Renewable Energy Production Using Pico-hydroelectric Scheme: Design and Implementation for a Remote Uwowo Village

R.E. Ochagwuba
Electrical Eng'g Dept.,
The Federal polytechnic
Idah, Nigeria
raphochagwuba@yahoo.com

S.O. Igbinovia
Electrical Eng'g Dept.,
University of Benin,
Benin-City, Nigeria
samigbinovia2006@yahoo.com

B.U. Ayanta
Civil Eng'g Dept.,
University of Benin,
Benin-City, Nigeria.

A.Y. Anekunu
Electrical Eng'g Dept.,
The Federal Polytechnic
Idah, Nigeria
anekyusuf67@yahoo.com

Abstract: An assessment of Uwowo stream located in the hydrologic region of Kogi state, Nigeria was carried out in order to determine the available hydroelectric power potentials. Gross head measurement was determined using Garmin GPSmap 76 S Global Positioning System and the float method of discharge measurement was adopted and carried out for three consecutive years. This study applied RETScreen software to assess the feasibility of small-scale hydro power renewable energy and Green House Gas (GHG) emission reduction analysis. The assessed site is in the category of pico hydroelectricity with 1kW firm power, 32.1MWh annual energy capture and a GHG emission reduction equivalent to 26.1 tons of carbon dioxide (tCO2). The implementation of the site involved the application of the technologies of Pump –As – Turbine (PAT) and Induction Motor- As - Generator (IMAG). The field test conducted on the system gave output no load voltage of 72.01 V which was used to power some lighting bulbs and recharging of phone cells in a household in Uwowo village.

Keywords: Green House Gas, induction generator, pico-hydroelectric, pump – as - turbine .

I. Introduction

THE welfare of rural communities of a nation in relation to education, healthcare, increased productivity is enhanced by the provision of basic energy requirements as demonstrated by International Evaluation Group of the World Bank [5]. Renewable energy resources are cheaper, decentralized and more environmentally friendly for application in remote areas. Pico hydro electric power systems provides up to 5 kW [6] and it is the option that provides the least power output amongst the off-grid hydroelectric energy systems.

The Uwowo stream in Idah, Kogi state, Nigeria, originates from a hilly terrain and runs past Uwowo rural dwellers is of perennial flow regime. To assess demand for pico hydro scheme in this community, the necessity for establishment of the basic conditions were identified as follows:

- the location of this community is approximately 3 km from the national grid, meaning the community is without electricity supply and no hope of connecting her to this main grid of power supply by the three tiers of government in the near future, hence the very importance of this study in view of the renewable natural resource "Uwowo stream".

The photographs of the Uwowo stream and rural dwellers are shown in Figure 1.

Fig. 1. Uwowo stream/village

The approximate electric power potential at a hydroelectric plant is determined by the equation Verdin, (2004) ,

$$P = \eta \, x \, \rho \, x \; g \, x \; Q \, x \; \mathrm{H} \qquad (1)$$

II. Materials And Design Methodology

The design and implementation of Uwowo pico hydroelectric power scheme include the following methodology:

- Selection of high elevation points along the stream at the intake and reference turbine installation point was determined using GPS, model: Garmin *GPSmap* 76S ;
- Determination of stream flow was done by the method of measuring the depth of stream bottom downstream locations at a known distance apart. A floating object (plastic ball) was placed at the streamline and timed to float to the downstream line. The weekly, monthly and yearly averages were carried

out for three years consecutively shown in Table1 with the resulting hydrograph shown in Figure 2;

TABLE I
Flow measurements at Uwowo site

Months	Uwowo Average Discharge (m^3/s)			
	2008/2009	2009/2010	2010/2011	Average
June	0.510	0.582	0.546	0.55
July	0.460	0.491	0.492	0.48
August	0.567	0.567	0.564	0.57
September	0.839	0.853	0.876	0.85
October	0.582	0.586	0.620	0.60
November	0.360	0.385	0.368	0.37
December	0.240	0.242	0.244	0.24
January	0.159	0.163	0.170	0.16
February	0.127	0.133	0.136	0.13
March	0.157	0.159	0.155	0.16
April	0.210	0.200	0.211	0.21
May	0.298	0.337	0.376	0.34

