



Scope and Potentials of Renewable Energy Hybrid Power System in Semi-arid Region of Northern Nigeria: Maiduguri and its Environs

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ABSTRACT

This research focuses on studying the scope and potentials of using solar-wind hybrid energy system for power generation in the semi-arid region of northern Nigeria (Maiduguri and its environs). Many of the villages of Maiduguri and the surrounding local governments areas are not connected to the national grid and they have no any source of power except using fossil fuelled generators, as such there is the need to find ways of harnessing the renewable energy sources of these areas in order to generate power for the use in these areas. Maiduguri and its environs have an average wind speed of 6.72m/s at 30m height and solar irradiance of 6.176kW/m² and an average wind speed of about 5m/s at 30m hub height. The result of the study shows that the power generation potentials of wind and solar resources good and promising. The complementary nature of the two energy sources makes the hybrid system a good means of power generation in the area. With the solar-wind hybrid system about 2.3MWh/m²yr can be generated in the study area. This result showed that energy can be generated for domestic and utility use by using solar-wind hybrid power system since the energy output from the hybrid system is so promising.

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INTRODUCTION

Energy is the backbone of every society; it plays an important role in human and economic development of a nation. Energy is an essential ingredient for socio-economic, technological as well as economic growth and development of every society. Energy systems are used to generate or convert and from one form to another as well deliver the energy for use. Olaoyeet; et al, (2016) reported Nigeria has a poor electricity generation and distribution.

Mai jama'a, et.al; (2015) stated that Nigeria has an electricity consumption per capita of 149 kWh between the year 2010 and 2014 and this

has contributed to its industrial underdevelopment. Rural areas are the most hit by this lack of electricity supply. According to a report by Eke, (2014) and Akpu, (2012) about 15.3 million households in Nigeria (about 50% of the households in the country) most of them living in the rural areas are not connected to the National. According to the projections of the Japanese International Cooperation Agency (JICA) even by the year 2020, only less than 50% of the households in the semi-arid region will have access to electricity, and for Nigeria to meet up its energy needs, it requires per capital power capacity of 1000 kWh (Nnaemeka et al, 2014 and Eke, 2014).

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Nigeria's energy problems are not due to the absence of energy generation resources, but are rather due to the lack of resources utilization. The country is blessed with abundant conventional and renewable energy (RE) sources such as wind, hydro, solar, wind, biomass, crude oil etc. However, despite the abundance of these energy resources, there is persistent electricity generation and supply deficit, which may be attributed to the underutilization of these potentials (Idris *et. al*; 2012). The Nigerian power sector is presently characterized by chronic shortages, epileptic and poor power quality supply as such it hinders development of the country.

In many rural areas in Nigeria where there is no access to the national grid or the grid is remote, wind energy could provide a cost effective option for rural electrification. Access to electricity in the rural area of Nigeria has been put to about 20%; hence the need to explore the use of renewable energy resources for power generation (Akinboro, et al 2012). The most dominant method of generating electricity employed in Nigeria is the use of thermal plants that depend on fossil fuels such natural gas, diesel and or petrol, which are defleatable in nature, hazardous to the environment because they emit abundant greenhouse gasses in our atmosphere and causing climate change and other substantial health problems. To meet Nigerians energy needs, energy potentials of each and every region should be harnessed to supply power to the populace. Now it is the time to start looking for and development of technologies to make the project self-reliant in term of electricity generation and supply.

Many people rely on the conventional energy sources to satisfy their energy needs but because of its depleting and hazardous nature, the world's attention has turned towards developing and harnessing the renewable energy resources. These renewable energy resources include sun, wind,

biogas, tides, geothermal and water. Solar and wind energy have been deemed clean, available and inexhaustible and also eco- friendly, these characteristics have made them more attractive. Despite the fact that renewable energy sources are clean and abundant in nature, all renewable energy sources have some draw backs. One of the drawbacks of renewable energy systems such as solar as well as wind energy is the fluctuation of energy supply due to fluctuations from the energy sources, resulting in intermittent delivery of power. This drawback can be avoided by hybridizing different energy sources which have complimentary characteristics (Ani and Abubakar, 2015). Hybrid energy stations have proven to be advantageous for decreasing the depletion rate of fossil fuels, as well as supplying energy to remote rural areas, without harming the environment (Dalwadi and Mehta, 2012).

