [32-34].

Electricity generation has also caused massive environmental and social problems. There is a need to change the way energy is produced and used to reduce these impacts while providing energy services to a large number of people who have inadequate or no access to electricity [24, 35-40]. 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, and 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 [41-50].

It has been indicated that 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 [51-62]. Environmental concerns have continued to drive the search for cleaner technologies as well as higher energy conversion efficiencies. 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 [63-70].

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Within this scenario, renewable energies must used as a key tool in the contribution towards sustainable development in the less developed regions of the world [71-78]. 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 CO2 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 [79-84].

Water is the best choice of all the renewable sources of energy because a small-scale hydropower is one of the most cost-effective and reliable energy technologies to be considered for providing clean electricity generation. Hydropower is a renewable, economic, non - polluting and environmentally benign source of energy. Hydropower stations have inherent ability for instantaneous starting, stopping, load variations etc, and help in improving reliability of power system [85-92]. 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 [93-97].

Hydropower throughout the world provides around 17% of electricity from the currently installed capacity as well as the ones under construction, making it by far the most important renewable energy for electrical power production. It has been predicted that hydropower production is set to increase threefold over the next century [98, 99]. According to a publication of Focus on Renewable Energy, hydropower remains the renewable source of energy that contributes most to electricity generation. It puts the total global installed capacity at the end of 2010 at around 1,031 GW, with around 39 GW of new capacity being installed in 2010. The total estimated annual power generation from hydropower (as of the end of 2010) amounted to some 3,618 TWh/y [99, 100].

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, 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 2,330 MW. The overall hydropower resource potentially exploitable in Nigeria is in excess of 11,000 MW. 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 [101-103].

Hydroelectric power plants despite having many advantages over other energy sources, have potential environmental impacts that are negative [104-109]. Since it depends on the hydrological cycle, hydropower is not a reliable source of energy [110, 111]. 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 [112].

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 affect them directly [113-115]. 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 [116-120]. 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 [105, 121-123]. The foregoing demerits are more directly applicable to large hydropower schemes.

There is therefore a strong case for small hydropower (SHP) systems as means of more effectively supplying energy. Small and mini hydro projects have the potential to provide energy in remote and hilly areas where extension of grid system is un-economical. These projects are economically viable, environmentally benign and need a relatively short time for implementation [101, 124-130]. Overall, SHP can contribute to achieving the SDGs as far as certain key conditions are seriously considered in SHP electrification in developing countries. It has been strongly advocated in Nigeria that since small-scale hydropower systems possess obvious advantages over large hydro systems, that problems of topography are not excessive; they can be set up in all parts of the country so that the potential energy in the large network of rivers can be tapped and converted to electrical energy. In this way the nation's rural electrification projects can be greatly enhanced. However, a lot of the efforts being made currently to revitalize the hydropower sector still focus on large schemes. No particular mention is made of pico-hydro as a viable option for a way out of the energy crisis in Nigeria [65, 101, 131, and 132].

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This work is an aspect of an attempt to develop a simple pico-hydro system which utilizes a recycling water source that is undergoing development at University of Agriculture, Makurdi, Nigeria []154-160]. Work has been done in the area of designing and simulating pico-hydro systems which will utilize water supplied from the mains to residential buildings [146, 151]. 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 in Nigerian locations because water from the mains is generally not available, or grossly intermittent where available. The study is in line with current trends in energy supply issues. There is a general shift to renewable sources, smaller, decentralized, more environmentally benign systems and more efficient utilization. This system will contribute towards reducing the negative environmental impacts of conventional hydropower systems while reducing the rampant utilization of gasoline and diesel generators with the attendant emission of greenhouse gases as well as the frequent need for routine maintenance. With only about 1.1% of Nigerian rural households having access to the several rural electrification programmes, this system could play a vital role in ensuring a reasonable increase of access to decentralized end-user controlled electricity. It does not need the usual naturally flowing water sources as conventional hydropower schemes thereby removing the fluctuation of power production due to seasonal rainfall variations. It brings the hydro system to the point of use and the uncertainty of rainfall will not affect its use. As in the case with gasoline and diesel generators, the end user will be able to have more control over the power system with the emission of greenhouse gases greatly reduced. The exposure of centralized energy supply systems to frequent sabotage will ultimately be significantly mitigated. The challenges encountered during this work revolved around the maintenance of the water recycling circuit as well as the design and/or selection of the appropriate turbine. These and other critical issues form the nucleus of future development efforts of this system.

This aspect of the work deals with the influence of the penstock diameter on the shaft power of the system. The penstock is a very strategic component of the system. It is a pipe that carries water from the intake to the turbine. Most micro hydropower systems will include some type of penstock. Depending on the site characteristics, the penstock length may range from a few feet for manmade structures to several hundred feet for some run-of-the stream sites. In general, the optimum penstock is as short, straight, and steep as practical and has a continuous downward gradient. Some of the major factors that must be considered in selecting a penstock route include accessibility, soil conditions, natural or man-made obstructions, gradient and above-or below-ground installation. A number of factors are usually considered before selecting a penstock material which include cost, availability, properties and joining methods and installation limitations. A well designed penstock or pipeline is one of the most important components of a hydroelectric system. An inefficiently design fails to maximize the power available at a site. Common penstocks are smooth plastic PVC or polyethylene. It is important to use a pipe of sufficient pressure rating [161-167]. Many of the operational issues with conventional penstocks will be eliminated for this system because the penstock is just a vertically located PVC pipe looping the overhead reservoir and the turbine.

Materials and Methods

The set up for this study is the same used for other aspects of the general work aimed at developing the system into a self-running status capable of supplying clean and decentralized energy [131, 154-160].The set up consists of a pump and a locally fabricated turbine connected in a closed loop with the help of PVC piping as penstock, a 2000 litres overhead tank and a 3000 litres underground reservoir. The suction pipe of the pump draws water from the underground reservoir to the overhead tank to create a head. Water is then released from the overhead tank through the penstock and terminating in a nozzle. The flow through the turbine is regulated using a gate valve installed before the penstock inlet. The water jet strikes the blades which are attached to the periphery of the hub, thus transferring its kinetic energy to the shaft causing the rotary motion of the hub and the shaft assembly. A 300 mm diameter pulley is connected to the turbine shaft and transmits power to a 50 mm diameter pulley connected at the alternator via a toothed v-belt drive in a step up ratio of 1:6 to satisfy the minimum condition for generating voltage. The water in the turbine casing is directed through an outlet port into the underground reservoir from where it is recycled to the overhead tank by the pump. The pump is rated 1.11 kW with a flow capacity of 50 litres/min. Two tachometers (DT-2268 Contact Type Digital and DT-2858 Digital Photo/Contact) were used to measure the rotational speed of the turbine and alternator shafts while a Mastech model MY-62 multi-meter was used for measurement of the electrical quantities. The water levels in the two reservoirs before and after each operation were measured with a calibrated dip stick and the duration also noted. The procedure was carried out for penstock diameters of 0.0762, 0.0635, 0.0508, 0.0445 and 0.0381 m, turbine runner diameters of 0.45, 0.40, 0.35, 0.30 and 0.25 m, and nozzle area ratios of 1.0, 0.8, 0.6, 0.4 and 0.2. The measured data were used to compute shaft power and turbine efficiency. The data was then subjected to a two-factor ANOVA. Figure 1 shows the entire system set up.

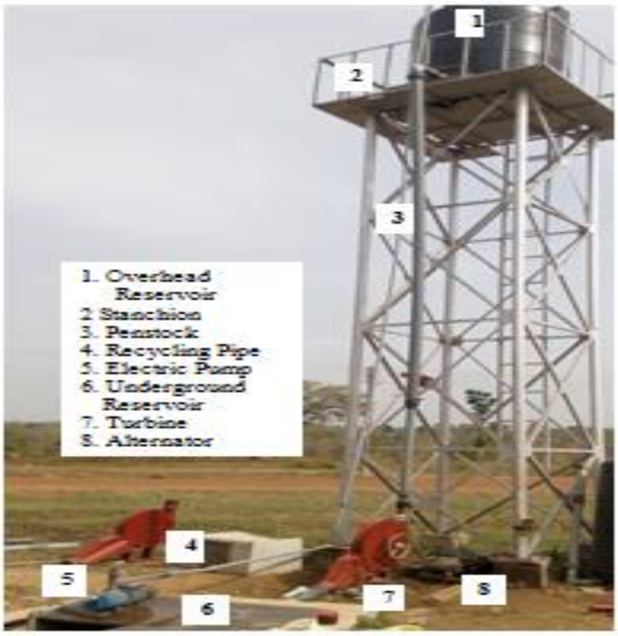

Figure 1. The set up for the study.

