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Estimated Power Output from a Simplified Pico Hydropower System

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Authors' contributions

This work was carried out in collaboration between all authors. Author AOE designed the study, performed the computations, arrangement the results, wrote the protocol and wrote the first draft of the manuscript. Author JSI supervised the analyses of the study. Author LO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Based on the results of no-load tests carried out on a simplified Pico hydropower system currently undergoing development, on-load tests were carried out. A turbine of runner diameter 0.40 m, penstock diameters in the range $0.0381\,m \leq D_p \leq 0.0508\,m$ and nozzle area ratios in the range $0.2 \leq A_2/A_1 \leq 0.6$ were used for the on-load tests. A 2.5 kW alternator was linked to the turbine using a v-belt drive on pulleys of ratio 6:1. The effective vertical height from the outlet of the reservoir to the plane of the turbine shaft was 6.95 m. A 0.74 kW electric pump was used to recycle the water to the overhead reservoir. The rotational speeds of the turbine and alternator shafts, the volume of water displaced and voltage were measured for each penstock diameter and nozzle area ratio. The measured data were used to compute the system volumetric flow rate and to estimate the power output based on the alternator manufacturer's specifications. The turbine efficiency was also computed. The system developed a maximum voltage of 224 V with $D_p = 0.0508\,m$ and a minimum voltage of 111 V with $D_p = 0.0381\,m$ and $A_2/A_1 = 0.6$. The corresponding estimated power outputs

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were 2.125 kW and 1.545 kW respectively. The mean maximum and minimum efficiencies based on the estimated power output were 0.85 and 0.618 respectively. The overall results indicate very good potential for the system as a clean, decentralized small power generation unit that gives control to the user.

Keywords: Estimated power; Pico hydropower; on-load tests; turbine runner diameter; penstock diameter; nozzle area ratio.

1. INTRODUCTION

The role of energy in the economic development of any nation cannot be overemphasized though its production and application can also affect the environment adversely [1-7]. The attainment of the Sustainable Development Goals (SDGs), especially by developing nations, largely depends on greater access to clean energy. Also, Nigeria's vision for a robust economy and society hangs on energy availability and sustainability [8-16]. However, the stark reality is that access to energy is very minimal as a result of a mix of several factors. Several rural electrification programmes have not been able to achieve the noble goals they were aimed at. There is hardly any functional energy supply system in Nigeria that operates near the installed capacity, and are frequently susceptible to limitations resulting from human and natural causes. Moreover, many of them are large with resultant low efficiencies and utilize energy resources that produce adverse effects on the environment. Apart from the adverse effect on the environment, these fossil resources are significantly depleting and sustainability cannot be guaranteed [17]. Exploration and transportation of new deposits also compound the negative effects on the environment such as oil spillage while escalating friction in the host communities. The need, therefore, exists for exploration of alternative sources and better utilization and management of existing ones [18-25].

Globally, there is a clamour for the use of renewable energy sources rigorously. Interest is also growing in smarter, smaller and more decentralized energy systems which will utilize these renewable sources and the conventional ones more efficiently [26-33]. These systems convey more control to the end user, creating more sense of responsibility with regard to the maintenance and security of the system, especially with the prevalent activities of saboteurs as a result of terrorism and/or insurgency. Also, development of systems that generate the required power at or close to the point of the application has the potential of mitigating attacks on supply structures, particular with the growing restiveness in host communities in developing countries like Nigeria partly due to economic imbalance and poverty resulting usually form perceived or actually unfavourable government policies. The need to maintain and protect the supply structure is also entirely eliminated [34-43].

Hydropower has numerous advantages over other renewable energy sources but the large schemes which are generally predominantly in use in many countries like Nigeria also pose a lot of environmental problems [44-55]. These include harm to aquatic animals and habitat, the possibility of enhancement of disease to the neighbouring communities, as well as the displacement of settlements [56-60]. Large to small hydro which depend on flowing water sources are affected by the hydrological cycle (seasonal fluctuation) which translates to blackouts and significant power outages at some periods of the year. Also, debris and silt blockages of turbine passages often arise which also affect power supply. Furthermore, there are concerns about increasing emissions from the hydropower reservoirs [61-65].

Research on very small and pumped storage hydro is gaining momentum. Pico-hydro power provides a very good option. It suits the general characteristics of smarter, smaller decentralized systems which can be utilized in locations where larger conventional systems cannot be optimally located [66-70]. It has become a very useful option in the Asian developing countries where the topography has imposed great natural barriers to the uptake of conventional grid-connected energy systems [71-76]. There are many sites suitable for Pico-hydro development in Nigeria as in many other African countries but the deliberate focus has not been given to its development by articulating realizable policies geared towards achieving solutions to the energy crisis [34]. For instance, no direct mention is made of Pico-hydro systems in the current aggressive efforts of the Federal Government to strengthen and/or resuscitate and make more effective the hydropower sector in Nigeria [24].

Moreover, it has been verified that seasonal fluctuations of water levels also affect the operation of the conventional Pico-hydro schemes. Low water levels do not allow optimal operation while very high ones can sweep the units away [69-71]. Developing a means of applying the advantages of hydropower while greatly minimizing the operational and natural shortcomings will be a step in the right direction. Hence, developing of a Pico-hydro system that does not require naturally flowing water becomes necessary.

This work is a study of a simplified Pico-hydro system that is a variant of the pumped hydro scheme which could be operated where there is no naturally flowing water by utilizing overhead water storage. Such a system will eliminate several of the issues that conventional hydropower systems have to contend with while retaining its substantial advantage as a system for power supply in the mould current renewable energy systems' best practices. It will be decentralized thereby conceding control to the user and reducing the risk of sabotage. The limitation imposed by seasonal variations of water levels on conventional Pico-hydro systems will be eliminated as well. The SDGs, as well as Nigeria's vision for a robust economy and society at large, will be enhanced on a general note. Farms and small and medium scale enterprises will be offered an ultimately cheaper and cleaner energy option over which more control will be had. Rural areas, particularly those without the naturally flowing water, can also have access to this energy option which will, in the long run, justify the perceived 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 whole regions to ransom for some reason simply because access to the output or sources of centralized systems is within their immediate reach and/or control will be limited. An opportunity will be created for employment in terms of fabrication of the components of the system, installation and maintenance when necessary. This study itself is an aspect of a series of studies geared towards establishing the system for end-user status. The basic issues are therefore drawn from the earlier studies [77-84].

2. MATERIALS AND METHODS

The basic conceptual design for this work was adapted [85]. Of the five locally fabricated turbines used so far, the one with runner diameter of 0.40 m was selected for the current study as it appears to have been more accurately fabricated. Along with it, three PVC pipes of diameters in the range $0.0381\,m \leq D_p \leq 0.0508\,m$ were used as penstocks along with nine nozzle area ratios in the range $0.2 \leq A_2/A_1 \leq 0.6$ for each. An average net head of 6.95 m was used. The turbine and alternator shafts were linked using a v-belt drive on a pair of pulleys mounted on each shaft in order to amplify the rotational speed of the turbine shaft (N_T). The pulleys were machined from cast aluminium blanks with the diameters of the driving and driven pulleys being about $D_1 = 0.3\,m$ and $D_2 = 0.05\,m$. The diameters were fixed in order to get a ratio of 6:1. This was to ensure that the requirement for the rotational speed of the alternator to generate power was met considering the values of the maximum rotational speeds (N_{max}) of the turbine shaft obtained during the no-load tests. This ratio was in excess of the actual value required but it was deliberately used to compensate for any resistive load that has to be overcome. The whole set up is shown in fig. 1 and an enlarged view of the components on the ground level in Fig. 2.

