

EFFECT OF THE NUMBER OF SPLINED BLADES OF A LOCALLY-FABRICATED TURBINE ON THE PERFORMANCE OF A SIMPLIFIED PICO HYDROPOWER SYSTEM

ABSTRACT

The basic operational parameters of a simplified Pico hydropower system were investigated using five locally fabricated turbines with 3, 5, 7, 9 and 11 splined blades in conjunction with a vertical penstock of diameter 0.0762 m and nozzle of diameters 0.0158, 0.0212, 0.0266, 0.0343 and 0.042 m. Water from an overhead reservoir 6.95 m high was discharged through the penstock to the turbines one after the other and recycled to the overhead reservoir using a 1.11 kW pump. For the on-load tests, a 3.9 kVA generator was linked to the system by a 6:1 pulley ratio belt drive. The mean rotational speeds of the shafts of each turbine and generator, volume of water displaced in the reservoirs and electrical quantities were measured for each nozzle diameter, while the shaft power, flow rate and efficiency were then computed. Dimensionless flow, head and power coefficients, and specific speed were computed and a functional characteristic relating them developed. The turbine with 11 blades developed a maximum voltage of 238 V with the largest nozzle diameter and a minimum voltage of 2.3 V with the smallest. The corresponding estimated power output computed using the manufacturer's specification on the generator were 1765.96 W and 7.613 mW respectively. The mean maximum and minimum efficiencies based on the estimated power output were 0.8797 and 0.0007 respectively. This basically indicates that the larger nozzle diameters combined with the higher number spline blades favour good operation of the system. These show that the system has the potential of being a simple, environmentally friendly and decentralized small power generation system that could potentially contribute to the improvement of the Nigerian energy crisis.

Keywords: Dimensionless coefficients, Locally fabricated turbine, Nozzle diameters, Pico hydropower, Rotational speed, Splined blades.

INTRODUCTION

The ever-escalating gap between demand and supply of electricity poses a challenge in both technologically developing and advanced countries. In Nigeria, the energy crisis has continued to grow due to the inability of the government to develop a far extending plan to cope with the demand for energy. Under these crucial circumstances, there is therefore a need to seek alternative sources for power generation [1-3]. The summary of all the approaches to the energy crisis is generally the development of smaller, smarter, decentralized systems and more efficient utilization of existing ones. These are less expensive, more environmentally benign and concede the control to the end user thereby reducing the exposure to influence of outsiders with whatever motivation [4-6].

Energy plays a critical vital role in the economic growth, progress, and development, as well as poverty eradication and security of any nation. The standard of living of any given country can be directly related to the per capita energy consumption, which measures the per capita income and the prosperity of a nation [7-10]. Future economic growth crucially depends on the long term availability of energy from sources that are affordable, accessible, sustainable and environmentally friendly. The world energy crisis is largely due to the rapid population growth and the increase in the living standard of whole societies. It has engulfed Nigeria for more than two decades, has been enormous and has largely contributed to the incidence of poverty by paralyzing industrial and commercial activities [11-16].

A large proportion of Nigerians still do not have access to electricity giving rise to an increasing power crisis in the nation [17-19]. It has been established that about 40% Nigerian households had access to the national grid while more than 45% do not, with much more than 6% supporting their grid access with personal petrol/diesel generators and around 3% relying completely on self-generator. About 1.1% have access to the rural electrification programs and nearly 75% of Nigerians still depend on firewood as their cooking fuel with about 20% relying on kerosene. This is directly as a result of the low access to electricity and its low reliability of services. An urgent need for efforts for further developments of the overall Nigerian electricity sector as well as rural electrification programs to ensure rapid economic development therefore exists [20-22]. The energy revolution will require moving from electricity systems based on centralized 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 [2, 23].