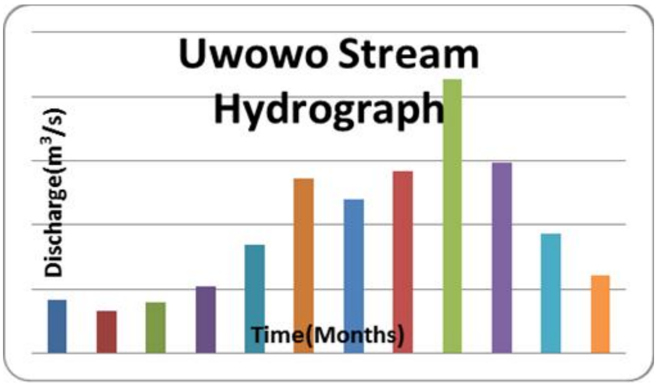


Fig. 2. Uwowo stream hydrograph

TABLE II
Results of Head Measurement and Estimated Power Demand at Uwowo Site /Village

Stream Name	Head (m) Gross	Net	Estimated Power Demand by the Inhabitants
Uwowo	2.68	2.407	4.93

- Application of RETScreen Software**:** The RETScreen Clean Energy project analysis software is a clean energy awareness, decision which support capacity building tool used worldwide to assess energy production , cost savings, emission reduction, financial viability, risk and sensitivity analysis for various types of Renewable-energy and Energy –efficient Technologies(RETs)[7]. In this work, the RETScreen software (version 4.0) was applied to assess the power potential and greenhouse gas reduction analysis. The summary of findings using RETScreen software assessment at Uwowo site is shown in Table 3.

- Desgn and implementation of Uwowo stream picohydroelectric power scheme involves the following:

A. Design and Construction of Forebay Tank

It is desired to design and construct a tank of capacity in the range of 20,000 – 30,000 liters to maintain fairly constant water volume at dry and rainy seasons. The selected high elevation point at the intake is on a natural bed of rock, forming the foundation footing of the tank and taking a heptagonal shape because of the terrain. Being a reinforced concrete structure, a design factor of 0.102h and 0.164h was used for the thickness of the upper and foot of the tank as against factors of 0.4h and 0.7h respectively recommended when using stone masonry for pico hydro systems[6]. The volume of the forebay tank yielded a result of 27,150 litres (5,972.17 UK gallons, 7,172.27 US gallons) and its isometric view is shown in Figure 3.

B. Design and Construction of the Flushing Sluice and Overflow Control Outlet

The flushing and overflow facilities include lengths of unplastified Polyvinyl Chloride (uPVC) pipes used to drain water from the tank at times of routine maintenance and discharging excess water into the main stream respectively. The design which is based on the relationship according to [1] is given by (2) and (3) below

$$Area\ of\ Inlet = \frac{Area\ of\ Penstock\ x\ Sec\theta}{Coefficient\ of\ Contraction(\beta).} \quad (2)$$

For low heads, $\beta = 0.7$

$$Area\ of\ inlet = \frac{A_p\ x\ Sec\theta}{0.7} \quad (3)$$

Where Θ is angle that the axis of the inclined penstock makes with the water surface.

The computed areas for the flushing and overflow inlets yielded approximately$0.0117\ m^2$.

The cross section of bell-mouthed flushing sluice and overflow discharge outlet are shown in Figure 4 and 5.