The associated frictional losses were estimated using the expression given by [128] for pipes of diameter greater than 5 cm and flow velocity below 3 m/s as 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 $V = 4Q/\pi D^2$, shown in equation 1.

$$H_f = (6.87L/D^{1.165})[V/C]^{1.85} \quad (1)$$

The turbulence losses were estimated using equation 2.

$$Ht = \sum [K_i (V^2/2g)] \quad (2)$$

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. For change in penstock dimensions, K values were obtained using an expression given by [128], where d = smaller inner diameter and D = the larger inner diameter, shown in equation 3.

$$K_c = 0.42\,[1 - (d/D)^2] \quad (3)$$

The net head available was computed using equation 4.

$$H_n = H - H_L \quad (4)$$

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

The experimental system discharge Q_e was determined for each penstock size by timing the process of discharging water from the overhead reservoir and then computed from equation 5, where t = time taken to discharge some water from the tank.

$$Q_e = \text{Vol. of water discharged}/t \quad (5)$$

The shaft power, P_s, was computed from first principles using equation 6.

$$P_s = \omega T \quad (6)$$

where ω = the angular velocity and T = torque [166].

The efficiency as a performance indicator for the system was determined using equation 7.

$$\eta = P_s / P_f \quad (7)$$

where $P_f = \rho g Q H$ = fluid power.

Results and Discussion

The change in computed head loss (H_L) in relation to the penstock diameter was investigated and the plots presented in Fig. 2 for turbine runner diameter, $D_T = 0.45\ m$. Expectedly, the general tendency of the curves indicated that H_L increased with decreasing penstock diameter, D_P, for each nozzle area ratio (A_2/A_1) in accordance with Darcy's equation [128, 168]. Very few exceptions were shown on the curves for A_2/A_1 = 0.6 and 0.2 after D_P = 0.0445 m. These isolated cases can be attributed to some disparities in the gross head values used. This was probably necessitated during periods when the water in the overhead reservoir was discharged and then refilled in order to make some adjustment or by some other error of judgment.

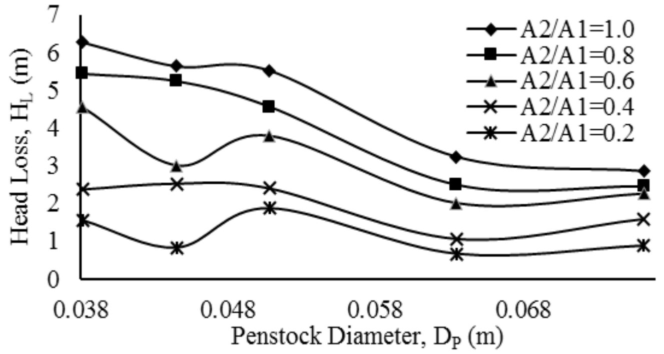

Figure 2. Variation of head loss with penstock diameter for turbine runner diameter of 0.45 m.

On the whole from Table 1, the mean head loss for the system during the no-load tests was in the range $1.885\ m \leq H_L \leq 4.161\ m$ for $0.0762\ m \geq D_P \geq 0.0381\ m$. This confirms that H_L reduced with increasing D_P by visual inspection. The characteristics of H_L against D_P for the other turbine runner diameters were quite similar to the ones for DT = 0.45 m. The results indicate good potentials for utilizing large penstock diameters for the system with the risk of increased cost [169-172]. However, as in every other engineering endeavor, the aim for further work will be to break even such that the cost will be justified by the system output power.

Also from Table 1, the mean efficiencies of the system based on penstock diameters were in the range $0.51 \leq \eta \leq 0.776$ for $0.0381\ m \leq D_P \leq 0.0762\ m$. This agrees with the fact that the flow rate and hence the shaft power reduces with reducing penstock diameter. This is in line with the fact that the power output is proportional to the flow rate while the flow rate is inversely proportional to the penstock diameter [173-178]. This generally affirms the need to utilize largest feasible values of D_P for any given situation.

Table 1. Mean Values of some of the System Parameters.

Penstock Dia., D_p (m)	Turbine Runner Dia., D_T (m)	Head Loss, H_L (m)	Net Head, H_n (m)	Flow Rate, Q x 10^{-3} (m^3/s)	Efficiency
0.0762	0.45	2.006	6.408	15.475	0.765
	0.40	1.839	6.445	14.710	0.777
	0.35	1.834	6.580	14.774	0.782
	0.30	1.995	6.419	15.492	0.763
	0.25	1.752	6.660	14.394	0.792
		1.885	6.505	14.965	0.776
0.0635	0.45	1.891	6.505	9.482	0.775
	0.40	1.954	6.419	9.649	0.766
	0.35	1.965	6.339	9.807	0.764
	0.30	2.068	6.205	10.036	0.750
	0.25	1.919	6.493	9.699	0.772
		1.959	6.392	9.735	0.765
0.0508	0.45	3.625	4.797	7.955	0.570
	0.40	3.308	5.100	7.478	0.609
	0.35	3.142	5.260	7.310	0.627
	0.30	2.564	5.807	6.500	0.694
	0.25	2.999	5.379	7.124	0.643
		3.128	5.269	7.273	0.629
0.0445	0.45	3.443	4.960	5.427	0.591
	0.40	3.719	4.689	5.700	0.558
	0.35	3.894	4.459	5.742	0.534
	0.30	3.024	5.377	5.185	0.613
	0.25	4.039	4.374	5.976	0.520
		3.624	4.772	5.646	0.563
0.0381	0.45	4.131	4.279	4.131	0.509
	0.40	4.416	4.190	4.331	0.499
	0.35	4.178	4.179	4.190	0.502
	0.30	4.314	4.079	4.246	0.487
	0.25	3.767	4.645	3.964	0.552
		4.161	4.274	4.172	0.510

Figure 3 shows the variation of efficiency with the nozzle area ratio for each of the penstock diameters for the turbine of runner diameter $D_T = 0.45\ m$. It also shows that larger penstock diameters also favor higher efficiencies. This is indicated by the clustering of the curves for $D_P \geq 0.0635\ m$ at the top of the family of curves while those for $D_P \leq 0.0508\ m$ are clustered at the bottom. The effective operation of the system is therefore enhanced by the use of large diameter penstocks and lower A_2/A_1 ranges in and optimal mix in order to produce the magnitude of torque required for power generation [179-183]. The efficiency and A_2/A_1 characteristics for the other turbine runner diameters were more or less similar in orientation and shape to the ones for $D_T = 0.45\ m$.

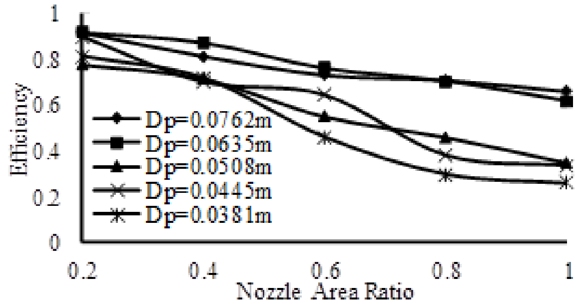

Figure 3. Variation of turbine efficiency with nozzle area ratio for turbine of runner diameter 0.45 m.

All the plots for each D_P show some undulations as the nozzle area ratios are changed. Ideally, the variations should approximate a smooth curve but inconsistencies can be attributed to a number of factors. Mainly, the variation of the flow rate resulting from the fact earlier established that the overhead reservoir discharges faster than it replenished affects the computed power from which the efficiency is computed. Another reason is that since the nozzles were installed one after the other, there were definite misalignment errors with contributed to shaft revolutions that did not follow the ideally consistent pattern. Furthermore, little fabrication inconsistencies were present here and there which could also have contributed. It is also worthy of note that these curves were obtained for $D_T = 0.45\ m$ which offered a greater resistance to the water jet thereby increasing the possibility of developing inconsistent torque. At the present stage of the work, it is quite inconvenient to derive a relationship that can capture these issues and probably others not mentioned or yet envisioned. However, the general trends of the curves are adequate at present to give a clear picture of the behavior of efficiency with nozzle area ratio. Addressing those issues more carefully for future development of the work will hopefully yield smoother curves.

A two – factor analysis of variance without replication at 5% significance level was performed on the system parameters in three conveniently selected pairs namely: shaft power and penstock diameter; efficiency and penstock diameter; and system flow rate and penstock diameter. The summary of the results are shown in Table 2. The analysis for shaft power against penstock diameter shows that significant difference existed between the shaft power at 5% level with the penstock of diameter 0.0762 m across the turbine runner diameters and nozzle area ratios. There were only significant variations with the remaining penstock diameters across the turbine runner diameters at the same level. The analysis for turbine efficiency against penstock diameter at the same level of significance shows that there was significant difference in the efficiency with penstock diameters 0.0762 m and 0.0508 m across both turbine runner diameters and nozzle area ratios. With penstock diameters 0.0635 m, 0.0445 m and 0.0381 m, differences only existed across the turbine runner diameters. The analysis for the volumetric flow rate against penstock diameter at the same significance level revealed that there was significant difference in the flow rate with only penstock of diameter 0.0508 m for both runner diameters and nozzle area ratios. No significant differences existed with diameter 0.0762 m while differences only existed across the runner diameters with penstock diameters 0.0635 m, 0.0445 m and 0.0381 m. The results of this analysis generally support the various interactions of the parameters of the system discussed so far. The differences observed are also statistically significant.