Hydropower is a renewable, economic, non-polluting and environmentally benign source of energy. Amongst all renewable sources of energy it is the most reliable and cost effective accounting for about 19% of global electricity production from both large and small power plants second only to fossil fuels. A small-scale hydropower is one of the most cost-effective and reliable energy technologies to be considered for providing clean electricity generation. [24-28]. A lot of hydropower stations have been built all over the world and a large number of hydro power projects of capacity greater than 100, 000 MW are currently being deployed, Asia having a large proportion [29, 30]. In Nigeria, the part currently explored at Kainji, Jebba and Shiroro is a small proportion of the available 14750 MW, with the present Government making several efforts to improve and stabilize the power sector, including the Mambilla and Gurara projects [15, 18, 22, 31-34]. The country has consistently experienced epileptic power supply partly as a result of its inability to exploit its vast hydropower potential in addition to the fact that the available large hydropower plants are not operating up to installed capacity [21, 35-37].

However, large hydropower schemes are generally affected by seasonal fluctuations in water level apart from adversely affecting marine ecology as well as the social well-being of people. To combat the problem of seasonal variation in water level as well as other issues with conventional hydropower systems, alternative methods, using pumped storage have been developed. Pumped storage involves storing water at a higher level and releasing it to generate power by turning a turbine at a lower level. Small hydro schemes have gained popularity especially in rural communities due to its simplicity in design, ease of operation, low environmental impacts in comparison to large hydropower schemes [29, 35, 38-42]. Furthermore, communities could take advantage of simple drinking water projects or irrigation systems to install small hydro schemes. Generally, developing ways of utilizing the advantages of hydropower which minimize the operational and natural shortcomings is a step in the right direction.

Nigeria, like many African countries, needs development, and indeed sustainable development, driven by sustainable energy supply in order to eliminate poverty and advance the living standard of the citizens in the long run. The huge renewable energy potentials that abound in the country in the form of water bodies, large and small, need be harnessed and transformed into electricity, modern fuels, and process heat required for driving the economy (). However, appropriate policies and legislations must be put in place with relevant technologies such as Pico hydro acquired and utilized as well as attract private investments in order to fully realize the potentials. However, most of the projections and hydropower activities do not directly consider Pico hydro technology thereby excluding the majority of Nigerians living in the rural areas [6]. However, an aggressive attention to the technology can contribute to the enhancement of the SDGs' goals [43]. Farms and small and medium scale enterprises could be offered an ultimately cheaper and cleaner energy option over which they have more control. The adverse effect of the use of other energy sources on the environment and the potential threat of insurgent activities on the largely centralized energy system will reduce [44, 45].

Pico hydro is the smallest hydro power generation scheme. It is a clean and renewable source of energy available to localities with water potential. Pico hydro has been found to be more cost effective compared to diesel, photovoltaic and wind sources of power generation for off grid electrification; especially in rural areas. Pico hydro systems are reliable as individuals or communities could protect their facilities from sabotage and terrorist attacks [46-48].

Pico hydro system has been given increasing interest within multiple fields. This is due to the increasing demand for energy on a global basis in addition to the growing focus on meeting this demand by utilizing renewable energy resources [49-52]. It has been predicted that Pico hydro system will play a key role in the supply of energy in the foreseeable future. Although many innovations on Pico hydro schemes have been done several studies are still continually being carried out to improve the efficiency of the systems. Achieving an increase in efficiency in the order of 0.1% would lead to a large increase in electrical power output, hence providing energy independence while mitigating climate change and curbing the energy crisis [53-56]. Although Pico hydro has enormous social and environmental benefits, it still harbors some disadvantages among which are its site specific nature, high capital costs and lack of support from government institutions which all serve as barriers for adopting the scheme [57-60].