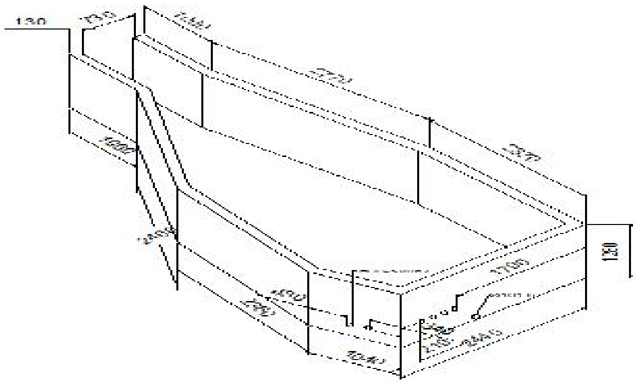


Fig.3. Isometric view of Uwowo forebay tank

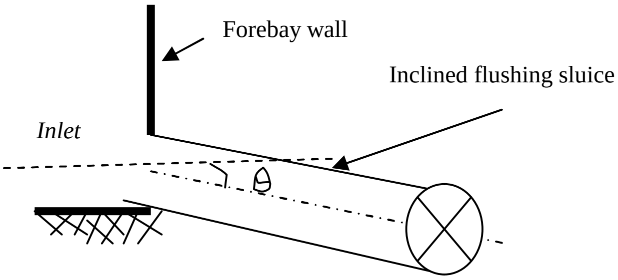


Fig.4. Cross-section of bell-mouthed flushing sluice

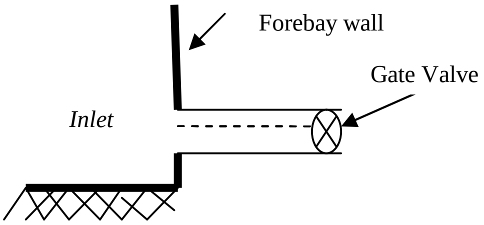


Fig.5. Cross-section of bell-mouthed overflow discharge outlet.

C. Penstock Selection and Configuration

The type of penstocks selected for this study is a combination of asbestos cement and uPVC pipes. The advantages that asbestos cement pipes offer include their relative strength to withstand stress and resistance to ultra violet radiation, which allows for surface mounting. The uPVC pipes were used at the intakes from the forebay tank, Y-joints and the connection to the Pump- As-Turbine.

In the Uwowo Pico hydroelectric piping system, to build up adequate water pressure, a pattern of initial four (4 No) penstocks take in water, converge to two (2No) penstocks and finally converge to one (1 No) penstock which then feeds the turbine nozzle via an elbow. The piping configuration of the Uwowo pico hydro scheme is shown in Figure 6.

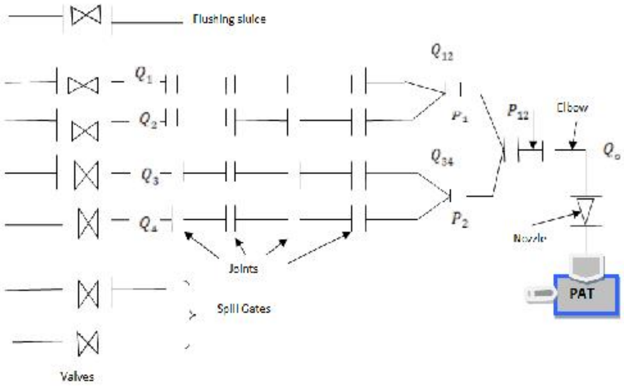


Fig 6 Uwowo Pico hydro scheme piping configuration

Determination of net hydraulic head

The ***Hazen-Williams*** formula [4] was adopted to compute the head loss in the various pipe segments given by

$$h_l = kL\left[\frac{\left(\frac{Q}{C}\right)^{1.852}}{D^{4.8655}}\right] \quad (4)$$

Also the ***Hazen-Williams roughness coefficient*** for asbestos cement and uPVC pipes were employed. The sum of head loss at pipes' entrance, gate valves and joints are neglected. The overall head loss in the pipes gave $0.273\ m$, therefore the net head would be approximately $2.407\ m.$ The results of the preliminary investigations carried out at Uwowo site is shown in Table 1 and Table 2.

D. Selection of Pump – As – Turbine

A standard centrifugal Etanorm pump (ETANORM Standardized Pump, 2010) was selected for application as PAT. The pump features are as follows:

Type: ETANORM M65/160KSB AKTIENGESELLSCHAFT

Speed: 2,900r/min Flow rate : Up to 1,900m^3/h (5281/s)

Head: Up to 102m (max)

Design: Horizontal volute casing No:6-106-120 224/1

E. Selection of Induction Generator

The Heinz Guggel –Inc Stuttgart squirrel cage induction motor was selected for application as Induction Generator (IG). The name plate of the motor provides the following:

3-phase Delta; 0.37 kW; 220/380 V; 2.6/1.6 A; 50 Hz; 690 rpm;