The water pump used for the on-load tests was a 0.74 kW Ocean type model JSW10M with rated maximum head and discharge of 45 m and 50 litres/minute respectively. The mean experimental discharge was computed as 7.79 x 10^{-4} m^3/s by monitoring the water level in the underground reservoir for a period of time using a calibrated dip stick before and after each operation. For each of the penstocks and the corresponding nozzles, the rotational speed of the turbine shaft (N) was measured using the DT-2268 and DT-2858 Contact Type Digital Tachometer for each nozzle configuration and penstock diameter. The tachometers have a measurement range of 2.5 – 99,999 Rpm. The resolution is 1/1000 Rpm, accuracy $\pm$ 0.05% + 1 Rpm and photo detecting distance of 300 mm. They have memory capability of showing the last value, maximum value and minimum value, and a typical sampling time of 1 second. Also, the depth of water in the overhead reservoir was monitored using the calibrated dipstick. The voltage developed across the alternator was also measured using a Mastech Model MY-62 multi-meter for each operation. The penstock diameters, nozzle area ratios and the resultant potential differences were related and useful empirical equations were developed. The power output was estimated using the manufacturer's

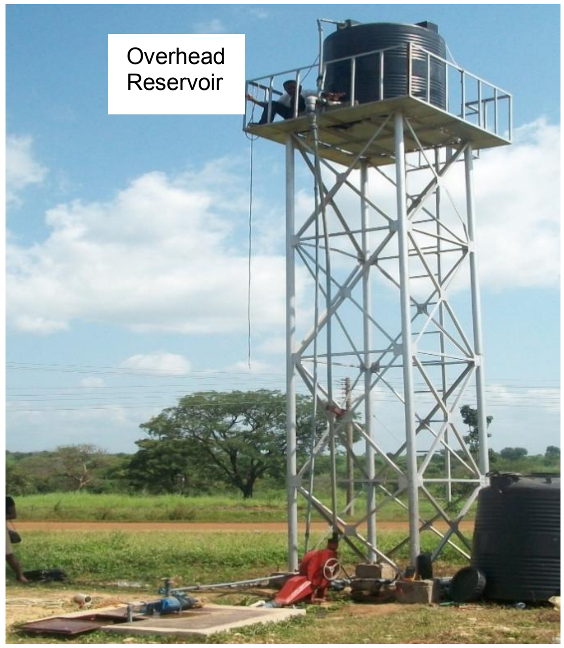

Fig. 1. The complete system set up of the system used for the Study

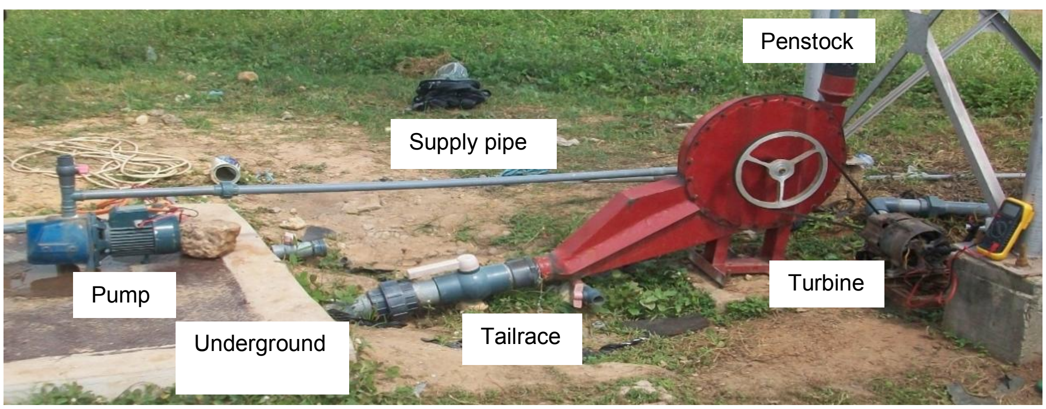

Fig. 2. Enlarged view of the 0.74 kW Pump, Turbine and Penstock

information on the alternator [86]. This was done by comparing the measured voltage to the rated voltage and power of the alternator.

3. RESULTS AND DISCUSSION

Generally, the characteristic curves obtained for voltage developed and the penstock diameter as shown in Fig. 3 indicate an increase in voltage with increasing penstock diameter. As presented in the discussion for the no-load results, the rotational speed of the turbine shaft increases with penstock diameter, especially for the smaller nozzle area ratios. This results from a combination of lower head losses and higher flow rates for larger penstock diameters and a more effective water jet creation by smaller nozzle area ratios. The tendency of the curves of the voltage increasing in a general sense with penstock diameter and decreasing nozzle area ratio indicates that potentially, larger penstock diameters can enhance the development of higher magnitudes of voltage [87-89]. This is especially indicated by the curve for $A_2/A_1 = 0.4$. These general relationships are shown in the figure tally with basic generator behaviour which shows that the voltage (or electromotive force) developed directly depends on the current flowing, flux, impedance, power generated and the speed of rotation of the shaft [90-93]. Hence, the various combinations of penstock diameters and nozzle area ratios that will produce high shaft rotational speeds are desirable for effective power generation using this system. The curve for $A_2/A_1 = 0.4$ showed a slight deviation from those of the other two in terms of the curvature. This possibly was brought about by slight better fabrication and better alignments in installing the nozzles. These could have contributed to the different curvature. However, the curve adequately shows the general trend of the voltage increasing with D_p.

The limitation at this stage of the work is that penstock diameters outside the range $D_p \geq 0.0508\,m$ were not very compatible with the fabricated turbines in terms of blade aperture available for interaction with the water jet. Wider aperture blades could give better results with larger values of D_p since higher volumetric flow rates which are necessary for hydropower generation will be permitted. However, increasing the blade aperture infinitely could present some difficulties. The first one will be the reduction of the volume of the 'cup' profile of the blade adapted for the turbine used in this study which could adversely affect the torque developed by the turbine runner. Furthermore, the wider aperture may increase the drag on the runner as the blades rotate with the water in the casing which can also reduce the torque developed [94-96]. The turbine can, however, be scaled up to accommodate larger values of D_p at the expense of additional cost. With further development of the system, however, very beneficial tradeoffs will hopefully be achieved.

The observations from the no-load tests which led to the recommendation of nozzle area ratios in the range $0.6 \geq A_2/A_1 \geq 0.2$ as more compatible to the turbines were confirmed during the on-load tests. Fig. 4 highlights the dependence of the voltage developed with the voltage increases as A_2/A_1 decreases. It corroborates the trend and implication of the results shown in Fig. 3. The curve for $D_p = 0.0381m$ exhibited a tendency of reduction in voltage if A_2/A_1 were further decreased beyond 0.2. This shows that very small values of D_p as well as A_2/A_1 will not be beneficial for the good performance of the system since the voltage developed may be adversely affected. Also, the curve for $D_p = 0.0381m$ occupied the lower portion among the curves confirming that the development of higher voltages is favored by the application of larger values of D_p [97-100].