The variation of the maximum shaft revolution, N_{max}, for each penstock sizes, D_P, while varying the turbine runner diameter, D_T, and nozzle area ratios, A_2/A_1, from 1.0 to 0.2 was investigated. Figure 4 shows the variation of N_{max} and D_P for D_T = 0.40 m. The general behavior of N with D_P for all the runner diameters is polynomial in nature with very high R^2 values especially for A_2/A_1 = 0.2 for all the 5 values of D_T. In terms of the values of D_P, the highest value of N was given by the 3 smaller penstock sizes (D_P = 0.0508, 0.0445 and 0.0381 *m*) in no particular trend to enable the selection of a particular value. This indicates that the D_P values more compatible with the operation of this system lie in the range $0.0381\ m \leq D_P \leq 0.0508\ m$. Apart from the curve for A_2/A_1 = 0.2 for $D_T = 0.45\ m$, the ones for D_T = 0.40, 0.35, 0.30 and

Table 2. Summary of Two-factor ANOVA of the System Parameters

Item	D_P/D_T (m)	Source of Var.	F	P-value	$F_{critical}$
Shaft Power	0.0762	Rows	220.9539	8.85E-14	3.006917
		Columns	8.138502	0.000885	3.006917
	0.0635	Rows	73.66187	4.25E-10	3.006917
		Columns	0.990853	0.440648	3.006917
	0.0508	Rows	7.111425	0.001726	3.006917
		Columns	0.181441	0.944677	3.006917
	0.0445	Rows	9.118368	0.00049	3.006917
		Columns	1.993737	0.144049	3.006917
	0.0381	Rows	34.17819	1.19E-07	3.006917
		Columns	1.241224	0.333119	3.006917
Efficiency	0.0762	Rows	245.6151	3.86E-14	3.006917
		Columns	4.795308	0.009812	3.006917
	0.0635	Rows	161.0242	1.05E-12	3.006917
		Columns	1.153194	0.367716	3.006917
	0.0508	Rows	133.8105	4.42E-12	3.006917
		Columns	10.37049	0.000244	3.006917
	0.0445	Rows	57.79864	2.61E-09	3.006917
		Columns	2.025627	0.139127	3.006917
	0.0381	Rows	145.0873	2.36E-12	3.006917
		Columns	1.760154	0.186271	3.006917
Flow Rate	0.0762	Rows	0.463501	0.761555	3.006917
		Columns	0.924528	0.474063	3.006917
	0.0635	Rows	180.6098	4.29E-13	3.006917
		Columns	1.050431	0.41245	3.006917
	0.0508	Rows	181.6896	4.09E-13	3.006917
		Columns	16.17104	1.77E-05	3.006917
	0.0445	Rows	43.26647	2.19E-08	3.006917
		Columns	2.136191	0.123413	3.006917
	0.0381	Rows	153.5066	1.52E-12	3.006917
		Columns	2.523662	0.081805	3.006917

0.25 *m* show a tendency towards a linear relationship with maximum shaft revolution recorded by the smallest D_P in each case. This sheds more light on the fact that baring discrepancies of any kind, the smaller penstocks as well as the smaller values of A_2/A_1 should direct the water jet more accurately on the runner blades for the turbines used in this work.

Though the Darcy and Poiseuille equations favor flow rate reduction with decreasing D_P, the observation that smaller values of D_P enabled the creation of higher values of N_{max} can be traced to two issues directly related to the configuration of the components of the set-up. First of all, smooth edge reducers were used to progressively change D_P from 0.0762 m to 0.0381 m. Though losses were introduced which increase with decreasing A_2/A_1, flow acceleration was also introduced which enabled the increase in kinetic energy downstream of the reducers. The smallest D_P was installed downstream of four reducers. This improves the chances of the developing a higher rate of change of momentum which produces the rotation of the turbine shaft. Secondly, the percentage of the water delivered off the blades within the casing was lower for the smaller D_P. This is because the aperture of the blades for all the turbines was the same. Under this condition, more water was delivered off the target with larger values of D_P during the operation of the turbines thereby producing a lower torque. Hence, effective operation of the system is favored by a good synergy between penstock diameter and blade aperture in order to develop the requisite rotation of the turbine shaft. The relationship between the penstock diameter and turbine cup width as well as shape is a serious contending research issue for the next phase of the development of this system.

The results of the investigation of the relationship between the computed shaft power and penstock diameter are shown in Fig. 5 for $D_T = 0.45$ *m*. The trend of the curves has some resemblance in appearance with those in literature for conventional hydropower systems with slight departures [184-187]. The departures from the conventional trends are expected however, because the ideas that have been adapted for the analysis and operation of this system apply to conventional hydropower systems with basically different configurations.

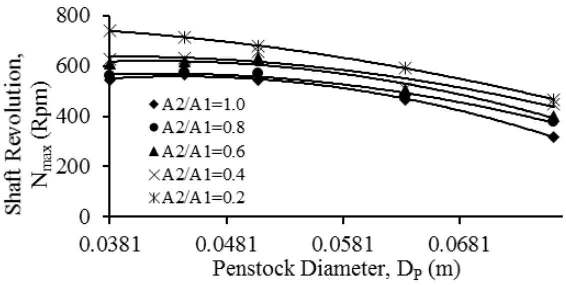

Figure 4. Variation of maximum shaft revolution with penstock diameter for turbine runner of 0.40 m Diameter.

Generally, the curves indicate that the shaft power increases with penstock diameter as a direct consequence of increasing flow rate. This is in agreement with the Poiseuille and Darcy equations as well as the effect of local or turbulent losses which depend on the flow velocity and some loss coefficient associated with the make-up of the pipeline. The flow velocity from the continuity equation involves the flow rate which depends on the penstock cross-sectional area. Consequently, larger values of D_P will enhance the production of higher shaft power as a result of the associated higher flow rates for a given turbine runner diameter and net head.

For the larger values of D_P, the range $0.6 \leq A_2/A_1 \leq 1.0$ produced higher shaft power and there was a sharper increase as indicated by the steepness of that portion of the curves. This derives from the fact that the hydraulic losses in the penstock is inversely proportional to D_P^n, where $4 \leq n \leq 5$ [188-191]. Hence, larger values of D_P will permit lower losses thereby favoring higher shaft power production.

For the lower values of D_P ($0.381\ m \leq D_P \leq 0.0508\ m$), the range $0.2 \leq A_2/A_1 \leq 0.6$ produced the higher values of shaft power. This is because though the flow rate is reduced, a more effective water jet was created as earlier explained. This also corroborates the earlier assertion that these ranges of nozzle area ratios as well as penstock diameters were more compatible with the turbines used for the study with respect to the interaction of the water jet and the turbine blades. The relationship between the shaft power and the penstock diameter for other turbine runner diameters were similar to the ones for $D_T = 0.45$ *m* in Fig. 5.

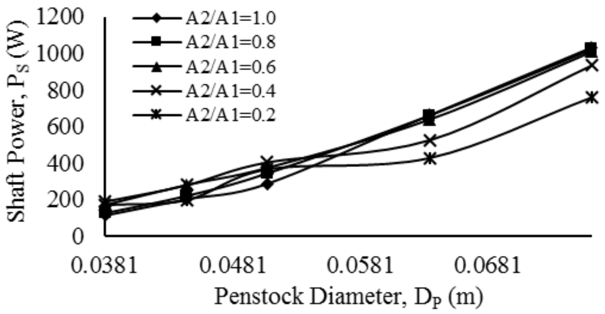

Figure 5. Variation of shaft power with penstock diameter for turbine of runner diameter 0.45 m.

Conclusion

A simplified pico-hydro system is being developed employing an overhead reservoir with provision for water recycling and its performance tests indicate good promise for power generation. The effective performance of the system depends on the use of appropriately large penstock diameters and small nozzle area ratios for a given height of reservoir above the ground and diameter of turbine runner. The recommendations for this work are issues for immediate handling as the next phase(s) of this work. In order to implement the findings of this and previous studies on this system, the following are projected issues for consideration:

(1) Modification of the delivery pipe from the pump in order to balance the ratio of delivery to discharge from the reservoir;

(2) Testing with the overhead reservoir located above 7.0 m to take advantage of greater head;

(3) Use of multiple overhead reservoirs (or larger capacity ones) as part of further development;

(4) Introduction of solar power for powering the recycling system in order to explore the hybridization option; and

(5) Undertaking an economic/environmental comparative analysis of this system with a stand-alone solar power system and a fossil fuel-powered system.