A simplified Pico hydropower system has been undergoing development in The Department of Mechanical Engineering at Joseph Sarwuan Tarka University (formerly University of Agriculture), Makurdi, Nigeria for some years now in a bid to introduce a simple, decentralized and environmentally benign energy supply option into the Nigerian mix. The system has an overhead and underground reservoirs linked with a penstock (vertical PVC pipe) through a locally fabricated and simplified turbine having a very simplified turbine of some configuration. The water is then recycled from the underground reservoir to the overhead one for the process to continue. The several studies so far have utilized the conceptual system design presented in Edeoja *et al.* [61]. Specific aspects of the studies have been on the effect of penstock diameter and configuration [62-64], effect of penstock area reduction [65, 66], effect of blade cross section [58, 67], effect of number of v-blades [68], effect of included angle of v-blades [62], effect of

flat blade twist angle [44, 65], and effect of hub to blade ratio [1, 66]. Others have been on shaft power as a function of flow rate net head product [69], nozzle area ratios [70], estimated power output [54], and turbine dimensionless coefficients and net head/flow rate characteristic [71]. A more recent study considered the combined effects of penstock configuration, number of v-blades, blade twist angle and hub to blade ratio [1]. The results so far have instigated further interest in fine tuning the system's good potentials for deployment, with the issue still being tackled revolving around the water recycling aspect. The unique feature of this effort is recycling the water to enable the application of the system where naturally flowing water is not available. The pump saddled with this aspect is still powered externally, meaning that the system could be successfully deployed using a hybrid scheme with solar energy to power the pump. This of course will increase the cost significantly. However, the initial goal of developing a standalone system is still on and is the background leading to the current investigations. The present system being developed is an effort to bring the potentials of Pico hydro systems to bear on the various efforts geared towards attainment of Green energy that is sustainable and affordable. Furthermore, it will confer control to end user being decentralized thereby reducing its vulnerability to sabotage. Also, the system will not be directly affected by the environmental and weather issues that affect conventional hydropower systems. Continuing efforts are however still on to bring it to the target self-running status.

Theoretical Background

The following basic theory was incorporated in the computations of the system parameters. The power input to a hydraulic turbine is given by the equation 1 [61, 72].

$$P_h = \rho g Q H_n \quad (1)$$

where H_n is the net head and is defined by Corb [73] as in equation 2, ρ = density, g = acceleration due to gravity, and Q = volumetric flow rate.

$$H_n = H_g - H_L \quad (2)$$

where H_g is the gross head and H_L is the sum of all head losses in the penstock, given by $H_L = H_f + H_{minor} + K_C$. The head loss is made up of the major and minor losses caused by viscous forces in the pipe and secondary flow structures resulting from changes in direction and geometry of the flow, respectively. The major losses H_f can be found using equation 3 [73].

$$H_f = \frac{6.87L}{d^{1.165}} \times \left[\frac{V}{C} \right]^{1.85} \quad (3)$$

where $V = Q/A$ is the mean flow velocity, d = penstock diameter, L = penstock length and C = the Hazen-Williams coefficient (between 135 and 140 for plastic pipes and 150 for steel pipes), A = cross sectional area of the flow [74].

The minor losses is defined by Corb [73] as in equation 4, with K_i = loss coefficients for pipe shape/geometry which have been determined experimentally. K_c is the contraction loss coefficient which is dependent on the ratio of pipe diameters d/D , where d is internal diameter of the small pipe and D internal diameter of the large pipe given by equation 5. The contraction normally occurs at the end of the pipe or penstock before entry into the turbine in the form of reducers to produce the water jet [61, 75].

$$H_{minor} = \frac{V^2}{2g} \sum K_i \quad (4)$$

$$K_c = 0.42 \left[1 - \left(\frac{d}{D} \right)^2 \right] \quad (5)$$

The efficiency of the turbine is given by equation 6 [61, 72].

$$\eta = \frac{\text{Power output from shaft}}{\text{hydraulic power input}} = \frac{P_s}{P} \quad (6)$$

The power output or shaft power is given by equation 7 [72, 73].

$$P_s = \rho Q (V_1 + V_2) \frac{2\pi DN}{60} \quad (7)$$

where V_1 and V_2 are the velocity of water through the pipe and velocity of water through the nozzle to develop torque respectively.