The curves for $D_p \geq 0.0445\,m$ both exhibit this tendency with the one for $D_p = 0.0445\,m$ showing a steeper curvature upwards. This could have been as a result of the slightly more accurate alignment of the nozzle in directing the water jet on the blades. The figure indicates that for each D_p , $A_2/A_1 = 0.2$ enhanced the development of the highest voltage values of 150, 206 and 224 V for $D_p = 0.0381$, 0.0445 and 0.0508 m respectively. The use of nozzles in conventional hydropower turbine practice is indispensable and the observations in this work attest to that [73, 94, 101, 102]. It appears that the use of the range of values $A_2/A_1 < 0.2$ could further enhance the production of higher voltage values. This is obvious from the fact that $A_2/A_1 = 0.2$ gave the highest voltages for all D_p examined. Further stages of this work will consider only nozzles with $A_2/A_1 < 0.2$ which will, however, be more delicate to fabrication requiring more precision work and as a result increasing fabrication costs. Generally, the plots also show more clearly that larger D_p support higher voltage values and hence, higher power generation capacity.

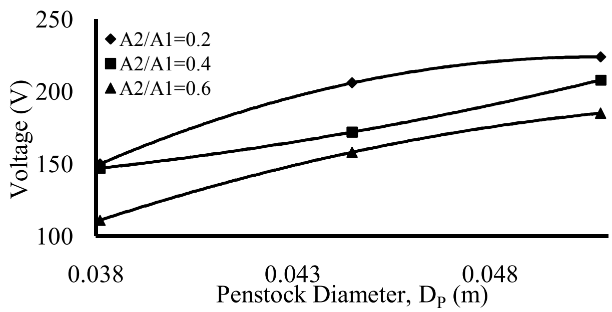

Fig. 3. Variation of voltage developed with penstock diameter for the selected range of nozzle area ratios

From the foregoing, the pair of $D_p = 0.0508\,m$ and $A_2/A_1 = 0.2$ is appropriate for potentially generating about 2.5 kW which is the minimum rating of the alternator used for this work at 224 V. Further scaling up of the turbine capacity to accommodate higher capacity generators is a target of future development of the system. However, maintaining such a supply steadily will require especially a better match between the value of D_p and the diameter of the supply pipe used for recycling the water. The diameter used for this work is 0.0254 m which translates to a supply pipe diameter to D_p ratio of 1:2. This means that the penstock discharges water nearly twice as fast as it is being recycled back to the overhead reservoir so that there is continuous variation in the head available to the turbine. The target ratio is 1:1, without compromising the desired result so that a reasonable and steady head can be maintained with the resultant effect of minimizing the fluctuation of the rotational speed of the turbine shaft (N_T). Another approach could be the introduction of multiple overhead reservoirs or a larger capacity one so that some degree of similarity can be established between the supply and discharge from the overhead reservoir. This will, in turn, stabilize the voltage developed and hence the power generated. At its current stage based on the results obtained so far, even the minimum voltage developed of 111 V corresponding to $D_p = 0.0381\,m$ and $A_2/A_1 = 0.6$ can generate sufficient power to operate appliances with rated voltage of 110 V. Hence, the output as it is presently is strongly suitable for hybridization with solar power and/or the inclusion of suitable inverter systems that could enhance storage of the generated power for later use.

Fig. 5 shows the plots of the voltage developed against the rotational speed of the alternator shaft (N_A) for $D_p = 0.0508\,m$. This curve and the one for $D_p = 0.0445\,m$ had exponential trends with positive equal indices but slightly different coefficients. This means that they indicate that increasing shaft rotational speed favours increasing voltage as earlier established. The expressions were $V = 67.638e^{0.0007N_A}$ and $V = 56.963e^{0.0007N_A}$. The difference in the coefficients shows that the larger diameter penstock will permit the development of higher voltage. Moreover, for a given nozzle area ratio as earlier asserted, N_A will be higher for the larger penstock diameters resulting in a higher exponential index. The relation for $D_p = 0.0381m$ was, however, polynomial in nature though it also maintained the tendency of increasing voltage with N_A. All the curves like the one in Fig. 5 show the direct dependence of the voltage developed on N_A . The need to ensure the selection of parameters to ensure high values of N_A therefore exists in order to obtain a good system performance. Expectedly, the pair of $D_p = 0.0508\,m$ and $A_2/A_1 = 0.2$ produced the highest value of $N_A = 1821$ rpm.

When the values of A_2/A_1 were considered instead of the values of D_p, the observation that smaller values of A_2/A_1 influence the development of higher voltages in conjunction with larger values of D_p . This generally buttresses the observation that increasing N_A should produce higher voltage values. Both observations show that a proper interaction of A_2/A_1 and D_p is key to good system output as in conventional hydropower schemes because of the creation of the requisite values of N_A.

Figs. 6 and 7 show the variation of Q_R and net head (H_n) product with A_2/A_1 and D_p respectively. The product, $Q_R H_n$, is part of the

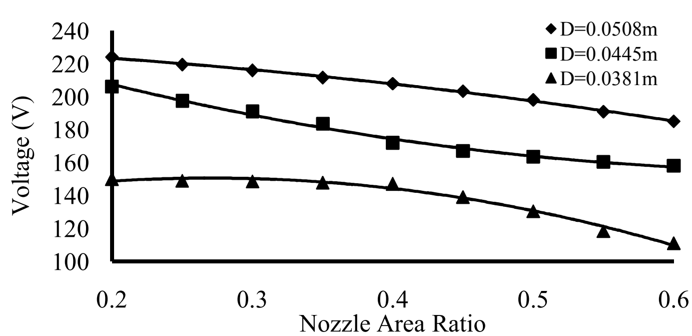

Fig. 4. Variation of voltage developed with nozzle area ratios for three of the penstock diameters

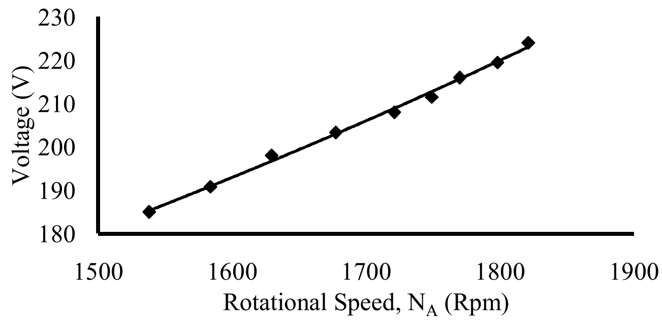

Fig. 5. Variation of voltage developed with rotational speed for 0.0508 m penstock diameter and the range of nozzle area ratios selected

expression for computing the power generated by a hydropower system. Its behaviour with these other system parameters could suggest an indication of the potentials of the system to generate power. The curves for all the values of D_p in Fig. 6 shows that $Q_R H_n$ generally increases with increasing A_2/A_1. This derives from the fact already established from the discussion of the no-load tests results that smaller values of A_2/A_1 support reduction in flow rate which then reduces $Q_R H_n$. From the general behaviour of the curves, if the flow rate and net head can be fixed for a system, then a clue as to the approximate nozzle area ratio required will be obtained which is beneficial in obtaining some other parameters. This agrees with the presentation of [86,96,97, 103-106] of an expression for determining the approximate diameter of the water jet required as $D_{jet} = 0.54[C_d Q_{max}/H_n]^{0.5}$, where are the coefficient of discharge and Q_{max} = maximum flow rate delivered by the nozzle. The curvature of the trend for $D_p = 0.0381\ m$ shows that small values of requires larger ranges of A_2/A_1 to improve on the head loss characteristics. This is shown by the sharper increase in $Q_R H_n$ for the larger ranges of A_2/A_1.

