Effect of the Included Angle of V-Shaped Blade on the Performance of a Simplified Pico-Hydro System

Alex Okibe Edeoja, Joy Acheyini Edeoja, Margaret Enuwa Ogboji

Abstract- The effect of the included blade angle on a simplified Pico hydro system currently undergoing development was investigated. Five turbine runners having 6 v-shaped blades with included angles of 30°, 60°, 90°, 120° and 150° were fabricated and tested on system. The alternator shaft speed, water level in the reservoirs and the voltage generated were measured for each blade angle. The results obtained indicated that the speed and hence the voltage decrease as the blade included angle of increases. A maximum speed of 1810 rpm and a corresponding voltage of 224 V were obtained with 30° included angle which decreased progressively to 1750 rpm and 218 V for 150°. These results suggest that for optimum performance of the Pico hydro turbine, smaller included blade angles for the configuration used translating to deeper blades are necessary. Further reduction of the included angle beyond this range will require much smaller water jets however. This observation is useful in the further development of this system for use in buildings and small workstations in isolated locations as long as water for the reservoir is available. This system can potentially reduce dependence on petroleum operated systems and contribute towards mitigating the epileptic power supply of the national grid while curbing the problem of environmental pollution, restiveness and the threat of terrorism with the attendant high rates of sabotage and vandalization.

Index Terms - Blade included angle, environmentally friendly, epileptic power supply, Pico hydro system, shaft speed, turbine runners, v-shaped blades, voltage

1 Introduction

THE challenge of the 21st century is how to develop sustainably and maintain the quality of life for a growing population with higher expectations for well-being [1], [2]. Underlying this challenge is the need for sufficient and sustainable supplies of energy to provide the economic activity underpinning these expectations [3]. Hence, energy can be considered as a prime agent for wealth creation and economic development. Historical data attest to a strong relationship between availability of energy and economic activities [4].

Humanity, however, have been faced with the problem of energy from time immemorial. Energy scarcity is becoming widespread and persistent and it has plagued many developing countries for decades. Developed countries too are now becoming more acutely aware of the risk of energy scarcity following recent developments in the world energy market [5], [6], [7], [8]. In recent years, oil and coal prices have risen geometrically and developing countries are no longer strangers to blackouts and are worried about energy scarcity as nearly every aspect of development from reducing poverty to improving health care requires reliable access to modern energy services [9].

Currently the global energy demand is rising fast as population and emerging economies like China and India are growing exponentially with small and medium enterprises springing up. In developing countries of Africa like Nigeria, the international energy agency forecasts that energy demand would be 50% higher in 2030 than they are today [4], yet fossil fuels on which the world depend are finite and are far from environmentally friendly. This therefore is gradually drifting the world's attention from non-renewable to potential renewable energy resources for power generation like wind, solar and hydro power resources [10], [11]. Renewable energy currently constitutes 15% of the world's energy mix with hydropower making 90% of it [12].

Hydropower is the energy from falling water and is a proven technology for electricity generation. Amongst all renewable sources of energy it is the most reliable and cost effective accounting for 19% of global electricity production from both large and small power plant second only to fossil fuels [13], [14], [15], [16], [17].

Electricity plays a very important role in the socio-economic and technological development of every nation. The electricity demand in Nigeria and other developing countries far outstrips the supply and the supply is epileptic in nature [18]. These countries are faced with acute electricity problems, which are hindering their development and economic growth despite the availability of vast natural resources in these countries. Although smaller off grid systems are available, there have been noted to be inefficient. A need therefore exist for the development of alternative sources of power [19], [20], [21].

The world has endless potential for hydropower generation. Numerous hydropower stations have been built all over the world and a large number of hydro power projects with a capacity of 100, 000 MW currently going on globally with Asia having the largest contribution of 84, 000 MW [22], [23]. Nigeria is richly endowed with abundant water resources whose potential is 14,750 MW of power. About 1980 MW of this po-

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tential is explored at Kainji, Jebba and Shiroro hydropower stations, each contributing 760 MW, 600 MW, and 540 MW respectively, leaving 12,200 MW unexplored [24]. This implies that only 14 % of the nation's hydropower potential is in use. The country currently experiences an epileptic power supply as a result of its in ability to exploit its vast hydropower potential in addition to the fact that the available large hydro power plants are not operating up to installed capacity [25].