The flow (K_Q), head (K_H) and power (K_P) coefficients as well as specific speed (K_S) can be computed using equations 8 – 11 [71, 76].

$$\text{Flow coefficient, } K_Q = \frac{Q}{ND^3} \quad (8)$$

$$\text{Head coefficient, } K_H = \frac{gH}{N^2 D^2} \quad (9)$$

$$\text{Power coefficient, } K_p = \frac{P}{\rho N^3 D^5} \quad (10)$$

$$\text{Specific speed, } K_S = \frac{K_p^{1/2}}{K_H^{5/4}} \quad (11)$$

where N rotational speed of the runner in rpm, P the turbine power output in kW, and H_n the net head in meter. The term specific speed K_S arises from the idea of a given type of machine producing a unit power at a unit head, when running at this speed. Specific speed is then neither dimensionless (specific) nor a speed. It is better regarded as a “shape factor”. It is its ability to describe the shape of a turbine designed independently of turbine size that makes specific speed useful to the turbine designers.

MATERIALS AND METHODS

Mild steel was used for the entire turbine wheel construction. The reasons for using mild steel include its good weldability, machinability, ductility and toughness in addition to the availability of the material at an affordable cost compared to other metals. The runner for this study is highly simplified and locally fabricated, made up of a circular hub welded to two circular supports of diameter equal to that of the turbine wheel with a hub to blade ratio of 0.55. Holes of diameter 20 mm are drilled on the circular supports to accommodate the shaft which is appropriately secured to the supports. The radius of the cover is 20 cm wide in order to accommodate the largest penstock diameter used in previous aspects of the study which is 76.2 mm and to facilitate welding operations during the fabrication. The blades were made up of flat strips of the sheet metal of about 10 cm width were then appropriately welded around the periphery of the hub and unto the inner faces of the circular support. The diameters of the runners as well as the circular hub to blade ratio were adopted from Edeoja *et al.* [66] and Edeoja *et al.* [61]. The hub and blades were fabricated from a 2 mm thick mild steel sheet. Five runners were fabricated with 3, 5, 7, 9 and 11 splined blades.

The 5 runners are shown in Figure 1. A support made of 2×2 mm angle iron was provided for the turbine at the foot of the stanchion beneath the penstock. The support is firmly held in place with concrete with adequate clearance to allow the free rotation of the turbine wheel. Adequate provision was made to channel the water back to the underground reservoir and a fitting protective cover was used to prevent water splashing during the operation of the system and to serve as a guide for the nozzle. Two bearings matching the shaft diameter are provided at the ends of the support on which the turbine runner is mounted.



Fig. 1. Turbine Runners with Splined Blades used for the study

The experimental system in this study consists of a pump and a locally fabricated turbine connected with the help of PVC piping as penstock to a 2000 liters overhead tank and a 3000 liters underground reservoir. A drain allows the water downstream of the turbine to be returned into the underground reservoir. Figure 2 shows the runner and support assembly (a) as well as the alternator used (b). Care was taken to align the turbine runner and the nozzle so as to ensure adequate clearance between the runner, penstock and nozzle. The turbine was coupled to a 3.9 kVA alternator via a belt pulley drive of ratio about 1:6 provided by a 600 mm diameter pulley is connected to the turbine shaft and a 50 mm diameter pulley connected at the alternator. Water is released from the overhead tank through the penstock and it flows through tapered. The flow through the turbine is regulated using a gate valve installed before entry to the penstock. The water jet striking the runner produces a torque resulting in the rotation of the turbine shaft and the alternator shaft. The suction pipe of the pump draws water from the underground reservoir and returns it to the overhead tank to create a head.