The sun and the wind are nature's ultimate energy sources and can be harnessed using the right technologies. Due to the depletion of fossil fuels, renewable energy sources such as solar and wind energies are of wide interest. Nowadays, the costs of renewable energy systems and their components are declining and becoming more affordable. These renewable energy sources (wind and sun) offer imminent financial benefits, as it becomes cheaper to produce and implement them. If renewable energy is added to the present energy supply, more than sixty thousand megawatts (60,000MW) or sixty Gigawatts (60GW) of power required to place Nigeria in the category of industrialized nation can be achieved without significant increase in environmental pollution (Olaoye *et. al*, 2016).

Solar and wind are the fastest growing renewable energy sources. They form the base of the solutions to our ever diminishing conventional energy resources. Wind and solar resources will be a viable option for energy generation.

Solar energy and wind energy were shown to be clean, available and inexhaustible which are also eco- friendly, these characteristics have made them more attractive and the energy sector is focusing on how to use these sources on a larger scale. However, all renewable energy sources have some drawbacks that depend on unpredictable factors such as weather and climatic conditions, but this weakness can be overcome by the complementary nature of both the wind and solar energy sources and this brings us to the development of hybrid solar-wind power plant concept (Dalwadi and Mehta, 2012). The search for a more reliable and less costly renewable energy system has brought about the hybrid use

of two energy sources: solar and wind energy. Hybrid power generation system (HPGS) is a power generating system that combines two or more modes of electricity generation together, usually using renewable technologies such as Solar Photovoltaic (PV) & Wind turbines (Hoque *et al.*, 2012). Wind and solar energy sources are the cheapest available natural resources for renewable energy and they best complement each. The excess energy from the solar PV and Wind turbine are stored in a Battery Bank through Hybrid Controller. Energy stored in the battery is drawn by electrical loads through the inverter, which converts DC power into AC power.

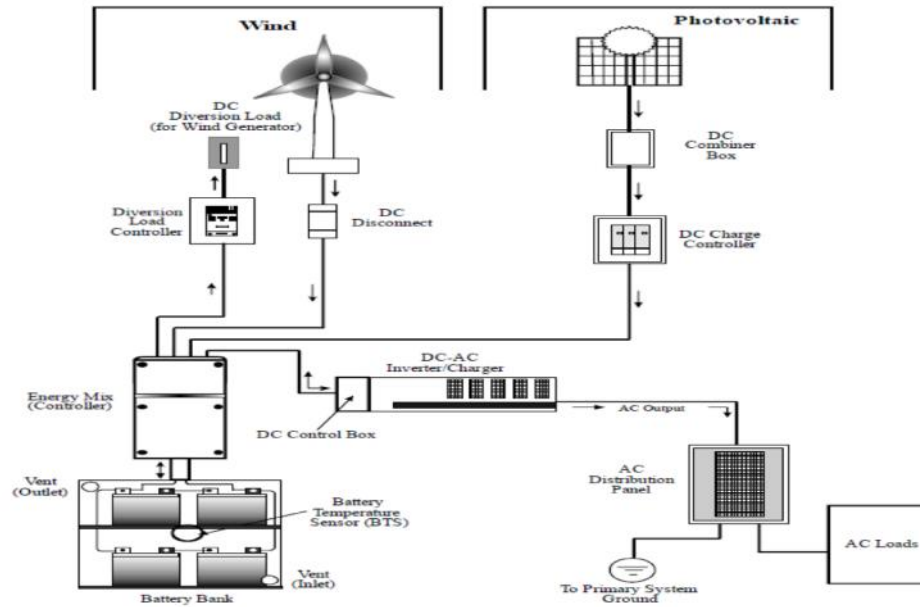


Figure 1: Schematic diagram of solar – wind hybrid power system
 Source: Adejumobiet *al.*, 2011

Solar-wind hybrid power system is the best hybrid combination of all renewable energy systems and is suitable for most of the applications. A hybrid energy system generates power without harming the environment.