As larger scale hydro schemes are becoming a challenge due to socio-economic and environmental concerns, small hydro schemes continue to gain increasing popularity especially in remote areas due to its simplicity in design, ease of operation, low environmental impacts in comparison to larger hydro power scheme [26], [27], [28]. Furthermore, communities could take advantage of simple drinking water projects or irrigation systems to install small hydro schemes [29].

Pico hydro (< 5 kW) is the smallest standalone power generation mostly installed to supply small loads. Over the last few decades, it has been proven as a cost effective, clean and reliable method of generating electricity and mechanical power for off-grid applications and will play an important role in rural electrification into the foreseeable future [13]. In Nepal for instance, Three hundred Pico hydro schemes constructed by practical action are producing electricity while 900 others are used for mechanical power only [30]. Pico hydro has become more prevalent in sub-Saharan Africa as well, where electrification rates are some of the world's lowest [31]. Although Nigeria has successfully benefited from large and small scale hydropower to generate electricity but little or no efforts are been made towards utilizing hydro generation in the range of micro and Pico hydro systems, despite its available potential [32]. If fully utilized it would contribute remarkably to reducing the energy problems of domestic and commercial consumers in addition to providing a cheap source of power to remote areas where the extension of grid system is comparatively uneconomical.

Pico hydro systems like other decentralised systems are not prone to sabotage and terrorist attacks as individuals and communities take responsibility of safeguarding their own facilities (Edeoja et al, 2015b). While Pico hydro present significant advantages including cost over other methods of electricity generation, its implementation also present several challenges including a heavy dependence on site specific conditions for scheme design [33], [34], [35]. Off the shelf systems have been designed to reduce the site specific design but this does not completely eliminate the need for technical expertise and periodic maintenance [36], [37]. Also, besides the requirement of flowing water, the exploitation of hydropower requires civil works which constitute the major cost and electromechanical devices such as a turbine and generator. To further reduce the cost of the technology standard pumps and induction motors could be used in place of conventional generators and turbines [38], [39], [40], [41].

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 [42], [43], [44]. Pico hydro systems are reliable as individuals or communities could protect their facilities from sabotage and terrorist attacks. Although Pico hydro has enormous social and environmental benefits, it still harbours 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 [45], [46], [47].

The turbine blades are a major part of the turbine they are usually made of steel and are fixed at regular interval around the circumference of a hub to form the runner. The blades are pushed by the falling water tangentially around the wheel. The thrust produced by the water on the blades produces torque on the shaft and as a result the wheel revolves. The Shape of and dimensions of turbine blades has evolved for maximum efficiency through experience and theoretical modelling over many years [48], [49], [50], [51]. However currently published literature provides few details on blade angle of inclination. Recent research on blade geometry aimed at improving the functionality and efficiency of hydro power systems all over the world are continually being carried out. Alnakhlani *et al* [51] in Sebelas Maret University, Indonesia studied the effect of the bucket and nozzle dimension on the performance of a Pelton water turbine. Their results showed that there is a proportional relationship between the efficiency rate and the size of bucket and angle attack. Efficiency increases with the increase in bucket size. Chukwuneke *et al* [50] at Nnamdi Azikiwe University, Awka, Nigeria also conducted an experimental investigation of the effect of head and bucket splitter angle on the power output of a Pelton turbine. They obtained a maximum power output at splitter angle 23^o followed by 21^o, 15^o, 10^o and 3^o using varied turbine speed (1700, 1400, 1200 and 1000rpm). The force generated by the bucket due to the splitter was increased as the turbine speed was increasing.

This study seeks to find the optimum blade angle of inclination for the simplified Pico hydro turbine, in order to improve its efficiency and provide additional data in this area of study. This system involves an overhead water reservoir with a locally fabricated turbine at its foot [52]. It is widely accepted that there is a strong correlation between socio- economic development and the availability of electricity. Nigeria has experienced an economic backdrop in the recent past as its electricity demand far outstrips the supply and the supply is epileptic in nature. Developing Pico hydro schemes which are cheaper and reliable means of power generation for urban homes, communities and rural dwellers would help improve the standard of living and the economic state of the country. Furthermore its impact on the environment is more benign.