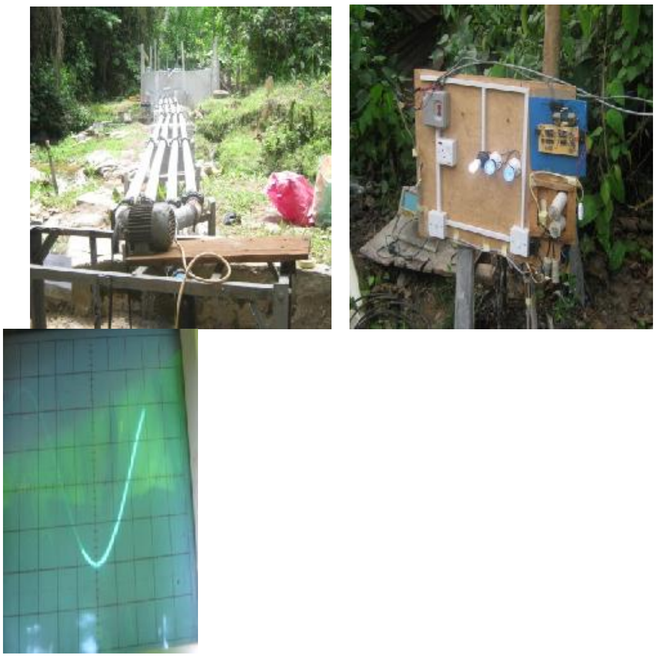


Fig 7 Uwowo site stream engine assembly / experimental set up and village lighting

F. Selection of pulley and belt drive systems

Since the rotational speed of the PAT shaft is inadequate to drive the Induction Generator (IG) above the synchronous speed, it becomes necessary to use a speed step-up system comprising pulleys and belt drive. Pulleys made of aluminum were applied because of advantages of resistance to corrosion and light weight. The following pulley sizes and belt were selected for application:

PAT Pulley: 30mm diameter, IG Pulley: 150mm diameter, Ratio: 1: 5

Belt Drive: A72 (12.5 x 1875) , 420mm diameter

G. Determination of Capacitor Value of Heinz Guggel –Inc Stuttgart squirrel cage Induction Generator

The C-2C arrangement of capacitors was adopted and the capacitance value were determined from the given equations Smith, (2001),

$$c = \frac{1}{2\pi f X_c} \quad (5)$$

but
$$X_c = \frac{V}{I_{per\ phase}} \quad (6)$$

therefore,
$$C = \frac{I_{per\ phase}}{2\pi f V} \quad (7)$$

The induction motor operated as induction generator at 50Hz profile is shown in Table 5.

H. Field Set up at Uwowo site

The field tests conducted at the Uwowo site includes opening the inlet gate to allow water into the tank and thus through the penstocks to drive the PAT and IMAG .The output voltage (V), current(A), power(W), frequency(Hz) and temperature (^{o}C) of the system are measured. The photographs of the experimental set up at Uwowo site and Uwowo village electrification scheme is shown in Figure 7.

III. RESULTS AND DISCUSSIONS

The average flow and head measurements are presented in Table 1 and Table 2 respectively. The Uwowo stream hydrograph shown in Figure 2 confirms its perennial flow regime. In the RETScreen emission analysis worksheet, the net annual greenhouse emission reduction yielded a figure of 26.1 tons of carbon dioxide meaning that 26.1tons of CO_2 is saved from polluting the atmosphere at implementation of Uwowo site using hydro power resources. The results of the field test and measurements are presented in Table 5. For the field tests conducted at Uwowo site, average voltage value of 72.05V was produced and used to recharge phone cells as well as power 9 watts, 11 watts, 13 watts, 18 watts and up to 40 watts energy saving bulbs which provided lighting in a household at Uwowo village between the hours of 9.00 AM and 6.00 PM each day. When a 200 MHz, Model GW INSTEK GOS-6200 oscilloscope was used to monitor the output, it showed undistorted sinusoidal waveform. A minimum and maximum frequency of 65 Hz and 71Hz respectively were realized at site and village. These frequency values are out of the limits of +1.0% or -1.0% (+0.5Hz or -0.5Hz) of 50 Hz statutory value of the electric power utility in Nigeria (NCC,2001). The temperature of the IG and that of water discharged from the draft tube does not vary significantly.

TABLE III

Summary of RETScreen Results of Assessment at Uwowo site

Firm Flow (m^3/s)	Turbine Type & Manufacturer	Turbine Eff. at design flow (%)	Power Capacity(kW)	Firm Power(kW)	Capacity Factor(%)	Annual Energy(MWh)	Net GHG Reduction(t) CO_2	Hydro Category
0.15	PAT(Etanorm KSB)	79	2	1	91	32.1	26.1	Pico