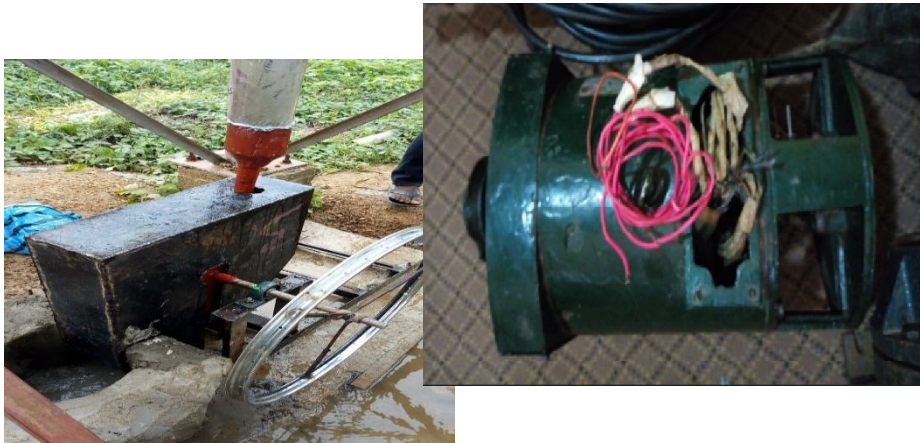


Fig. 2. (a) Runner and Support assembly and (b): Alternator used for the study.

Figure 3 shows the whole set of the system operation. The main variables monitored in this study were the rotational speeds of the turbine and alternator shafts, the depths of water in the overhead and underground reservoirs before and after each operation, the time taken for each operation and the voltage developed by the alternator and/or the current. The data was used to compute the gross head available, the head losses, the net head available, the flow rate and the power generated. The water depths were monitored using calibrated dip sticks and a tape while a stop clock was used for timing each operation. A tachometer was used to measure the rotational speeds of the shafts while a multimeter was used to measure the voltage developed and/or the current flowing. The procedure was repeated for each of the turbine runners. All the data were then plotted and also conveniently analyzed for variance at 95% confidence level.

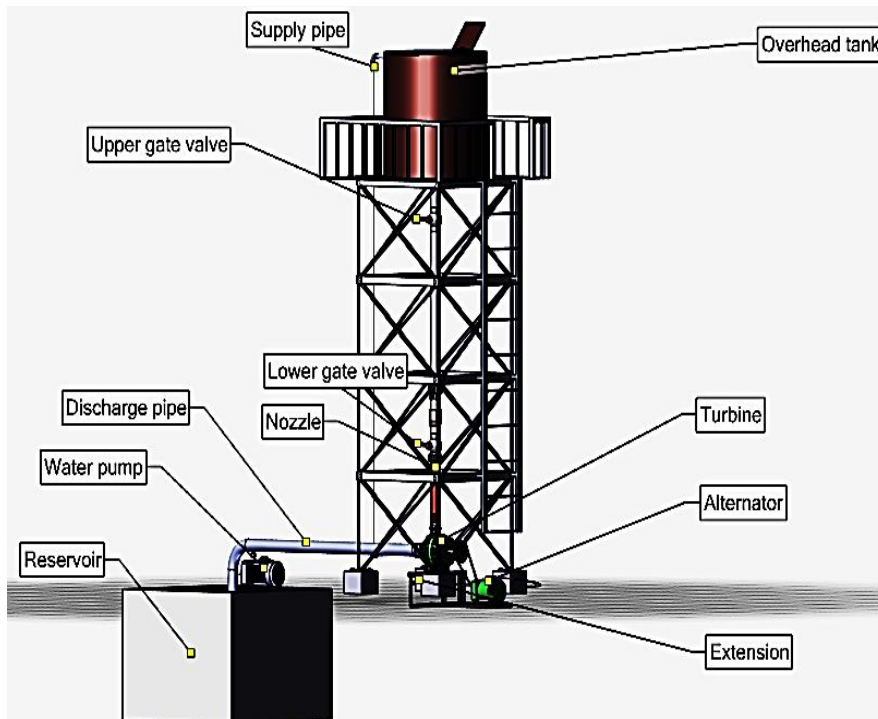


Fig. 3. The current experimental set up of the system.