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References

[1] ECA, "Correlation and causation between energy development and economic growth", 2014, 1-18. Economic Consulting Associates https://assets.publishing.service.gov.uk/ media/57a089bae5274a27b2000229/EoDHD116Jan2014 EnergyEconomicGrowth.pdf

[2] I. Arto, I. Capellán-Pérez, R. Lago, G. Bueno, and R. Bermejo, "The energy requirements of a developed world", Energy for Sustainable Development, 33, 2016, 1-13.

[3] IEA, "World Energy Outlook 2015 Edition", 2015, 1 – 12. International Energy Agency. www.iea.org/t&c/.

[4] BP, "BP Energy Outlook 2017 Edition", 9-22, 74-77, 90-94, 2017. British Petroleum www.bp.com/energyoutlook #BPstats.

[5] BP, "BP Energy Outlook 2016 Edition: Outlook to 2035", 2016, 44, 74-77, 90-94. British Petroleum. www.bp.com/energy outlook#BPstats.

[6] E. Bergasse, W. Paczynski, M. Dabrowski, and L. Dewulf, The Relationship between Energy and Socio-Economic Development in the Southern and Eastern Mediterranean, MEDPRO Technical Report No. 27/February 2013. https://www.ceps.eu/system/files/MEDPRO%20TR27_CASE %20Bergasse_%20Energy%20and%20Socio-economic%20Dev elopment_updated_15Feb2013.pdf

[7] M. Saatci and Y. Dumrul, "The relationship between energy consumption and economic growth: evidence from a structural break analysis for Turkey", Int. J. of Energy Economics and Policy, 3(1), 2013, 20-29.

[8] C. Gil, "Scientific production of renewable energies worldwide: an overview", Renewable and Sustainable Energy Reviews, 18, 2013, 134–143.

[9] E. Toklu, "Overview of potential and utilization of renewable energy sources in Turkey", Renewable Energy, 50, 2013, 456– 463.

[10] K. Athanas and N. McCormick, Clean energy that safeguards ecosystems and livelihoods: integrated assessments to unleash full sustainable potential for renewable energy, Renewable Energy, 49, 2013, 25 - 28.

[11] N. Sawangphol and C. Pharino, "Status and Outlook for Thailand's Low Carbon Electricity Development", Renewable and Sustainable Energy Reviews, 15, 2011, 564–573.

[12] J. Sreekanth, N. Sudarsan, and S. Jayaraj, "Clean development mechanism as a solution to the present world energy problems and a new world order: a review", Int. J. of Sustainable Energy, 2012, 1–27.

[13] I. Yuskel, "Renewable energy status of electricity generation for future prospect", Renewable Energy, 50, 2013, 1037-1043.

[14] R. Bhoyar and S. Bharatkar, "Potential of micro sources, renewable energy sources and application of micro grids in rural areas of Maharashtra State India", Energy Procedia, 14, 2012, 2012 – 2018.

[15] M. Capik, A. O. Yılmaz, and I. Cavusoglu, "Hydropower for sustainable energy development in Turkey: the small hydropower case of the Eastern Black Sea Region", Renewable and Sustainable Energy Reviews, 16, 2012, 6160–6172.

[16] H. Gujba, Y. Mulugetta, and A. Azapagic, "Power generation scenarios for Nigeria: An environmental and cost assessment", Energy Policy, 39, 2011, 968–980.

[17] H. Gujba, Y. Mulugetta, and A. Azapagic, "Environmental and economic appraisal of power generation capacity expansion plan in Nigeria", Energy Policy, 38, 2010, 5636–5652.

[18] E. I. Ohimain, "Diversification of Nigerian electricity generation sources", Energy Sources, Part B: Economics, Planning, and Policy, 10(3), 2015, 298-305.

[19] J. Chikaire, F. N. Nnadi, and N. O. Anyoha, "Access to sustainable energy: a panacea to rural household poverty in Nigeria", Continental Journal of Renewable Energy, 2 (1), 2011, 7–18.

[20] X. Zhang and A. Kumar, "Evaluating renewable energy-based rural electrification program in Western China: emerging problems and possible scenarios", Renewable and Sustainable Energy Reviews, 15, 2011, 773–779.

[21] N. Kaseke and S. G. Hosking, "Sub-Saharan Africa electricity supply inadequacy: Implications", Eastern Africa Social Science Research Review, 29(2), 2013, 113-132.

[22] B. Mainali, and S. Silveira, "Financing Off-Grid Rural Electrification: Country Case Nepal, Energy, 36, 2011, 2194 - 2201.

[23] B. Mainali, and S. Silveira, "Renewable energy markets in rural electrification: country case Nepal", Energy for Sustainable Development, 16, 2012, 168-178.

[24] A. Gurung, A. K. Ghimeray, and S. H. A. Hassan, "The prospects of renewable energy technologies for rural electrification: A review from Nepal", Energy Policy, 40, 2012, 374 – 380.

[25] A. Gurung, O. P. Gurung, and S. E. Oh, "The potential of a renewable energy technology for rural electrification in Nepal: A case study from Tangting", Renewable Energy, 36, 2011, 3203 - 3210.

[26] S. Abdullah and A. Markandya, "Rural electrification programmes in Kenya: policy conclusions from a valuation study", Energy for Sustainable Development, 16, 2012, 103–110.

[27] L. Shezi, Nearly 60% of Africans have no access to reliable electricity. 2015. http://www.htxt.co.za/2015/05/08/ nearly-60-of-africans-have-no-access-to-reliable-electricity/

[28] UNDESA, Electricity and Education: The Benefits, Barriers, and Actions for Achieving the Electrification of Primary and Secondary Schools, 2014. United Nations Department of Economic and Social Affairs. https://sustainabledevelopment.un.org/content/documents/160 8Electricity%20and%20 Education.pdf

[29] J. Omede and A. A. Omede, "Poor and inadequate electrical power generation, transmission and distribution in Nigeria: economic, psycho-social, health, security and educational consequences. J. of Applied Science, 1(7), 2015, 1-11.

[30] A. Yadoo and H. Cruickshank, "The role for low carbon electrification technologies in poverty reduction and climate change strategies: a focus on renewable energy mini-grids