TABLE IV

Results of Uwowo site / village performance

No of combined penstock used=4; Water level at the penstock : full

Induction generator speed (rpm)	Output Voltage (V) at site	Transmission line distance(m)	Conductor type & size	Output Voltage(V) at village	Load (W)	Frequency (Hz)	Frequency Deviation (Hz)
1,630	79.00	113 x 2 = (226m)	Aluminum ($16mm^2$)	78.00	9	71	+20.5
1,629	75.00			74.50	11	68	+17.5
1,626	71.50			70.50	20	67	+16.5
1,623	67.80			67.00	26	65	+14.5
1,620	62.05			61.20	40	65	+14.5

TABLE V

Induction motor operated as induction generator at 50 Hz profile

S/N	Description	Ratings
1	Type of connection of capacitor bank	'C' – '2C'
2	Ratings /particulars of induction motor	4-pole, Delta, 380V, 0.37KW 3-Phase
3	I_{cph} (A)	0.0013
4	I_{FL}(A)	2.6
5	$P.F_{FL}$	0.85
6	Speed for gen. at 50HZ (RPM)	690/2310
7	S (KVA)	1.711
8	P_o (KW)	1.45
9	Q_R(KVA_R)	0.902
10	Required cap, per phase (µF)	10.68 hoose 10 - 12

VI. RECOMMENDATIONS

To improve upon the voltage profile and power capacity of this site, the forebay tank size, penstocks, PAT, IG and excitation capacitor bank should be increased proportionately in order to meet up the estimated power demand by the inhabitants.

- To exercise frequency control of this station, thorough Load Frequency Control (LFC) studies should be carried out and thus the incorporation of a matching Electronic Load Controller (ELC) in the system.
- The Designated National Authority (Presidential implementation committee on SHP) should put forth simplified documentation on Pico hydro and information dissemination to ensure that the concerned local populace and general public are fully informed on Pico hydro matters.
- The socio-economic rejuvenation of the rural populace is the main aim of this work. It is therefore recommended that this study be encouraged with Nigerian and Kogi state governments' good political will by providing adequate funds to achieve this aim.
- United Nations International Development Organization (UNIDO) regional center for Small Hydro Power (SHP) in Africa, Abuja should capture this assessed site for full scale implementation and other International development agencies and Non-governmental Organizations (NGOs) should assist the civil society in Nigeria by implementing project of this kind.
- Manufacturers of hydroelectric components such as water turbines, nozzles, penstocks, etc should be encouraged to set up in Nigeria with low import duties on these components. The Federal government should ensure that the necessary legal, regulatory and institutional framework is put in place to attract investors in pico hydroelectric power generation.

REFERENCES

[1] Dandekar, M. M.and Shemah, K. N., (1999), "Water Engineering", VIKAS Publishing PVT Ltd, India. 265-269.

[2] ETANORM Standardized Pumps: "Selection Chart", Installation/Operating Manual KSB(2010).

[3] AKtiengesellschaft Pegnit, Frankenthel February, 1-28

[4] Hazen-Williams Equations: Engineering Toolbox Http://www.engineeringtoolbox.com accessed, July, 2011.

[5] International EvaluationGroup – World Bank (2008): The Welfare Impact of Rural Electrification: A Reassessment of the Cost and Benefit:URL:http://siteresources.worldbank.org/EXTRURELECT/Resources/full.doc.pdf accessed September, 2010.

[6] Maher, P. and Smith, N. (2001),"Picohdro for Village Power: A Practical Manual for Schemes up to 5KW in Hilly Areas",edition 2.0, May, 1-17.

[7] Mutlu, R (2010),"Feasibility Study of a Hydropower Plant: A Case Study of Niksar HEPP" Turkey. An unpublished MSc thesis of Middle East Technical University, Turkey. Pp1-126

[8] NCC(2001) National Control Centre Osogbo. Generation and Transmission Grid Operations 2000 Annual Technical Report. 1-90

[9] RETScreen International, "Centre overview," July 29, 2010. [Online]. Available: *http://www.retscreen.net/ang/g_contri.php*

[10] Smith, N.(2001) , "Motors as Generators" Published by ITDG Publishing, 103-105 Southampton Row, London WC1B 4HL, UK www.itdgpublishing.org.uk ISBN1 853392863, 1 -92

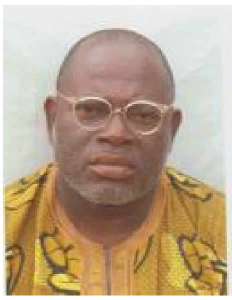
[11] Verdin, K.L. (2004), "Estimation of Average Annual Stream flows and Power Potentials for Alaska and Hawaii" Idaho National Engineering and Environmental Laboratory, Idaho Falls. INEEL Low Power Hydropower Resource Assessment & Technology Development Project. US Department of Energy. pp 1-21.