2 Materials and Methods

The runner comprised of a circular hub with six blades welded around its periphery. The hub and blades were fabricated from 2 mm and 1.5 mm thick mild steel sheet respectively. The reasons for using mild steel include its good weldability, machinability in addition to the availability of the material at an affordable cost compared to other metals. In constructing the runner a 24 mm diameter circle with six rectangles of dimension 140 mm x 80 mm were measured and marked out on the 2 mm and 1.5 mm metal sheets respectively. The shapes were cut off the sheet with an angle grinder trimmed and filed with a hand file to achieve desired edge smoothness. A 20 mm diameter hole was drilled centrally on the circular disc with four

10 mm holes at 90° to the central hole for passage of the shaft and securing the runner to the flange respectively. The rectangular sheets were then folded along their centre lines to include an angle of 30°. Scrap metal pieces were trimmed were welded to cover the blades ends. The blades were finally welded at 60° intervals around the circumference of the hub. The remaining four runners were formed using the same procedure but with the blades folded at 60, 90, 120 and 150°. Fig. 1 shows one of the runner assemblies used for the study.

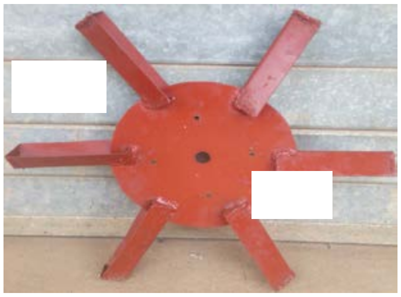

Fig. 1: The Runner Assembly

The runner was then clamped to the shaft flange with four M10 bolts and mounted in between two bearings and seals in the turbine casing. The turbine cover was then secured in position with M14 and M13 bolts and the turbine pulley was secured to the end of the shaft. Fig. 2 shows an assembled turbine. The upper and lower ends of the penstock were then connected to the overhead tank and the nozzle respectively. Care was taken to aligning the turbine runner, casing and the nozzle so as to ensure a clearance of 5 mm between the runner, penstock and nozzle. The turbine was coupled to a 2.5 kVA alternator via a toothed v-belt drive.

Fig. 2: The Assembled Turbine [52]

The experimental system in this study consisted of a pump and a locally fabricated turbine connected in a closed loop with a combination of two diameters of PVC piping as penstock, a 2000 l overhead tank and a 3000 l underground reservoir. The penstock consisted of a combination of 3 and 2 inches diameter pipes in the ratio 5:1 with the smaller diameter exiting into the turbine [53], [54]. The suction pipe of the pump draws water from the underground reservoir to the overhead tank to create a head. Water is released from the overhead tank through the penstock and terminating in a tapered nozzle. The flow through the turbine is regulated using a gate valve installed before entry to the penstock. 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 to the alternator via a toothed v- belt drive in a step up ratio of 1:6, causing the rotary motion of the alternator shaft, thereby 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 rated 1.0 Hp with a flow capacity of 50 l/min. A tachometer and a multi -meter were used to measure the speed of generator and turbine as well as respectively for each blade angle of inclination. Fig. 3 shows the entire system.

Fig. 3: The whole Experimental Setup

During the experiment the water level in the reservoir and overhead tank before and after the flow were continually measured with a calibrated dip stick and the time of flow was also taken. The difference in water level for the underground reservoir was used to compute the flow rate. The water level in the overhead tank before the flow is used in computing the gross head. Other constant parameters taken were the total length and diameters of the penstock, the bends and geometry of the penstock were also taken and used to compute the ma-

ISSN 2229-5518

jor and minor losses. The same procedure was repeated for all the four runners.