with case studies in Nepal, Peru and Kenya", Energy Policy, 42, 2012, 591–602.
[31] A. Yadoo, A. Gormally, and H. Cruickshank, "Low-carbon off-grid electrification for rural areas in the United Kingdom: lessons from the developing world", Energy Policy, 39, 2011, 6400 – 6407.
[32] M. O. Oseni, "Households' access to electricity and energy consumption pattern in Nigeria", Renewable and Sustainable Energy Reviews, 16, 2012, 990 – 995.
[33] C. A. Awosope, "Nigeria Electricity Industry: Issues, Challenges and Solutions", Covenant University 38th Public Lecture, Public Lecture Series. 3(2), October, 2014. www.covenantuniversity.edu.ng/content/download/35621/.../ 1 /.../38th+Public+Lecture. pdf
[34] A. Aliyu, A. Ramli, and M. Saleh, "Nigeria electricity crisis: Power generation capacity expansion and environmental ramifications', Energy, 61(8), 2013, 354-367.
[35] H. Benli, "Potential of renewable energy in electrical energy production and sustainable energy development of Turkey: performance and policies", Renewable Energy, 50, 2013, 33 - 46.
[36] G. Bekele and G. Tadesse, "Feasibility study of small hydro/PV/wind hybrid system for off-grid rural electrification in Ethiopia, Applied Energy, 97, 2012, 5 – 15.
[37] F. Manzano-Agugliaro, A. Alcayde, F. G., Montoya, A. Zapata-Sierra, B. Mainali, and S. Silveira, "Financing off-grid rural electrification: country case Nepal", Energy, 36, 2011, 2194 - 2201.
[38] A. S. Sambo, "Enhancing renewable energy access for sustainable socio-economic development in Sub-Saharan Africa", J. of Renewable and Alternative Energy Technologies, 1(1), 2015, 1-5.
[39] C. Ong, T. M. I. Mahlia, and H. H. Masjuki, "A review on energy scenario and sustainable energy in Malaysia", Renewable and Sustainable Energy Reviews, 15, 2011, 639–647.
[40] E. Nnaji, C. C. Uzoma, and J. O. Chukwu, "The role of renewable energy resources in poverty alleviation and sustainable development in Nigeria", Continental Journal of Social Sciences, 3, 2010, 31-37.
[41] B. Josimovic and T. Crncevic, "The development of renewable energy capacities in Serbia: case study of three small hydropower plants in the "Golija" Biosphere Reserve with special reference to the landscape heritage", Renewable Energy, 48, 2012, 537 - 544.
[42] R. Nepal, "Roles and potentials of renewable energy in less-developed economies: the case of Nepal", Renewable and Sustainable Energy Reviews, 16, 2012, 2200–2206.
[43] M. Ranjeva and A. K. Kulkarni, "Design optimization of a hybrid, small, decentralized power plant for remote/rural areas", Energy Procedia, 20, Technoport RERC Research, 2012, 258–270.
[44] A. Razak, K. Sopian, Y. Ali, M. A. Alghoul, A. Zaharim, and I. Ahmad, Optimization of PV-wind-hydro-diesel hybrid system by minimizing excess capacity", European J. of Scientific Research, 25(4), 2009, 663-671.
[45] S. Sanaeepur, H. Sanaeepur, A. Kargari, and M. H. Habibi, "Renewable energies: climate-change mitigation and international climate policy", Int. J. of Sustainable Energy, 2013, 1–10.
[46] S. K. Lohan, J. Dixit, S. Modasir, and M. Ishaq, "Resource potential; and scope of utilisation of renewable energy in Jammu and Kashmir, India", Renewable Energy, 39, 2012, 24 – 29.
[47] M. Melikoglu, "Vision 2023: feasibility analysis of turkey's renewable energy projection", Renewable Energy, 50, 2013, 570 – 575.
[48] O. V. Marchenko and S. V. Solomin, "Efficiency of hybrid renewable energy systems in Russia", Int. J. of Renewable Energy Research, 7(4), 2017, 1561-1569.
[49] E. Hossain, R. Perez, and R. Bayindir, "Implementation of hybrid energy storage systems to compensate microgrid instability in the presence of constant power loads", Int. J. of Renewable Energy Research, 7(2), 2017.
[50] M. S. H. Lipu, M. G. Hafiz, M. S. Ullah, A. Hossain, and F. Y. Munia, "Design optimization and sensitivity analysis of hybrid renewable energy systems: A case of Saint Martin Island in Bangladesh", Int. J. of Renewable Energy Research, 7(2), 2017.
[51] Y. Allahvirdizadeh, M. Mohamadian, and M. HaghiFam, "A comparative study of energy control strategies for a standalone PV/WT/FC hybrid renewable system", Int. J. of Renewable Energy Research, 7(3), 2017, 1463-1475.
[52] D. Paun and C. A. Paun, "The impact of renewable energy on the price of energy in Romania", Int. J. of Renewable Energy Research, 7(2), 2017.
[53] A. Ribal, A. K. Amir, S. Toaha, J. Kusuma, and K. Khaeruddin, "Tidal current energy resource assessment around Buton Island, Southeast Sulawesi, Indonesia", Int. J. of Renewable Energy Research, 7(2), 2017.
[54] M. M. Samy, "Techno-Economic analysis of hybrid renewable energy systems for electrification of Rustic Area in Egypt", Innovative Systems Design and Engineering, 8(1), 2017.
[55] UNFCCC, "Facilitating technology deployment in distributed renewable electricity generation", 2015. United Nations Framework Convention on Climate Change. http://unfccc.int/ttclear/misc/StaticFiles/gnwoerk_static/TEC_documents/6d62b12d1a87483da716d80e77d5349b/b4539aaf699b459e99 98606868dd49bd.pdf
[56] T. F. Karim, M. S. H. Lipu, and M. S. Mahmud, "Electricity access improvement using renewable energy and energy efficiency: a case of urban poor area of Dhaka, Bangladesh", Int. J. of Renewable Energy Research, 7(3), 2017, 1296-1306.
[57] Y. Choi, C. Lee, and J. Song, "Review of renewable energy technologies utilized in the oil and gas industry", Int. J. of Renewable Energy Research, 7(2), 2017.
[58] AREI, "Framework for transforming Africa to a renewable energy powered future with access for all", 2015, 11. Africa Renewable Energy Initiative. http://www.arei.org/wp-content/ uploads/2016/04/AREI-Framework_ENG-1.pdf.
[59] P. Ramchandra and D. Boucar, "Green energy and technology", 2011, 1-15, Springer, London Dordrecht Heidelberg New York.
[60] U. S. Kumar and S. Vijayarajan, "Feasibility study of optimization in renewable energy penetration to an isolated hybrid power plant", Int. J. of Trend in Research and Development, 4(4), 2017, 38-46.
[61] K. Oluoti, G. Megwai, A. Pettersson, and T. Richards, "Nigerian wood waste: a dependable and renewable fuel option for power production", World J. of Engineering and Technology, 2(3), 2014, 234-248.
[62] E. Omar, A. Haitham, and B. Frede, "Renewable energy resources: Current status, future prospects and their enabling technology", Renewable and Sustainable Energy Reviews, 2014, 39, 748–764.

[63] U. B. Akuru and O. I. A. Okoro, "Prediction on Nigeria's oil depletion based on Hubbert's Model and the need for renewable energy", ISRN Renewable Energy, 2011, 1-6.
[64] A. M. Van Voorden, S. O. Ani, and D. O. N. Obikwelu, "Autonomous Renewable Energy Systems", Nigerian J. of Technology, 28(1), 2009, 93–118.
[65] J. Bala, "Renewable energy and energy efficiency development in Nigeria". Keynote Paper at the 2-day Workshop on Renewable Energy and Energy Efficiency, 10th – 11th June, 2013, Nnamdi Azikiwe University, Awka.
[66] A. O. Obande, B. O. Abikoye, and P. E. Amiolemhen, The Use of Brewer's Spent Grain as an Effective Energy-Mix Strategy, International Journal of Engineering and Technology, 7(4), 2017.
[67] O. Ukwuoma, O. I. Ogundari, Y. O. Akinwale, and A. O. Adepoju, "Harnessing renewable energy resources for sustainable economic development in Nigeria", Proc. of 5th Annual and International Conference of the Renewable and Alternative Energy Society of Nigeria, Gregory University, Uturu, June 17th to 20th 2015, 103-115.
[68] S. M. Ogbonmwan and E. T. Ogbomida, "Renewable energy technologies for sustainable power supply in Nigeria", Proc. of 5th Annual and International Conference of the Renewable and Alternative Energy Society of Nigeria, Gregory University, Uturu, June 17th to 20th 2015, 96-102.
[69] A. S. Sambo, "Strategic development in renewable energy in Nigeria", International Association of Energy Economics. 4, 2009, 15-19.
[70] K. O. Amanze, E. I. Nnadi, and S. O. Oladejo, "Utilization of renewable energy for sustainable development in Nigeria", Proc. of 4th Annual and International Conference of the Renewable and Alternative Energy Society of Nigeria, Imo State University, Owerri, February 23rd to 26th 2014, 130-136.
[71] M. Nfah and J. M. Ngundam, "Identification of stakeholders for sustainable renewable energy applications in Cameroon", Renewable and Sustainable Energy Reviews, 16, 2012, 4661–4666.
[72] WHO, "Health in 2015: From Millennium Development Goals (MDGs) to Sustainable Development Goals (SDGs)", 2015, 3-11. www.who.int
[73] J. Shittu, "Towards achieving sustainable development for all: prioritizing targets for implementation. Which way forward for Nigeria?" Centre for Public Policy Alternatives, 2015, 1-18. www.cpparesearch.org/wp-content/.../Country-profile-on-SDGs-Nigeria-Final-Version.pdf
[74] N. Edomah, "On the path to sustainability: Key issues on Nigeria's sustainable energy development", Energy Reports, 2, 2016, 28-34.
[75] F. I. Ibitoye, The millennium development goals and household energy requirements in Nigeria, SpringerPlus, 2, 2013, 529. http://www.springerplus.com/content/2/1/529
[76] MDGs, Nigeria 2015 – Millennium Development Goals end point report. 2015. www.mdgs.gov.ng
[77] O. S. Oyedepo, "Energy and sustainable development in Nigeria: the way forward", Energy. Sustainability and Society, 2012, 2(1). https://link.springer.com /journal/13705/2/1/page/1
[78] A. S. Sambo, "The role of energy in achieving Millennium Development Goals (MDGs)", National Engineering Technology Conference (NETec 2008), Ahmadu Bello University, Zaria, 1st April, 2008.
[79] A. S. Sambo, "Renewable energy for rural development: The Nigerian perspective", ISESCO Science and Technology Vision, 1, 2005, 12 – 22.
[80] O. F. Ogunewo and T. O. Koledoye, "Renewable energy for reliable power supply in Nigeria", Proc. of 4th Annual and International Conference of the Renewable and Alternative Energy Society of Nigeria, Imo State University, Owerri, February 23rd to 26th 2014, 137-146.
[81] E. I. Efurumibe, A. D. Asiegbu, and M. U. Onuu, "Renewable energy and prospects in Nigeria", Scholarly J. of Scientific Research and Essays, 3(6), 2014, 73-76.
[82] O. K. Nwofor, C. E. Akujor, T. C. Chineke, E. A. Ugboma, R. C. Nwachukwu, D. Ebinuko, C. Achigbulam, O. Onumah, S. Prince, and Ibeawuchi, "Renewable energy development in the world's largest oil economies: the Nigerian situation", Proc. of 5th Annual and International Conference of the Renewable and Alternative Energy Society of Nigeria, Gregory University, Uturu, June 17th to 20th 2015, 82-88.
[83] U. K. Muhammad, S. Umar, M. Musa, and B. G. Danshehu, "Fabrication and performance evaluation of a prototype solar thermoelectric generator", Nig. J. of Solar Energy, 26, 2015, 43-50.
[84] I. N. Itodo, J. I. Dioha, P. A. Onwualu, and J. Ojosu, "Status of renewable energy in Nigeria", Energy Service Bulletin, 1, Solar Energy Society of Nigeria, 7, 2017, 11-23.
[85] I. Pérez-Diaz, J. R. Wilhelmi, and L. A. Arevalo, "Optimal Short-term operation schedule of a hydropower plant in a competitive electricity market", Energy Conversion and Management, 51, 2010, 2955–2966,
[86] I. Pérez-Diaz, J. R. Wilhelmi, and J. A. Sánchez-Fernández, "Short-term operation scheduling of a hydropower plant in the day-ahead electricity market", Electric Power Systems Research, 80, 2010, 1535–1542.
[87] ESHA, "Current status of small hydropower development in the EU-27", 2010. European Small Hydropower Association. http://www.streammap.esha.be/6.0.html.
[88] S. Kaunda, C. Z. Kimambo, and T. K. Nielsen, "Potential of small-scale hydropower for electricity generation in Sub-Saharan Africa", ISRN Renewable Energy, 1-15, 2012.
[89] W. S. Ebhota and F. Inambao, "Design basics of a small hydro turbine plant for capacity building in sub-Saharan Africa", African Journal of Science, Technology, Innovation, and Development, 8(1), 2016.
[90] H. D. Olusegun, A. S. Adekunle, I. O. Ohijeagbon, O. A. Oladosu, and H. A. Ajimotokan, "Retrofitting a hydropower turbine for the generation of clean electrical power", USEP: Journal of Research Information in Civil Engineering, 7(2), 2010, 61-69.
[91] A. A. Ghadimi, F. Razavi, and B. Mohammadian, "Determining optimum location and capacity for micro hydropower plants in Lorestan province in Iran", Renewable and Sustainable Energy Reviews, 15, 2011, 4125–4131.
[92] S. Kaunda, C. Z. Kimambo, and T. K. Nielsen, "Hydropower in the context of sustainable energy supply: a review of technologies and challenges, ISRN Renewable Energy, 2012, 2012.
[93] R. M. Barros and G. L. T. Filho, "Small hydropower and carbon credits revenue for an SHP project in national isolated and interconnected systems in Brazil, Renewable Energy, 48, 2012, 27 – 34.