About Authors:

Engr. Raphael Emola Ochagwuba was born on April,15 1964. He graduated from the Federal Polytechnic, Idah , Nigeria (ND, HND Elect/Elect Eng) (1984, 1987) and studied at the Abubakar Tafawa Balewa University, Bauchi, Nigeria (PGD, M. Eng Elect/Elect Eng) (1998, 2003).

His employment experience included the I.O. International Ltd,(Electrical Power Construction Engineers) Port Harcourt, as site Engineer, Federal Government College, Jos, Federal Polytechnic, Kaura Namoda and currently at the Federal Polytechnic, Idah as Chief Lecturer.

He was student member of IEE in 1987. He is currently Corporate member, Nigerian Institution of Engineering Management (MNIEM), Nigerian Society of Engineers (MNSE), and Registered Engineer, Council for the Regulation of Engineering in Nigeria(COREN). He is currently a Ph.D student of the University of Benin, Benin City, Nigeria. His research interests include Reliability studies of Electric Power Systems, Renewable Energy Systems and Small Hydro Power (SHP) development.



Professor Samuel Osamudiamen Igbinovia BEng (1986) (Elect/Elect), PGD (1997) (Computer Science), M. Eng (1999)& PhD (2007) (Power Systems and Machines).

Engr. Dr. Igbinovia S.O. after graduation in 1986 from the University of Benin has held positions such as: Technical Director for Leostine Nigeria ltd; Project Engineer for Skanga Nigeria Ltd and Sotak Electro-Mechanical

Engineering Services ltd. In January, 2000, Dr. Igbinovia S.O. joined University of Benin, Benin City, Nigeria as Lecturer II. He is presently an Associate Professor in Electrical/Electronic Engineering Department. He has served in several committees and appointed Acting Directors of Maritime Studies and Information Technology centres for two (2) years in the University of Benin. He is a corporate member of the Nigerian Society of Engineering (MNSE) and COREN Registered Electrical Engineer. His area of interest include: Power System Planning, Design and Analysis, Electrical and Mechanical Services Design, Installations and Maintenance, Energy Policy Development, Planning and Development of Renewable Energy System and Electronic load controllers for power flow optimization.

Prof. B.U. Anyata, PhD (Cornell University), BSc and MSc (Manchester University England). Presently he is a Professor of Water Resources & Environmental Systems Engineering in the University of Benin, Benin City. His research interests are in Water Resources & Environmental Systems, Solid Waste Optimization, and Wastewater modeling. He is also interested in application of systems analysis of Renewable Energy Systems. He teaches Public Systems Analysis, Renewable Energy Systems and the application of modeling in Fuzzy systems as well as probability applications in water resources systems. Prof. Anyata has more than thirty (30) years of teaching and research.

Engr. A.Y. Anekunu was born on the 13th of April, 1967. He finished his secondary education from Aquinas College Akure, Nigeria in 1985. In 1988 he obtained his National Diploma in Electrical & Electronic Engineering from The Federal Polytechnic Ado-Ekiti, Nigeria. He went further to Kwara State Polytechnic Ilorin where he obtained his Higher National Diploma in Electrical Engineering in the year 1991. In 1999, Engr. A.Y. Anekunu obtained the Postgraduate Diploma in Electrical Engineering from The Federal University of Technology Akure, Nigeria. He obtained Master of Engineering (M Eng) degree in 2010 from Ambrose Alli Universty, Ekpoma. He is presently running his PhD degree in Electrical Engineering at the University of Cape Town in South Africa. He has undergone training and worked in many industries and organizations including Ajaokuta Steel Company Limited, Ajaokuta; Directorate of Food Road, and Rural Infrastructures (DFRRI) in Afikpo; JAB-Technical Services, Ado-Ekiti; BELL-Papyrus Ltd, Oregun Lagos; Boulos Enterprises Limited, Lagos; Safety Products Manufacturing Company, Ogba Lagos. He works as a Senior Lecturer at The Federal Polytechnic Idah in Kogi State of Nigeria. He is a COREN registered engineer and corporate members of the Nigerian Society of Engineers, Institution of Electrical and Electronics Engineers IEEE (USA), Institution of Engineering and Technology, IET (UK), Association of Computing Machinery ACM (USA). His research interest is on renewable energy, machine design and drives