3 Results and Discussion

Fig. 4 shows the variation of alternator shaft speed with the blade included angle. The figure shows that the speed decreases with increase in the blade included angle from a maximum of 1810 rpm for a blade angle of 30° to a minimum of 1750 rpm at an angle of 150°. The decrease in the speed is as a result of increase in drag forces brought into play. As the blade angle of inclination increase, the rotational quality of the runner decreases due to the difficulty of the wider blades to cut through the fluid in the turbine casing [27], [30], [51], [55]. However, narrower blade angles enhance smoother blade entry into water thus increasing rotational quality of runners. The trend was a second-order polynomial shown as (1). It depicts that fact the smaller included angles favour the development of higher voltages.

$$N = -0.006\theta^2 + 0.247\theta + 1804 \quad (1)$$

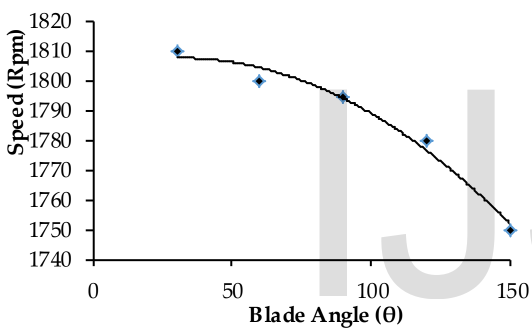

Fig. 4: Variation of Alternator Shaft Speed with Blade included Angle

The voltage also varied in a similar trend as the shaft speed since voltage is directly proportional to the speed. This is shown in fig. 5. A maximum voltage of 224 V at a blade angle of 30° and the minimum of 218 V at 150° were obtained. The second-order polynomial trend shown as (2) clearly shows that for an increasing blade included angle the voltage. Hence, as expected, the voltage progressively increased with increase in speed up to a maximum of 224 V at 1810 rpm since voltage is directly proportional to shaft speed as earlier stated.

$$V = -0.00006\theta^2 + 0.0379\theta + 225.2 \quad (2)$$

Fig. 6 shows the graph of voltage plotted against speed. The figure shows that voltage increases with the shaft speed and this agrees with the usual behaviour of alternating voltage generators. The decrease in voltage as the included angle increases directly derives from the fact the increased drag forces on the wider blades due to their inability to cut smoothly through the water in the turbine casing result in decreased shaft speed.

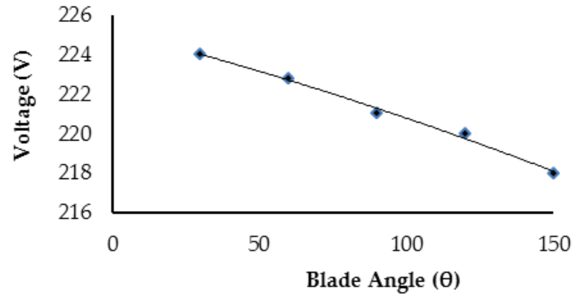

Fig. 5: Variation of Voltage with Blade included Angle

Equation 3 shows the relationship between them is a third order polynomial. The equation generally shows that the voltage developed directly depends on the speed of the shaft of the alternator. However, the polynomial trend could be as a result of some other system parameters which are not yet obvious but may have a bearing to the alignment of the water jet, smoothness of the surfaces and the like [27], [49], [50], [55].

$$V = -0.00002N^3 - 0.0948N^2 + 166.63N - 97394 \quad (3)$$

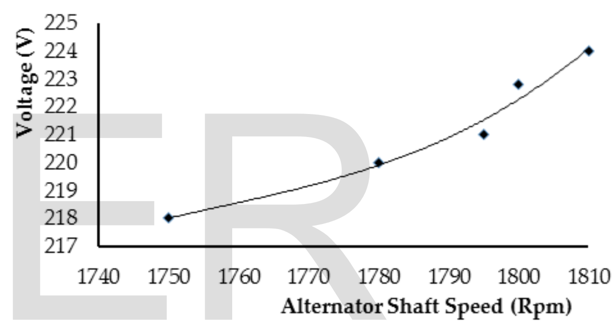

Fig. 6: Variation of Voltage with the Alternator Shaft Speed

Table 1 shows the analysis of variance of the alternator shaft speed and the voltage developed for each of the v-shaped blade included angle at 5% level of significance. The results show that the variation in these parameters at this level of significance varied significantly from one included angle to another thereby establishing statistically the effect of the variation of the angle on the performance of the Pico hydro system.