[94] A. W. Bhutto, A. A. Bazmi, and G. Zahedi, "Greener energy: issues and challenges for Pakistan-hydel power prospective", Renewable and Sustainable Energy Reviews, 16, pp. 2732 – 2746.
[95] E. Bozorgzadeh, "Hydropower development in Iran: vision and strategy", Comprehensive Renewable Energy, 6, 2012, 253 - 263.
[96] B. Hagin, "Hydropower in Switzerland", Comprehensive Renewable Energy, 6, 2012, 343 - 354.
[97] B. Dursun and C. Gokcol, "The role of hydroelectric power and contribution of small hydropower plants for sustainable development in Turkey", Renewable Energy, 36, 2011, 1227–1235.
[98] E. Erdogdu, "An analysis of Turkish hydropower policy", Renewable and Sustainable Energy Reviews, 15, 2011, 689–696.
[99] M., Ramos, K. N. Kenov, and B. Pillet, "Stormwater storage pond configuration for hydropower solutions: adaptation and optimization", J. of Sustainable Development, 5(8), 2012, 27–42.
[100] Z. Xingang, L. Lu, L. Xiaomeng, W. Jieyu, and L. Pingkuo, "A critical-analysis on the development of China hydropower", Renewable Energy, 44, 2012, 1 - 6.
[101] O. S. Ohunakin, S. J. Ojolo, and O. O. Ajayi, "Small hydropower (SHP) development in Nigeria", Renewable and Sustainable Energy Reviews, 15, 2011, 2006 – 2013.
[102] E. J. Bala, Achieving renewable energy potential in Africa", Joint WEC, AUC and APUA Workshop, Addis Ababa, Ethiopia, 17th – 18th June, 2013.
[103] A. S. Sambo, "Overview of policy landscape in Africa on SHP project development and management", International Hydropower Conference, Abuja, 2008.
[104] C. Finardi and M. R. Scuzziato, "Hydro unit commitment and loading problem for day-ahead operation planning problem", Electrical Power and Energy Systems, 44, 2013, 7–16.
[105] C. Cheng, J. Shen, X. Wu, and K. Chau, "Operation challenges for fast-growing China's hydropower systems and respondence to energy saving and emission reduction", Renewable and Sustainable Energy Reviews, 16, 2012, 2386 – 2393.
[106] I. P. Ifabiyi, "Relationship between power generation and reservoir elements in the Jebba hydroelectric reservoir, Nigeria", Global J. of Science Frontier Research, 11(8), Version 1.0, 1-11, 2011.
[107] O. Olukanmi and A. W. Salami, "Assessment of impact of hydropower dams reservoir outflow on the downstream river flood regime – Nigeria's experience", Hydropower – Practice and Application, Dr. Hossein Sammad-Boroujeni (Ed.), 2012. http://www.intechopen.com/books/hydropower-practice-and-application/assessment-of-impact-of-hydropower-dams-reservoir-overflow-on-the-downstream-river-flood-regime-niger
[108] A. Usman and I. P. Ifabiyi, "Socio-economic analysis of the operational impacts of Shiroro hydropower generation in the lowland areas of middle River Niger", Int. J. of Academic Research in Business and Social Sciences, 2(4), 2012, 57 – 76.
[109] K. Hussey and J. Pittock, "The energy–water nexus: managing the links between energy and water for a sustainable future, Ecology and Society, 17(1), 2012, 31 – 39.
[110] P. Block, "Tailoring seasonal climate forecasts for hydropower operations", Hydrology and Earth System Science, 15, 2011, 1355 – 1368,
[111] P. Block, "Tailoring seasonal climate forecasts for hydropower operations in Ethiopia's Upper Blue Nile Basin", Hydrology and Earth System Science Discussions, 7, 2010, 3765–3802.
[112] L. Cunbin, L. Xian, and W. Minxia, "Risk analysis simulation model of economic evaluation in hydroelectric engineering project", Research J. of Applied Sciences, Engineering and Technology, 4(14), 2012, 2222 – 2226.
[113] Z. D. Deng, J. J. Martinez, A. H. Colotelo, T. K. Abel, A. P. LeBarge, R. S. Brown, B. D. Pflugrath, R. P. Mueller, T. J. Carlson, A. G. Seaburg, R. L. Johnson, and M. L. Ahmann, "Development of external and neutrally buoyant acoustic transmitters for juvenile salmon turbine passage evaluation", Fisheries Research, 113, 2012, 94–105.
[114] P. Baumann and G. Stevanella, "Fish passage principles to be considered for medium and large dams: the case study of a fish passage concept for a hydroelectric power project on the Mekong mainstream in Laos", Ecological Engineering, 48, 2012, 79 – 85.
[115] N. Matthews, "Water grabbing in the Mekong basin – an analysis of the winners and losers of Thailand's hydropower development in Lao PDR", Water Alternatives, 5(2), 2012, 392 – 411.
[116] D. Yewhalaw, W. Legesse, W. Van Bortel, S. Gebre-Selassie, H. Kloos, L. Duchateau, and N. Speybroeck, "Malaria and water resource development: the case of Gilgel-Gibe hydroelectric dam in Ethiopia", Malaria Journal, 8, 2009, 21 – 30.
[117] V. Chanudet, S., Descloux, A. Harby, H. Sundt, B. H. Hansen, O. Brakstad, D. Serça, and F. Guerin, "Gross CO_2 and CH_4 emissions from the Nam Ngum and Nam Leuk sub-tropical reservoirs in Lao PDR", Science of the Total Environment, 409, 2012, 5382 – 5391.
[118] N. L. Uzoewulu, "Management and maintenance of reservoir water storage in a hydropower station", Proc. of 19th Engineering Assembly of COREN, 2010, 126 – 130.
[119] P. Nikolaisen, 12 Mega dams that changed the world but not necessarily for the better, 2015. http://www.tu.no/artikler/12-megadammer-som-endret-verden/223528
[120] H. P. Fjeldstad, I. Uglem, O. H. Diserud, P. Fiske, T. Forseth, E. Kvingedal, N. A. Hvidsten, F. Økland, and J. A. Järnegren, "Concept for improving atlantic salmon *salmo salar smolt* migration past hydro power intakes", J. of Fish Biology, 81, 2012, 642-663.
[121] M. B. Amor, P. Pineau, C. Gaudreault, and R. Samson, "Electricity trade and GHG emissions: assessment of Quebec's hydropower in the North-eastern American market (2006 – 2008), Energy Policy, 39, 2011, 1711 – 1721.
[122] M. S. Babel, C. N. Dinh, M. R. A. Mullick, and U. V. Nanduri, "Operation of a hydropower system considering environmental flow requirements: a case study in La Nga River Basin, Vietnam", J. of Hydro-Environment Research, 6, 2012, 63 - 73.
[123] H. Horlacher, T. Heyer, C. M. Ramos, and M. C. da Silva, "Management of hydropower impacts through construction and operation, Comprehensive Renewable Energy, 6, 2012, 49 - 91.
[124] I. A. Adejumobi, O. I. Adebisi, and S. A. Oyejide, "Developing small hydropower potentials for rural electrification, IJRRAS, 17(1), 2013, 105-110.
[125] ESHA, "Small hydro for developing countries, support from thematic network on hydropower project", European Commission. 2006. European Small Hydropower Association.