Fig. 7 corroborates the information obtained from Fig. 6 and shows that larger values of D_p favour increasing $Q_R H_n$. This is so because higher flow rates become involved with larger penstock diameters. The trend for $A_2/A_1 = 0.2$ appears more linear than the other two. It portrayed the fact that small values of A_2/A_1 can be complemented by larger D_p values in order to improve the product $Q_R H_n$. However, the transition is very gradual which explains the different trend for $A_2/A_1 = 0.2$. This shows that the magnitude of this product plays an important role in selecting appropriate matches of A_2/A_1 and D_p in order to achieve the desired results with this system. This is in accordance with conventional hydropower practice in which the flow rate and the available head play very strategic roles in deciding on a site or modification of an existing facility.

The power output (P_o) of the system was estimated using the manufacturer's specifications on shaft speed and maximum voltage for the alternator used for the study. The alternator used was for an ELepaq gasoline generator (SPC3000E2) with rated voltage 230 W,

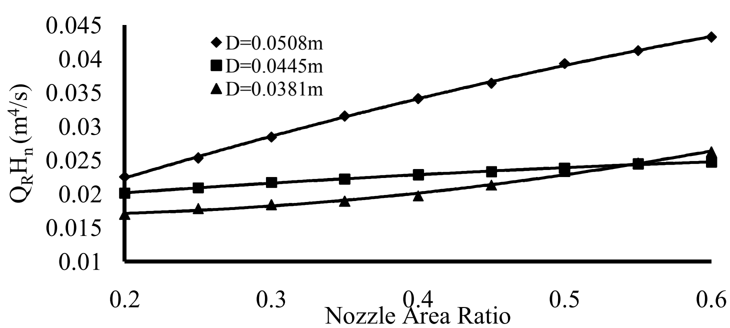

Fig. 6. Variation of the volumetric flow rate and net head product with nozzle area ratio

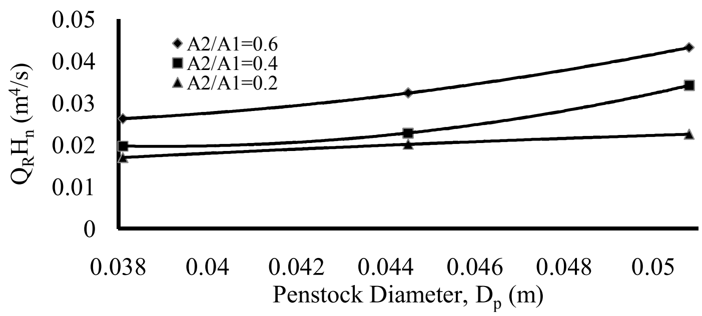

Fig. 7. Variation of the volumetric flow rate and net head product with penstock diameter.

frequency 50 Hz, output power 2.5 kW, maximum power 2.8 kW and power factor 1.0. Fig. 8 shows the plots of P_o against A_2/A_1. Expectedly, from the foregoing discussion as with the case of the shaft power during the no-load tests, P_o decreases with A_2/A_1 but this time more gradually and increases with increasing penstock diameter. Hence, higher power output is favored by smaller A_2/A_1 and larger D_p values. The trend for $D_p = 0.0445\,m$ appears slightly different due to losses encountered as a result of losses within the penstock which could have been different from those of the other two. Also, some slight leakages were experienced which could have added to the deviation. However, these and other possible issues permitted the trend to convey the general relationship between the estimated power and the nozzle area ratio.

The mean maximum estimated power generated by the system was 2.125 kW for $D_p = 0.0508\,m$ and the minimum value was 1.545 kW for $D_p = 0.0381\,m$. Theoretically, this power is adequate to run the pump used for recycling the water and supply the balance to the point of application. However, it is not adequate for that purpose since the power required to start the 0.74 kW pump used is much higher than 0.74 kW. Hence, in order to achieve the self-running status for the system, the turbine must be scaled up to generate higher power or some other source such as solar power can be used to run the pump through a hybrid system arrangement [29, 38].

Fig. 9 shows the variation of the system efficiency with A_2/A_1. Higher efficiencies are supported by smaller values of A_2/A_1. This arises from the fact that they create more effective jets which produce higher shaft rotational speeds. The figure resembles Fig. 46 which is because efficiency was computed from the output power data. This means that the explanation in the previous section of the curve for $D_p = 0.0445\,m$ still holds here. Hence, higher efficiency machines require that the penstock diameter is large enough and that the nozzle area ratio is reduced as low as possible.

It is worthy of note here that the efficiency values obtained from the on-load data were higher than the respective ones obtained from the no-load data. For instance, for $D_p = 0.05098\,m$, the mean no-load efficiency was 0.629 while the corresponding value for the on-load was 0.85. This is because of the magnification of the turbine shaft revolution nearly six times by using the pulley and belt drive. Undoubtedly, some

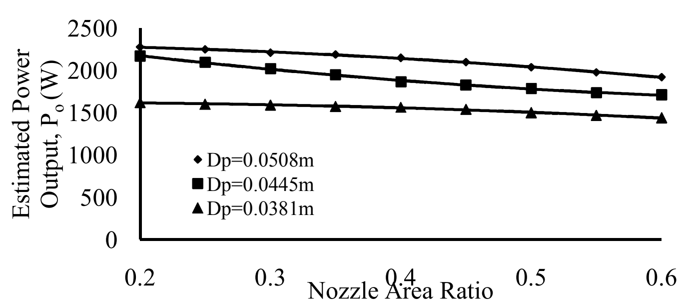

Fig. 8. Variation of estimated on-load system power output with Nozzle area ratio for the three Penstock diameters

mechanical losses may have been introduced but by and large the overall efficiency was improved. This value for the on-load tests compares well with 0.89 reported for single-nozzle Pelton wheels, being lower by only about 4%. However, with larger penstock diameters, the mean system efficiency could still be improved [86,107,108-109]. Considering the fact that this system is a departure from usual conventional turbine practice and that all the principles applied were developed for conventional systems, further modifications can bring more to light on the potentials of this system.

Fig. 10 shows an attempt to formulate an empirical expression of the estimated power output as a function of the product of the flow rate and net product on the basis of the penstock diameter 0.0508 m. The figure is similar to the ones for the other two penstock diameters. The empirical expressions are shown in Table 1. The first three on the table were obtained on the basis of penstock diameters. The curves have negative indices which generally increase with penstock diameter confirming the potentials of larger diameters for higher power generation.