RESULTS AND DISCUSSION

Figure 5 shows the variation of head loss with nozzle diameter for different number of turbine blades with no- and on-load tests. For both sets of tests, the head loss increased with increasing nozzle diameter in line with basic fluid flow principles which provides that the head loss varies inversely as some exponent of the pipe diameter [45, 74]. Both Figures indicate that the number of splined blades does not affect the head loss. This is shown by the almost single curve representing the variations in Figure 4(a) and the clustering of the curves in Figure 4(b) with some dispersions for the three middle nozzle diameters. Expectedly, the highest value for head loss was obtained in the nozzle with a diameter of 0.042 m for both no- and on-load tests [69, 77].

Fig. 4. Variation of Head Loss with Nozzle Diameter for the Number of Splined Blades for the (a) No-load and (b) On-load tests.

Figure 5 shows the variation of flow rate with net head for different number of turbine blades for the on-load tests. The flow rate decreased with increasing net head without any specific effect produced by the number of splined blades. This is because the flow rate increase with an increase in nozzle diameter and the bigger the nozzle diameter, the greater the volume of water displaced hence the lesser the net head. All the curves for all the number of splined blades were polynomials with R^2 values greater than 0.96, the least being for 3 blades. The curves resemble the flow rate and net head characteristic for conventional hydropower from which the required matching pair of flow rate and net head can be fixed in deciding on the site for situating the system [1, 69, 78]. Furthermore, the of the flow rate varied highly significantly with the nozzle diameter at 0.05 level of significance. This agrees with basic fluid flow principle which provides that the flow rate is highly dependent the flow area. The marginal variation of the flow rate with the number of splined blades also strengthens this fact [70, 79].

For the no-load tests, the turbine speed generally increased with the number of splined blades as shown in Figure 6(a). This is directly as a result of more surface area of blades available for interaction with the water jet as indicated by Edeoja *et al.* [63]. The speed indicated a tendency of increasing beyond 11 blades for the smaller nozzle diameters (0.0158 and 0.0212 m). This affirms the requirement of properly directing the water jet on the blade area available [66, 80]. For 3 blades, the larger nozzle diameters developed higher turbine speeds because the flow rates were higher thereby compensating for the smaller blade area available. The 0.0266 m nozzle diameter produced the highest turbine speed for the larger number of splined blades (7 to 11). This probably emphasizes the need for ensuring that with this system, a mean value of the smaller and larger nozzle diameters could favour better performance in conjunction with larger number of splined blades.

Fig. 5. Variation of Flow Rate with Net Head for the Number of Splined Blades for the On-load tests.

Figure 6(b) shows the situation for the on-load test. The general relationship is better indicated with the turbine speed increasing with number of splined blade for all the nozzle angles. This is because the turbine had been linked with the alternator thereby making up for any imbalances [68, 81]. Furthermore, the larger nozzle diameters produced higher turbine speeds for all the number of splined blades, as well as generally indicating a tendency of further increase beyond 11 blades. This shows that more blades could be utilized with larger nozzle ratios depending on the system output required which is good for the future implementation of the system [54]. The 2-factor ANOVA indicates that the turbine RPM varied significantly at 0.05 level along the rows and highly significant along the columns. This statistically confirms that the turbine speed was enhanced by the number of splined blades but to a greater extent by the nozzle diameter [70, 75, 82].

Fig. 6. Variation of Turbine Speed with number of Splined Blades for the Nozzle Diameters for the (a) No-load and (b) On-load tests.

Figure 7 shows the variation of generator speed with nozzle diameter for different number of turbine blades (a), and generator speed with number of turbine blades for the nozzle diameters (b) for the on-load tests. The highest value of alternator rotational speed was obtained in the nozzle with a diameter of 0.042 m. The rotational speed of the generator increased with increase in nozzle diameter this is because an increase in nozzle diameter admits more water leading to an increase in the weight of the turbine and consequently increase in the rate of change momentum of the turbine. The greater the momentum, the higher the generator rotational speed [66, 83].