[126]O. O. Fagbohun, "Studies on small hydro-power potentials of Itapaji Dam in Ekiti State, Nigeria", Int. J. of Engineering Science Invention, 5(1), 2016, 28-26.
[127]ESHA, "Small hydropower energy efficiency campaign action (SHERPA) - strategic study for the development of small hydro power (SHP) in the European union", 2008. European Small Hydropower Association (http://www.esha.be/.
[128]ESHA, "Guide on how to develop a small hydropower plant", 2004. European Small Hydropower Association http://www.esha.be/.
[129]UNIDO, "UNIDO projects for the promotion of small hydro power for productive use", UNIDO Evaluation Group, Independent Thematic Review, 2010, 20-39.
[130]S. Lajqi, N. Lajqi, and B. Hamidi, "Design and construction of mini hydropower plant with propeller turbine", Int. J. of Contemporary Energy, 2(1), 2016, 1-13.
[131]A. O. Edeoja, J. S. Ibrahim, and E. I. Kucha, "Conceptual design of a simplified decentralized Pico hydropower with provision for recycling water", J, of Multidisciplinary Engineering Science and Technology, 2(2), 2015, 22-34.
[132]A. O. Edeoja, J. S. Ibrahim, and E. I. Kucha, "Suitability of Pico-Hydropower technology for addressing the Nigerian energy crisis – A review", Int. J. of Engineering Inventions, 4(9), 2015, 17-40.
[133]M. F. Basar and M. M. Othman, "Overview of the key components of a Pico hydro power generation system", Latest Trend in Renewable Energy and Environment Informatics, 2013, 206-213.
[134]B. Ho-Yan, W. D. Lubitz, C. Ehlers, and J. Hertlein, "Field investigations in Cameroon towards a more appropriate design of a renewable energy Pico hydro system for rural electrification", 2014, In: Bolay J. C., Hostettler S., Hazboun E. (eds) Technologies for Sustainable Development. Springer, Cham, https://link.springer.com/chapter/10.1007/978-3-319-00639-0_5/fulltext.html
[135]V. Lahimer, M. Alghoul, K. B. Sopian, and M. I. Fadhel, "Research and development aspects of pico-hydro power", Renewable and Sustainable Energy Reviews, 2012, 16(8), 5861-5878.
[136]M. J. M. Ridzuan, S. M. Hafis, K. Azduwin, K. M. Firdaus, and Z. Zarina, "Development of pico-hydro turbine for domestic use", Applied Mechanics and Materials, 2015, 695, 408-412.
[137]M. Wohlgemuth, "Assessment of pico-hydro power potential in rural Ethiopia", BSc. Thesis, Dept. for Hydrology and River Basin Management, Technische Universität München. 2014.
[138]M. M. Othman, A. J. Razak, M. Basar, N. Muhammad, W. Wan Mohammad, and K. Sopian, "A review of the pico-hydro turbine: studies on the propeller hydro type", Int. Review of Mechanical Engineering, 9(6), 2015, 527-535.
[139]M. B. Farriz, H. Boejang, M. Masjuri, M. S. M. Aras, N. H. A. Razik, S. Mat, and K. Sopian, "Evolution of simple reaction type turbines for pico-hydro applications", Jurnal Teknologi, 77(32), 2015, 1–9.
[140]A. Nimje and G. Dhanjode, "Pico-hydro-plant for small scale power generation in remote villages", IOSR J. of Environmental Science, Toxicology and Food Technology, 9(1), 2015, 59-67.
[141]G. Yadav and A. K. Chauhan, "Design and development of Pico micro hydro system by using house hold water supply", Int. J. of Research in Engineering and Technology, 3(10), 2014, 114-119.
[142]J. Susanto and S. Stamp, "Local installation methods for low head Pico-hydropower in the Lao PDR", Renewable Energy, 44, 2012, 439 - 447.
[143]N. Smith and S. R. Bush, "A light left in the dark: the practice and politics of Pico hydro power in the load PDR", Energy Policy, 38(1), 2010, 116-127.
[144]S. Vicente and H. Bludszuweit, "Flexible design of a Pico-hydropower system for Laos communities", Renewable Energy, 44, 2012, 406 - 413.
[145]N. Sanunnaam, B. Sajjakulnukit, and R. Songprakorp, "Techno - socio - economic assessment of Pico hydropower installations in the Northern region of Thailand", Int. Conference on Environment Science and Engineering IPCBEE, 32, 2012, 114-118.
[146]H. Zainuddin, M. S. Yahaya, J. M. Lazi, M. F. M. Basar, and Z. Ibrahim, "Design and development of Pico hydro generation system for energy storage using consuming water distributed to houses, Int. J. of Electrical, Computer, Energetic, Electronic and Communication Engineering, 3(11), 2009, 1922-1927.
[147]P. Maher and N.P.A. Smith, "Pico hydro for village power - a practical manual for schemes up to 5 W in hilly areas", Micro Hydro Centre, Nottingham Trent University, 2001. http://www.eee.nottingham.ac.uk/picohydro/documents. html
[148]P. Maher, "Kenya case study 1 at Kathamba and case study 2 at Thima", 2002. http://www.eee.nottingham.ac.uk/ picohydro/documents.html#kenya
[149]P. Maher, "Design and implementation of a 2.2 kW Pico hydro serving 110 households", 2002, Micro Hydro Centre, Nottingham Trent University, http://www.eee.nottingham.ac.uk/ picohydro/documents.html.
[150]A. Pascale, T. Urmee, and A. Moore, "Life cycle assessment of a community hydroelectric system in rural Thailand", Renewable Energy, 36(11), 2011, 2799-2808.
[151]M. A, Haidar, F. M. Senan, A. Noman, and R. Taha, "Utilization of Pico hydro generation in domestic and commercial loads, Renewable and Sustainable energy reviews, 16, 2012, 518-524.
[152]M. Matewos and E. Minaye, "Designing portable micro - hydro for small scale hydro power plant construction", Int. J. of Engineering and Technology, 7(4), 2017, 515-518.
[153]T. Ajuwape and O. S. Ismail, "Design and construction of a 5 kW turbine for a proposed micro hydroelectric power plant installation at Awba dam, University of Ibadan", International Journal of Electrical and Power Engineering, 5(3), 2011, 131–138.
[154]A.O. Edeoja and L. Awuniji, "Experimental investigation of the influence of penstock configuration and angle of twist of flat blades on the performance of a simplified Pico-Hydro system", European J. of Engineering Research and Science, 2(7), 2017, 14-22.
[155]A. O. Edeoja, L. E. Ajeibi, and A. D. Effiong, "Influence of penstock outlet diameter and turbine hub to blade ratio on the performance of a simplified Pico hydropower system", Int. J. of Precious Engineering Research and Applications, 2(5), 2017, 31-46.
[156]A. O. Edeoja, M. Ekoja, and L. T. Tuleun, "Effect of penstock area reduction and number of turbine v-blades on the performance of a simple pico-hydropower system", European Journal of Advances in Engineering and Technology, 4(11), 2017, 797-806.