Some other expressions of the estimated power output as a function of $Q_R H_n$ were also formulated based on the nozzle area ratio. These ones all have positive indices which steadily reduce and the coefficients also decrease with increasing A_2/A_1 indicative of the reduction of power generation potential. The expressions so obtained will be useful for further attempts to raise the performance of this system to self-running status.

As with the no-load data, the nozzle area ratio was chosen as the independent parameter. Figs. 11 to 13 show the variation of the flow rate and estimated power output with the nozzle area ratio. The curves for the penstock diameters were similar to the ones plotted for the no-load data and can hence be used to determine trial values of the parameters of the system for future modifications.

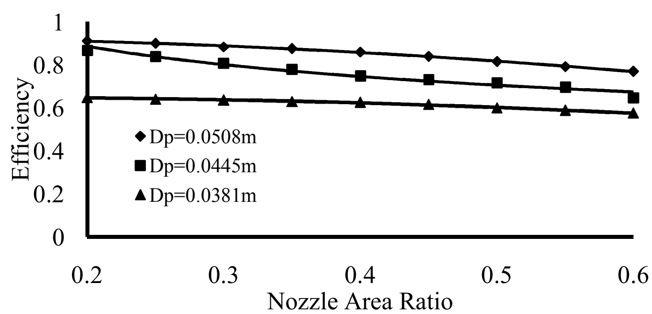

Fig. 9. Variation of on-load system efficiency with nozzle area ratio for the three penstock diameters

Table 1. Empirical expressions of the estimated power output as function of $Q_R H_n$

Parameter	Empirical expression	Trend type/R^2 value
D_p = 0.0508m	$P_o = 910.8(Q_R H_n)^{-0.247}$	Power/0.995
D_p = 0.0445m	$P_o = 20.757(Q_R H_n)^{-1.192}$	Power/0.896
D_p = 0.0381m	$P_o = 549.76(Q_R H_n)^{-0.266}$	Power/0.991
$A_2/A_1 = 0.20$	$P_o = 280905(Q_R H_n)^{1.26}$	Power/ 0.925
$A_2/A_1 = 0.25$	$P_o = 76812(Q_R H_n)^{0.951}$	Power/0.862
$A_2/A_1 = 0.30$	$P_o = 29252(Q_R H_n)^{0.7173}$	Power/0.853
$A_2/A_1 = 0.35$	$P_o = 17434(Q_R H_n)^{0.594}$	Power/0.863
$A_2/A_1 = 0.40$	$P_o = 13057(Q_R H_n)^{0.5293}$	Power/0.893
$A_2/A_1 = 0.45$	$P_o = 12953(Q_R H_n)^{0.539}$	Power/0.858
$A_2/A_1 = 0.50$	$P_o = 8448.3(Q_R H_n)^{0.438}$	Power/0.705
$A_2/A_1 = 0.55$	$P_o = 7252.7(Q_R H_n)^{0.4073}$	Power/0.675
$A_2/A_1 = 0.60$	$P_o = 5757.1(Q_R H_n)^{0.353}$	Power/ 0.556

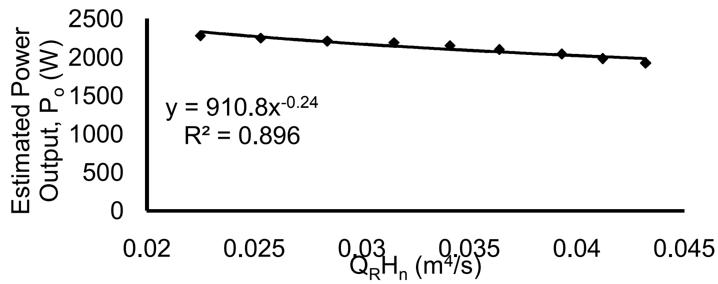

Fig. 10. Variation of estimated power output with the product of the flow rate and net head for the penstock of diameter 0.0508 m

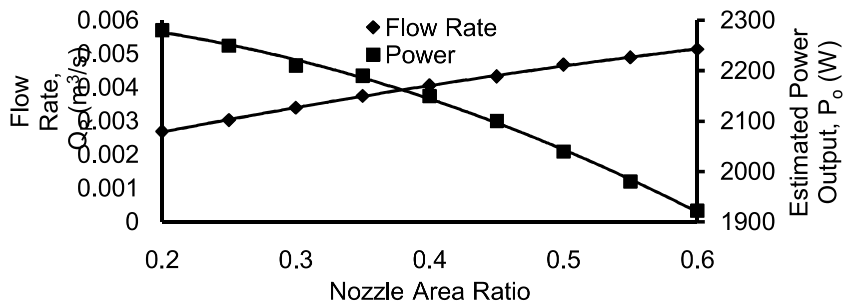

Fig. 11. Variation of flow rate and power output with nozzle area ratio for 0.0508 m penstock diameter

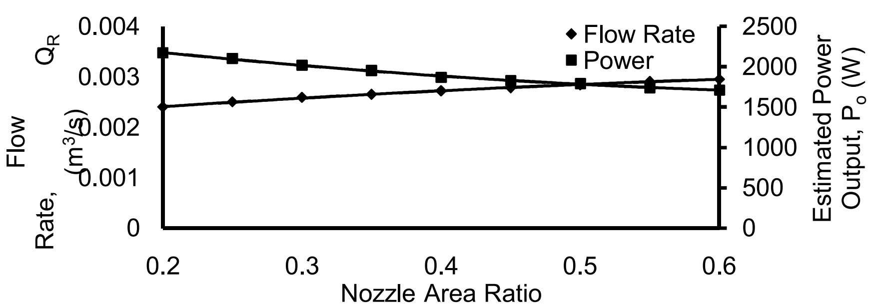

Fig. 12. Variation of flow rate and power output with nozzle area ratio for 0.0445 m penstock diameter

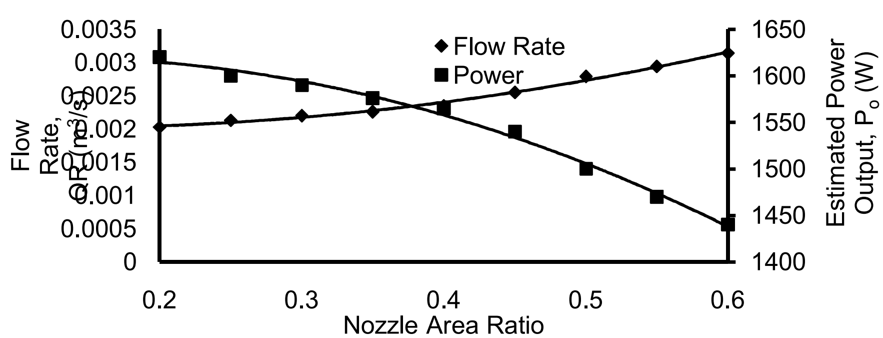

Fig. 13. Variation of flow rate and power output with nozzle area ratio for 0.0381 m penstock diameter