Fig. 7. Variation of (a) Generator Speed with Nozzle Diameter for the Number of Splined Blades, and (b) Generator Speed with number of Splined Blades for the Nozzle Diameters for the On-load tests.

Figure 7(b) shows that the generator speed had a general tendency similar to the variation of the turbine speed for the on-load tests. This is to be expected as the generator speeds were multiples of the turbine speeds due to the utilization of a belt drive to produce this effect. Again the largest nozzle diameter produced the highest generator speed as well as. These observations are in line with basic fluid mechanics principles and turbo machinery operations, and were consistent with previous results with the system using other configurations of turbine [65, 84]. Also, the more the number of splined blades the higher the generator speed, with 11 blades producing the highest speed for all the nozzle diameters which again agrees with basic turbine operation and previous studies on the system [1, 85]. This further affirms the critical need of matching appropriate sizes of nozzle diameter with number of splined blades. The 2-factor ANOVA indicates that the generator speed varied significantly at 0.05 level along the rows as well as along the columns. This statistically confirms that the generator speed was enhanced by the number of splined blades but to a greater extent by the nozzle diameter as with the case of the turbine rotational speed [11, 50].

Figure 8(a) shows the variation of shaft power with nozzle diameter for different number of turbine blades with on-load. The highest value of shaft power was obtained in the nozzle with a diameter of 0.042 m. The shaft power increased with increase in nozzle diameter and was highest in the turbine with 11 blades with a value of 2007 W. This was because the turbine had a larger effective surface area available for the increased volumetric flow rate resulting from the larger nozzle diameter leading to an increase in the momentum of the turbine and hence the shaft power [45, 69, 86].

Fig. 8. Variation of (a) Shaft Power with Nozzle Diameter for different Number of Splined Turbine Blades, and (b) Shaft Power with number of Splined Blades for the Nozzle Diameters for the On-load tests.

Figure 8(b) shows the variation of shaft power with number of splined blades. It shows that the shaft power increased with number of blades deriving from the patterns observed with the other parameters. Also, it was highest for the largest nozzle diameter and least for the smallest diameter, affirming that higher number of blades and larger nozzle diameters [49, 56]. The variation of the shaft power was highly significant statistically at 0.05 level along the columns (nozzle diameter) confirming the relevance of the effect of the parameter in generating the shaft power required to produce the necessary torques [62, 79, 87].

Figure 9 shows the variation of electrical power with alternator rotational speed for different number of turbine blades with on-load. The electrical power was highest at a rotational speed of about 2200 rpm in the turbine with 11 spline blades. The electrical power increased with an increase in the alternator rotational speed and was highest in the turbine with 11 blades with a value of about 1800 W. This was because the increase in the number of blades lead to an increase in the weight of the turbine and consequently an increase in momentum of the turbine. The greater the momentum, the higher the alternator rotational speed and hence the higher the electrical power generated [54, 69, 88].

Fig. 9. Variation of Electrical Power with Alternator Revolution for the different number of Splined Turbine Blades with on-load

Figure 10(a) shows the variation of electrical power with nozzle diameter for different number of turbine blades with on-load. The electrical power was highest in the spline turbine with 11 spline blades when the nozzle diameter was greater than 0.04 m. The electrical power increased with an increase in nozzle diameter and was highest in the turbine with 11 blades with a value of about 1800 W. This was because the increase in the nozzle diameter led to an increase in momentum of the turbine. The greater the momentum, the higher the alternator rotational speed and hence the higher the electrical power generated. Figure 10(b) shows the variation electrical power with number of splined blades. The Figure shows that the electrical power increased with number of blades deriving from the patterns observed with the other parameters. It was highest for the largest nozzle diameter and least for the smallest diameter as depicted in Figure 10(b). This affirms that higher number of blades and larger nozzle diameters. Furthermore, the variation of the electrical power at 0.05 significance level was only slightly with the nozzle diameter. The variation with the number of splined blades was almost insignificant. This agrees with the fact that several other parameters contribute to the electrical power generated along with the rotational speed which primarily depends on the flow through the nozzle [50, 52, 67, 79].