[157] A. O. Edeoja, J. A. Edeoja, and M. E. Ogboji, "Effect of the included angle of v-shaped blade on the performance of a simplified pico-hydro system", Int. J. of Scientific & Engineering Research, 8(8), 2017, 1208–1213.
[158] A. O. Edeoja, J. A. Edeoja, and M. E. Ogboji, "Effect of Number of Turbine Runner V-Blades on the Performance of a Simple Pico-Hydro System", Article in Press, Int. J. of Engineering and Technology, 2016, Ref. number 316145147726833.
[159] A. O. Edeoja, J. S. Ibrahim, and E. I. Kucha, "Investigation of the effect of penstock configuration on the performance of a simplified pico-hydro system", British J. of Applied Science & Technology, 14(5), 2016, 1-11.
[160] A. O. Edeoja, J. S. Ibrahim, and L. T. Tuleun, "Effect of Blade Cross-Section on the Performance of a Simplified Pico-Hydro System", American Journal of Engineering Research, 5(12), 2016, 1–9.
[161] D.T. Ipilakyaa, A.O. Edeoja, and A. Kulugh, "Influence of penstock outlet diameter and flat blade lateral twist angle on the performance of a simplified Pico hydropower system", Int. J. of Trend in Scientific Research and Development, 1(5), 2017, 394-406.
[162] B. Ziter, "Site assessment and design of a small off-grid hydroelectric system at the Jama-Coaque ecological reserve in coastal Ecuador", 2013. http://tmalliance.org/live/wp-content/uploads/2013/11/Late-Summer-2013-Hydroelectric-Final-Report-brett.pdf
[163] A. Adamkowski, "Discharge measurement techniques in hydropower systems with emphasis on the pressure-time method", Hydropower - Practice and Application, Dr. Hossein Samadi-Boroujeni (Ed.), 2012, ISBN: 978-953-51-0164-2, InTech. http://www.intechopen.com/books/hydropower-practice -andapplication/some-recent-achievements-in-discharge-measurements
[164] A. Von Flowtow, "Micro hydro penstock design", Oregon State University, Independent Study and Research Fellow Transcript Notation, June 2, 2012.
[165] K. V. Alexander and E. P. Giddens, "Optimum penstocks for low head micro-hydro schemes", Renewable Energy, 33(3), 2008, 507 –519.
[166] A. Kunwor, "Technical specifications of micro hydro systems design and its implementation: feasibility analysis and design of Lamaya Khola micro hydro power plant", BSc. Thesis, Arcada Polytechnic. 2012.
[167] M. J. Muchira, "Performance of a modified vehicle drive system in generating hydropower", MSc. Renewable Energy Technology Thesis, Kenyatta University, Kenya, April 2011, 44.
[168] M. T. Gatte and R. A. Kadhim, "Hydro power", In Energy Conservation, A. Z. Ahmed (Ed.), InTech Janeza Trdine 9, 51000 Rijeka, Croatia, 2012, 95 – 124. www.intechopen.com.
[169] G. Ingram, "Basic concepts in turbomachinery", Grant Ingram and Ventus Publishing ApS, 2009, 17, 88 – 91. www.bookboon.com
[170] F. Ayancik, U. Aradag, E. Ozkaya, K. Celebioglu, O. Unver, and S. Aradag, "Hydroturbine runner design and manufacturing", Int. J. of Materials, Mechanics and Manufacturing, 1(2), 2013, 162-165.
[171] B. J. Lewis, J. M. Cimbala, and A. M. Wouden, "Analysis and Optimization of Guide Vane Jets to Decrease the Unsteady Load on Mixed Flow Hydroturbine Runner Blades", 7th Int. Conference on Computational Fluid Dynamics (ICCFD7), Big Island, Hawaii, July 9-13, 2012, 1-12.
[172] R. Balaka, A. Rachman, and J. Delly, "Blade number effect for a horizontal axis river current turbine at a low velocity condition utilizing a parametric study with mathematical model of blade element momentum", Journal of Clean Energy Technologies, 2(1), 2014, 1-5.
[173] J. H. Park, N. J. Lee, J. V. Wata, Y. C. Hwang, Y. T. Kim, and Y. H. Lee, "Analysis of a Pico hydro turbine performance by runner blade shape using CFD", 26th IAHR Symposium on Hydraulic Machinery and Systems IOP Publishing IOP Conf. Series: Earth and Environmental Science, 15, 2012.
[174] K.V. Alexander, E.P. Giddens, and A.M. Fuller, "Axial-flow turbines for low head micro hydro systems", Renewable Energy, 34, 2009, 35 – 47.
[175] K.V. Alexander, E.P. Giddens, and A.M. Fuller, "Radial- and mixed-flow turbines for low head micro hydro systems", Renewable Energy, 34(7), 2009, 1885 - 1894.
[176] J. L. Chukwuneke, C. H. Achebe, P. C. Okolie, and H. A. Okwudibe, "Experimental investigation on the effect of head and bucket splitter angle on the power output of a Pelton turbine", Int. J. of Energy Engineering, 4(4), 2014, 81-87.
[177] R. Cobb and K. V. Sharp, "Impulse (turgo and pelton) turbine performance characteristics and their impact on pico-hydro installation", Renewable Energy, 50, 2013, 959-964.
[178] N, Pacayra, C. Sabate, and A. Villalon, "Assessment of streams in Oras, Eastern Samar: a basis for the design of pico-hydro projects and potential site for installation", Imperial J. of Interdisciplinary Research, 2(12), 2016, 1083-1088.
[179] S. Paudel, N. Linton, U. C. E. Zanke, and N. Saenger, "Experimental investigation on the effect of channel width on flexible rubber blade water wheel performance", Renewable Energy, 52, 2013, 1 – 7.
[180] B. Ho-Yan and W. D. Lubitz, "Performance evaluation of cross-flow turbine for low head application", Proc. of World renewable Energy Congress, Hydropower Applications, Moshfegh, B. (Ed.), 6, 1394 – 1399, 8 – 13 May, 2011. Linköping, Sweden.
[181] M. A. Khan and S. Badshah, "Design and analysis of cross flow turbine for micro hydro power application using sewerage water", Research J. of Applied Sciences, Engineering and Technology, 8(7), 2014, 821-828.
[182] M. M. Alnakhlani, M. Mukhtar, D. A. Himawanto, A. Alkurtehi, and D. Danardono, "Effect of the bucket and nozzle dimension on the performance of a Pelton water turbine", Modern Applied Science, 9(1), 2015, 25-33.
[183] A. Benzerdjeb, B. Abed, M. K. Hamidou, M. Bordjane, and A. M. Gorlov, "Experimental study on the effect of water velocity on the performance of a cross-flow turbine", Int. J. of Renewable Energy Research, 7(4), 2017, 2111-2119.
[184] S. Sangal, G. Arpit, and K. Dinesh, "Review of optimal selection of turbines for hydroelectric projects", Int. J. of Emerging Technology and Advance Engineering, 3, 2013, 424-430.
[185] B. Ho-Yan, "Design of a low head Pico hydro turbine for rural electrification in Cameroon", Thesis presented to The University of Guelph, 2012. https://dspace.lib.uoguelph.ca/ xmlui/handle/10214/3552
[186] W. Xuhe, Z. Baoshan, T. Lei, Z. Jie, and C. Shuliang, "Development of a pump-turbine runner based on multi-objective optimization", 27th IAHR Symposium on Hydraulic Machinery and Systems (IAHR 2014), IOP Conf. Series: Earth and Environmental Science, 22, 2014.

[187]R. Cobb, “Experimental study of impulse turbines and permanent magnet alternators for Pico-hydropower generation, Master degree thesis, Department of Mechanical Engineering, Oregon State University, 2011.
[188]S. Derakhshan and N. Kasaeian, “Optimal design of axial hydro turbine for micro hydropower plants”, 26th IAHR Symposium on Hydraulic Machinery and Systems, IOP Conf. Series: Earth and Environmental Science, 15, 2012.
[189]S. J. Williamson, B. H. Stark, and J. D. Booker, “Low head Pico hydro turbine selection using a multi-criteria analysis”, Proc. of the World Renewable Energy Congress, Hydropower Applications, B. Moshfegh (Ed.), 6, 1377 – 1385, 8 – 13 May, 2011. Linköping, Sweden.
[190]Y. Yassi and S. Hasemloo, “Improvement of the efficiency of a new micro hydro turbine at part loads due to installing guide vane mechanism”, Energy Conversion and Management, 51(10), 2010, 1970-1975.
[191]P. Maher, N. P. A. Smith, and A. A. Williams, “Assessment of Pico hydro as an option for off-grid electrification in Kenya”, Renewable Energy, 28, 2003, 1357–1369.