4. CONCLUSION

The performance of the simple Pico hydro system shows good promise towards actual implementation as a source of clean, decentralized and user-controlled energy with all the attendant benefits. However, there are several issues that still need to be addressed to arrive at this goal. They form the nucleus of immediate further aspects of this ongoing work. Such aspects include but are not limited to the utilization of solar power for the recycling of water and investigation of hybridization potentials, the investigation of the pump as turbine (PAT) option, scaling up the system for self-powering status and including locally developed generating and step up units.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Saatci M, Dumrul Y. The relationship between energy consumption and economic growth: Evidence from a structural break analysis for Turkey, Int. J. of Energy Econs. and Policy. 2013; 3(1):20-29.
2. ECA. Correlation and causation between energy development and economic growth, 1-18. Economic Consulting Associates; 2014. Available:https://assets.publishing.service.gov.uk/media/57a089bae5274a27b2000229/EoD_HD116_Jan2014EnergyEconomicGrowth.pdf
3. Akujor CE, Ogungbenro OA, Mejeha IM, Nwofor O, Alozie GA. The state of energy supply in nigeria: Need for more efficient utilization of fuelwood resources, Advances in Science and Tech. 2011; 5(1S): 1-4.
4. Gujba H, Mulugetta Y, Azapagic A. Power generation scenarios for Nigeria: An environmental and cost assessment Energy Policy. 2011;39:968–980.
5. Gujba H, Mulugetta Y, Azapagic A. Environmental and economic appraisal of power generation capacity expansion plan in Nigeria. Energy Policy, 2010;38:5636–5652.
6. Aliyu AS, Ramli TA, Saleh MA. Nigeria electricity crisis: Power generation capacity expansion and environmental ramifications. Energy. 2013;61:354-367.
7. Umar AA. Renewable and alternative energy: The Socio-economic Issues, Advances in Science and Tech. 2011; 5(1S):59-64.
8. WHO. Health in 2015: From Millennium Development Goals (MDGs) to Sustainable Development Goals (SDGs), World health Organization. 2015;3-11. Available :www.who.int
9. Edebeatu CC, Njoku I, Okujagu CU. Solar energy as an alternative to mitigating climate change for a sustainable Green environment, Proc. of 5th Annual and International Conference of the Renewable and Alternative Energy Society of Nigeria, Gregory University, Uturu. 2015;75-81.
10. Edomah N. On the path to sustainability: Key issues on Nigeria's sustainable energy development. Energy Reports. 2016;2:28-34.
11. Ibitoye FI. The millennium development goals and household energy requirements in Nigeria. Springer Plus. 2013;2:529. Available:http://www.springerplus.com/content/2/1/529
12. MDGs. Nigeria 2015 – Millennium Development Goals End point Report; 2015. Available:www.mdgs.gov.ng
13. Oyedepo OS. Energy and sustainable development in Nigeria: The way forward. Energy, Sustainability and Society. 2012; 2(1). Available:https://link.springer.com/journal/13705/2/1/page/1
14. Sambo AS. The role of energy in achieving Millenium Development Goals (MDGs), National Engineering Technology Conference (NETec 2008), Ahmadu Bello University, Zaria; 2008.
15. Shittu J. Towards achieving Sustainable Development for all: Prioritizing targets for implementation: Which way forward for Nigeria? Centre for Public Policy Alternatives. 2015;1-18. Available:www.cpparesearch.org/wp-content/.../Country-profile-on-SDGs-Nigeria-Final-Version.pdf
16. Ukwuoma O, Ogundari IO, Akinwale YO, Adepoju AO. 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. 2015;103-115.
17. Akuru UB, Okoro OI. A prediction on nigeria's oil depletion based on Hubbert's model and the need for renewable energy. ISRN Renewable Energy. 2011;1-6.
18. Ohimain EI. Diversification of Nigerian electricity generation sources, energy sources, Part B: Economics, Planning, and Policy. 2015;10(3):298-305.
19. Awosope CA. Nigeria electricity industry: Issues, challenges and solutions. Covenant University 38th Public Lecture, Public Lecture Series. 2014;3(2). Available:www.covenantuniversity.edu.ng/content/download/35621/.../1/.../38th+Public+Lecture. pdf
20. Kaseke N, Hosking SG. Sub-Saharan Africa electricity supply inadequacy: implications. Eastern Africa Social Science Research Review. 2013;29(2):113-132.
21. Omede J, Omede AA. Poor and inadequate electrical power generation, transmission and distribution in Nigeria: Economic, psycho-social, health, security and educational consequence. Journal of Applied Science. 2015;1(7):1-11.
22. Adejumobi IA, Adebisi OI, Oyejide SA. Developing small hydropower potentials for rural electrification. IJRRAS. 2013; 17(1):105-110.
23. Oseni MO. Households' Access to electricity and energy consumption pattern in Nigeria, Renewable and Sustainable Energy Reviews. 2012;16:990– 995.
24. Shezi L. Nearly 60% of Africans have no access to reliable electricity; 2015. Available:http://www.htxt.co.za/2015/05/08/nearly-60-of-africans-have-no-access-to-reliable-electricity/
25. UNDESA. Electricity and Education: The Benefits, Barriers, and Actions for Achieving the Electrification of Primary and Secondary Schools. United Nations Department of Economic and Social Affairs Available:https://sustainabledevelopment.un.org/content/documents/1608Electricity%20and%20 Education. pdf
26. Bala EJ. Renewable energy and energy efficiency development in Nigeria, Keynote paper at the 2-day Workshop on Renewable Energy and Energy Efficiency, Nnamdi Azikiwe University, Awka; 2013.
27. Amanze KO, Nnadi EI, Oladejo SO. 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, 2014;130-136.
28. CREN. Nigeria electricity crunch. Council for renewable energy, Nigeria, 2009. Available:www.renewablenigeria.org
29. Samy MM. Techno-economic analysis of hybrid renewable energy systems for electrification of rustic area in Egypt, Innovative Systems Design and Engineering. 2017;8(1).
30. Sambo AS. Enhancing renewable energy access for sustainable socio-economic development in Sub-Saharan Africa, Journal of Renewable and Alternative Energy Technologies. 2015;1(1):1-5.
31. Sambo AS. Strategic development in renewable energy in Nigeria. Inter. Association of Energy Econs. 2009;4:15-19.
32. UNFCCC. Facilitating technology deployment in distributed renewable electricity generation. United Nations Framework Convention on Climate Change; 2015. Available:http://unfccc.int/ttclear/misc/StaticFiles/gnwoerkstatic/TECdocuments/6d62b12d1a87483da716d80e77d5349b/b4539aaf699b459e9998606868dd49bd.pdf
33. Yuksel I. Renewable Energy Status of Electricity Generation for Future Prospect Renewable Energy. 2013;50:1037-1043.
34. Bala EJ. Achieving renewable energy potential in Africa, Joint WEC, AUC and APUA Workshop, Addis Ababa, Ethiopia; 2013.
35. Efurumibe EI, Asiegbu AD, Onuu MU. Renewable energy and prospects in Nigeria. Scholarly Journal of Scientific Research and Essays. 2014;3(6):73-76.
36. Itodo IN, Dioha JI, Onwualu PA, Ojosu J. Status of Renewable Energy in Nigeria, Energy Service Bulletin, 1, Solar Energy Society of Nigeria. 2017; 7:11-23.
37. Miawada NA, Abdullahi US. Overview of Renewable Sources in Nigeria, Advances in Science and Technology. 2011; 5(1S):70-74.
38. Muhammad UK, Umar S, Musa M, Danshehu BG. Fabrication and performance evaluation of a prototype solar thermoelectric generator. Nigerian of Journal Solar Energy. 2015;26:43-50.
39. Nwofor OK, Akujor CE, Chineke TC, Ugboma EA, Nwachukwu RC, Ebinuko D, Achigbulam C, Onumah O, Prince S, 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. 2015;82-88.
40. Obande AO, Abikoye BO, Amiolemhen PE. The use of Brewer's spent grain as an effective energy-mix strategy. International Journal of Engineering and Technology. 2017; 7(4).
41. Ogunewo OF, Koledoye TO. 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. 2014;137-146.
42. Ogbonmwan SM, Ogbomida ET. 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. 2015;96-102.
43. Orji CE, Akujor CE, Anusionwu BC. Review of major energy sources in Nigeria and their contribution to climate change: The need for renewable energy, Proc. of 4th Annual and International Conference of the Renewable and Alternative Energy Society of Nigeria, Imo State University, Owerri. 2014;124-129.
44. ESHA. Current status of small hydropower development in the EU-27. European Small Hydropower Association; 2010. Available:http://www.streammap.esha.be/6.0.html
45. ESHA. Small Hydropower Energy Efficiency Campaign Action (SHERPA) - Strategic study for the development of Small Hydro Power (SHP) in the European Union, European Small Hydropower Association; 2008.
Available:http://www.esha.be/
46. Fagbohun OO. Studies on small hydro-power potentials of Itapaji Dam in Ekiti State, Nigeria. Inter. Journal of Engineering Sci. Invention. 2016;5(1):28-26.
47. Kaunda CS, Kimambo CZ, Nielsen TK. Potential of small-scale hydropower for electricity generation in Sub-Saharan Africa. ISRN Renewable Energy. 2012;1-15.
48. RET Screen. Clean energy project analysis. RET Screen Engineering & Cases Textbook; 2012. Available:http://www.retscreen.net/ang/home.php
49. Sambo AS. Overview of policy landscape in Africa on SHP project development and management, international hydropower conference, Abuja; 2008.
50. Ohunakin OS, Ojolo SJ, Ajayi OO. Small Hydropower (SHP) Development in Nigeria, Renewable and Sustainable Energy Reviews. 2011;15:2006–2013.
51. Babel MS, Dinh CN, Mullick MRA, Nanduri UV. Operation of a hydropower system considering environmental flow requirements: A case study in La Nga River Basin, Vietnam, J. of Hydro-Environment Research. 2012;6:63-73.
52. Horlacher H, Heyer T, Ramos CM, Da Silva MC. Management of hydropower impacts through construction and operation, Comprehensive Renewable Energy. 2012;6:49-91.
53. Hussey K, Pittock J. The energy–water nexus: managing the links between energy and water for a sustainable future. Ecology and Society. 2012;17(1):31–39.
54. Usman A, Ifabiyi IP. 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. 2012;2(4):57–76.
55. Uzoewulu NL. Management and maintenance of reservoir water storage in a hydropower station, Proc. of 19th Engineering Assembly of Council for Regulation of Engineering in Nigeria (COREN). 2010;126–130.
56. Baumann P, Stevanella G. 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. 2012;48:79–85.
57. Deng ZD, Martinez JJ, Colotelo AH, Abel TK, LeBarge AP, Brown RS, Pflugrath BD, Mueller RP, Carlson TJ, Seaburg AG, Johnson RL, Ahmann ML. Development of external and neutrally buoyant acoustic transmitters for juvenile salmon turbine passage evaluation, Fisheries Research. 2012;113:94–105.
58. Fjeldstad HP, Uglem I, Diserud OH, Fiske P, Forseth T, Kvingedal E, Hvidsten NA, Økland F, Järnegren J. A Concept for Improving Atlantic salmon Salmo Salar