TABLE 1
ANOVA OF THE ALTERNATOR SHAFT SPEED AND THE VOLTAGE DEVELOPED FOR THE BLADE INCLUDED ANGLES

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1311.456	4	327.864	1.472461	0.358427	6.388233
Columns	6129637	1	6129637	27528.64	7.92E-09	7.708647
Error	890.656	4	222.664			
Total	6131839	9				

4 Conclusion

A study to determine the effect of v-shaped blade included angle on the performance of a simplified Pico hydro system has been conducted. The results obtained indicated a maximum speed and voltage of 1810 rpm and 224 V respectively for 30° included angle which decreased progressively to 1750 rpm and 218 V for an angle of 150°. Hence, based on the results of this work, it can be concluded that the speed and voltage generated by the Pico hydro system decrease with an increase in blade included angle. The increased performance of this turbine indicates that this system could be used to generate power for house hold use.

The results obtained in this work can further be improved and complemented with the following research suggestions:

1. Standard turbine housing with built in nozzle mounts which allows for large scale adjustments and accommodates different runner sizes should be incorporated since small jet misalignments can have a significant negative effects on turbine efficiency.
2. Larger diameter pipes should be used in transferring water to the overhead tank to sustain the flow circle.
3. Lighter metals such as aluminium should be used in fabricating the runners and blades as heavier meals like mild steel adds to the inertia and thus decrease turbine performance.

Acknowledgment

The authors wish to thank Mr. Linus Awuniji and Miss Mabel Udoh who greatly assisted during the data collecting processs. The contributions of Engr. T. Agana, Mr. Ken Edo and Mr. Tersoo Uor all of the University Water Works for their selfless contributions in all the plumbing work and supply of water; sometimes including the purchases, monitoring of data and the many need for adjustments during the course of the work.

References

[1] WHO, "Health in 2015: from MDGs, Millennium Development Goals to SDGs, Sustainable Development Goals", pp. 1-10, 2015. Available from www.who.int

[2] MDGs, "Nigeria 2015 Millennium Development Goals", End-Point Report (abridged version), pp. 3-13. Available at www.mdgs.gov.ng

[3] EEA, "Energy and environment report", EEA report No. 6/2008 European Environmental Agency.

[4] IEA, "World Energy Outlook", 2007 Edition. *International Energy Agency*

[5] M. Elbaradai, "Addressing the Global Energy Crisis - Managing the Effect of High Energy and Food Price", *The Commonwealth Finance Ministers Meeting, St Lucia, 6-8 October 2008.*

[6] K. Kamil, "Energy Policy and Climate Change in Turkey", *Energy Conversion and Management,* vol. 44, pp. 1671-1688, 2003.

[7] F.A. Sowumi, A.D. Odedej and V.O. Akinsoye, "Global food and Energy crisis: The need for sustainable food security and Energy program in Nigeria*" Current Research Journal for Social Science,* vol. 1, no. 1, pp. 15-23, 2009.

[8] J. Williams and A.F. Alhaji, "Parallel with Energy crisis underscore us vulnerability to oil supply shocks today?" *Oil and Gas Journal*, 101(5), 2003.

[9] I. Yuksel, "Renewable Energy Status of Electricity Generation for Future Prospect", *Renewable Energy*, vol. 50, pp. 1037-1043, 2013.

[10] E.J. Bala, "Achieving Renewable Energy Potential in Africa", Joint WEC, AUC and APUA Workshop, Addis Ababa, Ethiopia, 17th – 18th June, 2013.

[11] U.S. Department of Energy, "Renewable energy an overview" Energy Efficiency and Renewable Energy, 2001. Available from www.eere.energy.gov Accessed 8/11/2014.

[12] WAEA, "Hydropower Resource Assessment", Ministerial Conference on Water for Agriculture and Energy in Africa: The Challenges Of Climate Change. Sirte, Libyan Arab Jamahiriya. 15-17 December 2008.

[13] 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,* vol. 16, pp. 518-524, 2012.

[14] S. Mishra, S.K. Singal and D.K. Khatod, "Optimal Installation of Small Hydropower Plant - A review, *Renewable and Sustainable Energy Reviews*, vol. 15, pp: 3862– 3869, 2011.

[15] N. Lior, "Sustainable Energy and Development: The present (2009) Situation and Possible path for the future". *Energy,* vol. 35, pp. 3976-3994.