Figure 11(a) shows the variation of efficiency with nozzle diameter for different number of turbine blades with on-load. An efficiency of 0.82 was obtained in the nozzle with a diameter of 0.042 m. The efficiency increased with an increase in nozzle diameter and was highest in the turbine with 11 blades with a value of 0.85. This was because an increase in the nozzle diameter leads to an increase in the weight of the turbine and hence the alternator rotational speed. This leads to an increase in electrical power and hence the efficiency. Figure 11(b) shows the variation of the system efficiency with the number of splined blades for the various nozzle diameters. Except for the smallest nozzle diameter, the efficiency generally increase with the number blades. The trends affirms the observation in Figure 10 [51, 84, 85, 88].

Fig. 10. Variation of (a) Electrical Power with Nozzle Diameter for the Number of Splined Turbine Blades, and (b) Electrical Power with number of Splined Blades for the Nozzle Diameters for the On-load tests.

The trends for the three largest diameters were clustered with the one for the 0.0212 m nozzle diameter being the most linear. The clustering of the trends for the four largest nozzle diameters indicate reasonably efficient operation of the system with the all the blades. This shows good potential for the future implementation of the system as a standalone power source to contribute to the energy mix in the rural locations of Nigeria especially where there is no naturally flowing water for the uptake of conventional Pico hydropower [1, 58, 71]. For both rows and columns, the

efficiency of the system was slightly significant at 0.05 level indicating that statistically the number of splined blades and the nozzle diameter have a slight effect on the efficiency. This can be as a result of the assumptions made in the computations as well as the losses during the system operation, and the fact that other factors including the ones at the design stages could affect the efficiency of the system [61, 72].

Fig. 11. Variation of (a) Efficiency with Nozzle Diameter for Number of Splined Blades, and (b) Efficiency with number of Splined Blades for the Nozzle Diameters for the On-load tests.

Figure 12(a) shows the variation of head and power coefficients with flow coefficient for different number of turbine blades for no-load tests respectively. These relationships are standard procedure for comparing geometrically similar components, in this case the turbines. They are useful for reference purposes when the components are to be scaled up or down in future applications. They are not meant for comparing system parameters but to relate component dimensions to the head, flow rate and power output possible for any given system employing those components [69, 71]. Figure 12(b) shows similar variations of the power coefficient with the flow coefficient for all the turbines. It mirrors the relationship between the power developed and the system flow rate and shows that the relationship is virtually the same for all the turbines indicating the use of dimensionless quantities have conveniently unified the five turbines in terms of power and flow rate [71, 73, 76].

Fig. 12. Variation of (a) Head Coefficient with Flow Coefficient, and (b) Power Coefficient with Flow Coefficient for the Number of Splined Turbine Blades for the No-load tests.

CONCLUSION AND RECOMMENDATION

Based on the observations from this study, it can clearly be seen that to obtain maximum speed and power for this particular Pico-hydro system, a 0.042 m penstock outlet diameter with the 11 blade runner should be used. Hence, the combination of appropriately large nozzle diameter and high number of blades is favourable for an efficient operation of the system. The increased performance of this turbine indicates that this system could be used to generate power for small scale use. For further work, gear transmission will be incorporated in place of the belt drive, larger diameter pipes will be exploited for supplying water to the overhead tank to sustain the flow cycle and the use of larger or multiple overhead reservoirs will be attempted. Most importantly, a general awareness campaign will be undertaken for the technical understanding of Pico hydro technology by the local community so that rural electrification projects can be implemented more effectively.

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