Smolt Migration Past Hydro Power Intakes, Journal of Fish Biology. 2012;81:642-663.

59. Matthews N. Water grabbing in the Mekong basin – an analysis of the winners and losers of Thailand's hydropower development in Lao PDR, Water Alternatives. 2012;5(2):392–411.
60. Yewhalaw D, Legesse W, Van Bortel W, Gebre-Selassie S, Kloos H, Duchateau L, Speybroeck N. Malaria and water resource development: the case of Gilgel-Gibe hydroelectric dam in Ethiopia, Malaria Journal. 2009;8:21–30.
61. Ifabiyi IP. Relationship between Power Generation and Reservoir Elements in the Jebba Hydroelectric Reservoir, Nigeria, Global Journal of Science Frontier Research. 2011;11(8)Version 1.0:1-11.
62. Nikolaisen P. 12 Mega dams that changed the world but not necessarily for the better; 2015. Available:http://www.tu.no/artikler/12-megadammer-som-endret-verden/223528
63. Olukanmi O, Salami AW. 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. Available:http://www.intechopen.com/books/hydropower-practice-and-application/assessment-of-impact-of-hydropower-dams-reservoir-overflow-on-the-downstream-river-flood-regime-niger
64. Chanudet V, Descloux S, Harby A, Sundt H, Hansen BH, Brakstad O, Serça D, Guerin F. 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. 2012;409:5382–5391.
65. Amor MB, Pineau P, Gaudreault C, Samson R. Electricity trade and GHG emissions: Assessment of Quebec's hydropower in the North-eastern American market (2006 – 2008), Energy Policy. 2011;39:1711 – 1721.
66. Edeoja AO, Ibrahim JS, Kucha EI. Suitability of Pico-Hydropower Technology for Addressing the Nigerian Energy Crisis – A review, International Journal of Engineering Inventions. 2015;4(9):17-40.
67. Farriz MB, Boejang H, Masjuri M, Aras MSM, Razik NHA, Mat S, Sopian K. Evolution of Simple Reaction Type Turbines for Pico-Hydro Applications, Jurnal Teknologi. 2015;77(32):1–9.
68. Ho-Yan BP. Design of a Low Head Pico Hydro Turbine for Rural Electrification in Cameroon, Master's Thesis, The University of Guelph, Ontario, Canada; 2012.
69. Lahimer A, Alghoul M, Sopian KB, Fadhel MI. Research and development aspects of pico-hydro power, Renewable and Sustainable Energy Reviews. 2012;16(8): 5861-5878.
70. Ho-Yan B, Lubitz WD. Performance evaluation of cross-flow turbine for low head application, Proc. of World renewable Energy Congress, Hydropower Applications, Moshfegh, B. (Ed.), 8–13 May, 2011;1394–1399, Linköping, Sweden.
71. Nimje AA, Dhanjode G. Pico-hydro-plant for small scale power generation in remote villages. IOSR Journal of Environmental Science, Toxicology and Food Technology. 2015;9(1):59-67.
72. Pacayra N, Sabate C, Villalon A. Assessment of Streams in Oras, Eastern Samar: A Basis for the Design of Pico-hydro Projects and Potential Site for Installation, Imperial Journal of Interdisciplinary Research. 2016;2(12): 1083-1088.
73. Sanunnaam N, Sajjakulnukit B, Songprakorp R. Techno - socio - economic Assessment of Pico Hydropower Installations in the Northern Region of Thailand, International Conference on Environment Science and Engineering IPCBEE. 2012;32:114-118.
74. Wohlgemuth M. Assessment of pico-hydro power potential in rural Ethiopia, Bachelor of Science Thesis, Dept. for Hydrology and River Basin Management, Technische Universität München; 2014.
75. Yadav G, Chauhan AK. Design and Development of Pico Micro Hydro System by Using House Hold Water Supply, International Journal of Research in Engineering and Technology. 2014; 3(10):114-119.
76. Basar MF, Othman MM. Overview of the Key Components of a Pico Hydro Power Generation System, Latest Trend in Renewable Energy and Environment Informatics. 2013;206-213.
77. Edeoja AO, Awuniji L. 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 Journal of