[16] A. Bartel, "Hydro Potential and Development Activities", *Energy Policy,* vol. 30, pp. 1231-1239, 2002.

[17] W.F. Gary and D.M. Linkeb, "Hydropower as a Renewable and Sustainable Energy Resources Meeting Global Energy Resources in a Reasonable Way", *Energy Policy,* vol. 30, pp. 1216-1265, 2002.

[18] European Small Hydropower Association (ESHA), "Small Hydropower Energy Efficiency Campaign Action (SHERPA) - Strategic Study for the Development of Small Hydro Power (SHP) in the European Union", 2008. Available from: http://www.esha.be/.

[19] C.O. Osueke, D.C. Uguru-Okorie and V.K. Abanihi, "Electricity Stability in Nigeria Through Increased Hydro Power Generation", *International Journal of Emerging Technology and Advanced Engineering*, vol. 3, no. 1, pp. 9-13, 2013.

[20] M.O. Oseni, "Households' Access to Electricity and Energy Consumption Pattern in Nigeria", *Renewable and Sustainable Energy Reviews*, vol. 16, pp. 990-995, 2012.

[21] J. Ikeme and O.J. Ebohon, "Nigeria's Electric Power Sector Reform: What should for the key objectives?" *Energy Policy,* vol. 33, pp. 1213-1221, 2005.

[22] European Small Hydropower Association (ESHA), "Current Status of Small Hydropower Development in the EU-27", 2010. Available from: http://www.streammap.esha.be/6.0.html.

[23] European Small Hydro Association (ESHA), "Small hydro For Developing Countries", Support from Thematic Network on Hydropower Project, European Commission, 2008.

[24] K. Maohar and A.A, Adeyanju, "Hydropower resources in Nigeria". *Journal of Engineering and Applied Sciences*, vol. 4, no. 1, pp. 68-73.

[25] O.S. Ohunakin, S.J. Ojolo and O.O. Ajayi, "Small Hydropower (SHP) Development in Nigeria", *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 2006 – 2013, 2011.

[26] M.T. Gatte and R.A. Kadhim, "Hydro Power", In Energy Conservation, Ed. A. Z. Ahmed, Published by InTech Janeza Trdine 9, 51000 Rijeka, Croatia, pp. 95 – 124, 2012. Available at www.intechopen.com. Accessed 7/6/2013.

[27] 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*, vol. 51, no. 10, pp. 1970-1975, 2010.

[28] G. Gunkel, "Hydropower - A green energy? Tropical reservoirs and greenhouse gas emissions", *Clean - Soil, Air, Water*, vol. 37, no. 9, pp. 726 –734, 2009.

[29] European Small Hydropower Association (ESHA), "Guide on How to Develop a Small Hydropower Plant", 2004. Available from: http://www.esha.be/.

[30] B.R. Cobb and K.V. Sharp, "Impulse (Turgo and Pelton) Turbine Performance Characteristics and their Impact on Pico-Hydro Installations", *Renewable Energy*, vol. 50, pp. 959 – 964, 2013.

[31] L. Wang, "A Micro Hydro Power Generation System for Sustainable Micro Grid Development in Rural Electrification in Africa" *In: IEE Power Energy Society Meeting, Calgary Canada.* pp. 1-8, 2009.

[32] E.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.

[33] S. Kamaruzzaman and A.B. Juhari, "Pico Hydro: Clean Power from Small Streams", *Proc. of the 3rd WSEAS. Int Conf on Renewable Energy Sources*, 414-419, 2009.

[34] H. Zanuddin, M.S. Yahaya, J.M. Laze, M.F. Basar and Z. Ibrahim, "Design and Development of Pico Hydro Generation System for Energy Storage Using Consuming Water Distributed to Houses". *World Academy of Science, Engineering and Technology*, vol. 59, pp. 155-159, 2009.

[35] G.R. Pokharel, A.B. Chhetri, M.I. Khan and M.R. Islam, "Decentralized Micro-hydro Energy Systems in Nepal: En Route to Sustainable Energy Development", *Energy Sources, Part B: Economics, Planning, and Policy*, vol. 3, no. 2, pp. 144 – 154, 2008.