Engineering Research and Science. 2017; 2(7):14-22.
78. Edeoja AO, Ajeibi LE, Effiong AD. Influence of penstock outlet diameter and turbine hub to blade ratio on the performance of a simplified Pico hydropower system. International Journal of Precious Engineering Research and Applications. 2017;2(5):31-46.
79. Edeoja AO, Ekoja M, Tuleun LT. 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. 2017;4(11):797-806.
80. Edeoja AO, Edeoja JA, Ogboji ME. Effect of the Included Angle of V-Shaped Blade on the Performance of a Simplified Pico-Hydro System, International Journal of Scientific & Engineering Research. 2017; 8(8):1208–1213.
81. Edeoja AO, Edeoja JA, Ogboji ME. Effect of number of turbine runner V-Blades on the Performance of a Simple Pico-Hydro System, Accepted for publication in International Journal of Engineering and Technology, 2016, Reference number 316145147726833, Article in Press.
82. Edeoja AO, Ibrahim JS, Kucha EI. Investigation of the Effect of Penstock Configuration on the Performance of a Simplified Pico-hydro System. British Journal of Applied Science & Technology. 2016;14(5):1-11.
83. Edeoja AO, Ibrahim JS, Tuleun LT. Effect of blade cross-section on the performance of a simplified Pico-hydro system, American Journal of Engineering Research. 2016;5(12):1–9.
84. Ipilakyaa DT, Edeoja AO, Kulugh A. Influence of penstock outlet diameter and flat blade lateral twist angle on the performance of a simplified Pico hydropower system. International Journal of Trend in Scientific Research and Development. 2017;1(5):394-406.
85. Edeoja AO, Ibrahim JS, Kucha EI. Conceptual design of a simplified decentralized Pico hydropower with provision for recycling water. Journal of Multidisciplinary Engineering Science and Technology. 2015;2(2):22-34.
86. Muchira MJ. Performance of a modified vehicle drive system in generating hydropower, MSc. Renewable Energy Technology Thesis, Kenyatta University, Kenya, April 2011;44.
87. Gatte MT, Kadhim RA. Hydro Power, In Energy Conservation, A. Z. Ahmed, (Ed.), InTech Janeza Trdine 9, 51000 Rijeka, Croatia. 2012;95–124. Available:www.intechopen.com
88. Alexander KV, Giddens EP. Optimum Penstocks for Low Head Microhydro Schemes, Renewable Energy. 2008; 33(3):507–519.
89. RETScreen International. Clean Energy Project Analysis Engineering & Cases Textbook: Small Hydro Project Analysis, CANMET Energy Technology Centre – Varennes in Collaboration with NASA, UNEP & GEF; 2004. Available:http://www.retscreen.net/
90. Chukwuneke JL, Achebe CH, Okolie PC, Okwudibe HA. Experimental Investigation on the Effect of Head and Bucket Splitter Angle on the Power Output of a Pelton Turbine, Inter. Journal of Energy Engineering. 2014;4(4):81-87.
91. Khan MA, Badshah S. Design and analysis of cross flow turbine for micro hydro power application using sewerage water. Research Journal of Applied Sciences, Engineering and Technology. 2014;8(7): 821-828.
92. Kunwor A. 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.
93. Lajqi S, Lajqi N, Hamidi B. Design and construction of mini hydropower plant with propeller turbine, Inter. Journal of Contemporary Energy. 2016;2(1):1-13.
94. Douglas JF, Gasiorek JM, Swaffield JA. Fluid Mechanics, ELBS Edition of the 3rd Edition, ISBN 0 582 30555 1, Produced by Longman Singapore Publishers (Pte) Ltd. 1997;315, 316, 666–678.
95. Cobb BR, Sharp KV. Impulse (Turgo and Pelton) Turbine Performance Characteristics and Their Impact on Pico-Hydro Installation, Renewable Energy. 2013;50:959-964.
96. Sangal S, Arpit G, Dinesh K. Review of Optimal Selection of Turbines for Hydroelectric Projects, Inter. Journal of Emerging Technology and Advance Engineering. 2013;3:424-430.
97. Maher P, Smith NPA, Williams AA. Assessment of Pico hydro as an option for off-grid electrification in Kenya, Renewable Energy. 2003;28:1357–1369.

98. Lewis BJ, Cimbala JM, Wouden AM. Analysis and Optimization of Guide Vane Jets to Decrease the Unsteady Load on Mixed Flow Hydroturbine Runner Blades, 7th International Conference on Computational Fluid Dynamics (ICCFD7), Big Island, Hawaii, July 9-13, 2012;1-12.
99. Paudel S, Linton N, Zanke UCE, Saenger N. Experimental Investigation on the Effect of Channel Width on Flexible Rubber Blade Water Wheel Performance, Renewable Energy. 2013;52:1–7.
100. Simpson R, Williams A. Design of Propeller Turbines for Pico Hydro, Version 1.1c, April 2011. Available:www.picohydro.org.uk
101. Kjølle A. Hydropower in Norway: Mechanical Equipment, Survey prepared in the Norwegian University of Science and Technology, Trondheim, 2001;20.
102. Ridzuan MJM, Hafis SM, Azduwin K, Firdaus KM, Zarina Z. Development of pico-hydro turbine for domestic use, Applied Mech. and Mats. 2015;695:408-412.
103. Ajuwape T, Ismail OS. Design and Construction of a 5kW Turbine for a Proposed Micro Hydroelectric Power Plant Installation at Awba Dam University of Ibadan. Int. J. of Elect. and Power Eng. 2011;5(3):131–138.
104. Alexander KV, Giddens EP, Fuller AM. Radial- and mixed-flow turbines for low head micro hydro systems. Renewable Energy. 2009;34(7):1885-1894.
105. Alexander KV, Giddens EP, Fuller AM. Axial-flow turbines for low head micro hydro systems. Renewable Energy. 2009; 34(1):35–47.
106. Alnakhlani MM, Mukhtar M, Himawanto DA, Alkurtehi A, Danardono D. Effect of the Bucket and Nozzle Dimension on the Performance of a Pelton Water Turbine. Modern Applied Science. 2015;9(1):25-33.
107. ESHA. Small hydro For Developing Countries, Support from Thematic Network on Hydropower Project, European Commission. European Small Hydropower Association; 2006. Available:http://www.esha.be/
108. ESHA. Guide on How to Develop a Small Hydropower Plant, European Small Hydropower Association; 2004. Available:http://www.esha.be/
109. Othman MM, Razak AI, Basar M, Muhammad N, Wan Mohammad W, Sopian K. A Review of the Pico-Hydro Turbine: Studies On The Propeller Hydro Type, Int. Review Of Mech. Eng. 2015; 9(6):527-535.

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