[36] K. Alexander and E. Giddens, "Cost Effective Modular Systems for Low Heads", *Renewable Energy*, vol. 33, pp. 1379-1391, 2008.

[37] P. Maher and N. Smith, Pico hydro for village power – a practical manual for schemes up to 5 kW in hilly areas. Micro Hydro Centre – Nottingham Trent University, 2001. Available from: http://www.eee.nottingham.ac.uk/picohydro/documents.html

[38] C.P. Ion and C. Marinescu, "Autonomous Micro Hydro Power Plant with Induction Generator", *Renewable Energy*, vol. 36, pp. 2259 – 2267, 2011.

[39] N. Smith and S.R. Bush, "A Light Left in the Dark: The Practice and Politics of Pico Hydro Power In the Laos PDR", *Energy Policy*, vol. 38, no. 1, pp. 116-127, 2010.

[40] N. Smith and A. Williams, "Assessment of Pico Hydro as an Option for off Grid Electrification in Kenya". *Micro Hydro Centre Nottingham Trent University*, pp. 1357-1369, 2003.

[41] P. Maher, N.PA. Smith, and A.A; Williams, "Assessment of Pico hydro as an option for off-grid electrification in Kenya, *Renewable Energy*, 28: 1357 – 1369, 2003.

[42] A. Williams, "Pico Hydro for Cost Effective Lighting", B*oiling Point Magazine*, 14-16, May 2007.

[43] World Bank, "Technical and Economic assessment of off grid, Mini grid and grid electrification technologies", Summary report World Bank energy unit September 2006.

[44] A. Chhetri, G.R. Pokharel and M.R. Islam, "Sustainability of micro hydro systems - A case study", *Energy and environment*, vol. 20, no. 4, pp. 567-585, 2009.

[45] A. Pascale, T. Urmee and A. Moore, "Life cycle assessment of a community hydroelectric system in rural Thailand", *Renewable Energy*, vol. 36, no. 11, pp. 2799-2808, 2011.

[46] P. Maher, Kenya Case Study 1 at Kathamba and Case Study 2 at Thima. Available from: http://www.eee.nottingham.ac.uk/picohydro/documents.html#kenya, 2002.

[47] P. Maher, Design and implementation of a 2.2 kW Pico hydro serving 110 households, Micro Hydro Centre – Nottingham Trent University, Available from: http://www.eee.nottingham.ac.uk/picohydro/documents.html. 2002.

[48] B.R. Cobb, "Experimental Study of Impulse Turbines and Permanent Magnet Alternators for Pico-hydropower Generation", A Master degree thesis presented to the Department of Mechanical Engineering Oregon State University, 2011.

[49] S. Sangal, G. Arpit and K. Dinesh, "Review of Optimal Selection of Turbines for Hydroelectric Projects", *International Journal of Emerging Technology and Advance Engineering*, vol. 3, pp. 424-430, 2013.

[50] J.L. Chukwuneke, C.H. Achebe, P.C. Okolie and H.A. Okwudibe, "Experimental Investigation on Effect of Head and Bucket Splitter Angle on the Power Output of a Pelton Turbine", *Journal of Information Engineering and Applications*, vol. 4, no. 10, 2014.

[51] M.M. Alnakhlani, D.A. Mukhtar, A. Himawanto, Alkurtehi1 and D. Danardono, "Effect of the Bucket and Nozzle Dimension on the Performance of a Pelton water Turbine", *Modern Applied Science,* vol. 9, no. 1, 2015.

[52] A.O. Edeoja, S.J. 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 (JMEST)*, vol. 2, no. 2, pp. 22-34, 2015

[53] A.O. Edeoja, S.J. Ibrahim and E.I. Kucha, "A Simplified Pico Hydropower System with Provision for Water Recycling", 6th Annual and International Conference of the Renewable and Alternative Energy Society of Nigeria (RAESON), University of Nigeria, Nsukka, 20-23rd April, 2016

[54] A.O. Edeoja, S.J. Ibrahim and E.I. Kucha, "Investigation of the Effect of Penstock Configuration on the Performance of a Simplified Pico-hydro System", *British Journal of Applied Science & Technology*, vol. 14, no. 5, pp. 1-11, 2016.

[55] 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) 042031*