STUDY AREA

Maiduguri is located between latitudes 11 42N and 12 00 N and longitudes 12.54 and 13 14 E (Haruna 2010). She further claimed that Maiduguri covered an area of 543km². The city is bounded in the north by Jere LGA, in the west, south and south - west by Konduga LGA, in the north- west by Mafa LGA. Maiduguri urban is the capital of



Maiduguri metropolitan Council (MMC) and Jere Local Government Areas, it is located in semi-arid region of northern Nigeria (Mayomi and Mohammed, 2014). Many of the villages in the Jere, Mafa, Konduga and Magumeri local government areas that are surrounding Maiduguri were not connected to the national grid and they have no any source of power except using fossil fuelled generators, as such there is the need to find ways of harnessing the renewable energy sources of these areas in order to generate power for the use in these areas.

The semi-arid region of Northern Nigeria is endowed with an average solar radiation and sunshine hours of 7 kW/m²/day and 9 hours respectively (Ngala et al., 2013). According to studies conducted, wind-solar hybrid energy system is a viable power generation option in the semi-arid region of northern Nigeria (Muhammad et al., 2015). The wind and solar energy profile of the region is favourable for the operation of the energy system. However, despite the abundance of these energy resources, there is persistent electricity supply deficit, which may be attributed to the underutilization of these potentials (Idris et al., 2012). The aim of this is research work it to evaluated the scope, potential and viability of using solar-wind hybrid energy system in Maiduguri and its environs.

RENEWABLE ENERGY SOURCES

Wind Energy

Wind is air in motion. It is caused by the uneven heating of the Earth's surface by the sun. Today, wind energy is mainly used to generate electricity. The wind energy potential of Maiduguri is also characterized by the availability of flat land couple with an average wind speed of 4.7 m/s (Felix et al., 2012).

A wind turbine is used to harness the kinetic energy in wind to generate electricity. A typical wind machine consists of blades, generator, cable, and a tower. The blades catch the wind and spin, the generator converts mechanical

energy into electricity, the cable carries electricity to transmission line. The blades are connected to a drive shaft that turns an electric generator to produce electricity (Awogbemi and Komolafe, 2011). Energy in the shaft is then used to derive mechanical or electrical loads. This kinetic energy (K) is given by: (Lawan, 2012)

$$K.E = \frac{1}{2} M v_f^2 \quad (1)$$

Where M= mass of the air passing/striking the wheel, v_f is the velocity (free stream velocity). If A is the area through which volume V of air passing in a time t and ρ the density of the air, then $M = \rho V$ (2)

The available theoretical power is expressed as (Onawumi and Olaoye, 2011)

$$P_T = \frac{1}{2} \rho . V^2 = \frac{1}{2} \rho V^3 \quad (3)$$

Area of the rotor blade can be expressed in terms of diameter D as $\frac{\pi}{4} D^2$. Substituting this in equation 3.0 will give theoretical power as:

$$P_T = \frac{\pi}{8} D^2 V^3 \rho \quad (4)$$

Due to mechanical or transmission and generator losses, power generated by the electrical generator is less than the power extracted by the turbine blades. Mechanical power available for the load machine is obtained by the multiplying with the efficiency of the drive train (gearbox) and is expressed by equations 5 and 6 (Pecan et al. 200).

$$P_m = \frac{1}{2} \rho V^3 C_p \eta_m \quad (5)$$

Electrical power of the wind turbine is expressed mathematically as

$$P_e = \frac{1}{2} \rho V^3 C_p \eta_g \eta_m \quad (6)$$

Wind speed near the ground changes with height. This requires an equation that predicts wind speed at one height in term of the measured wind speed to another. The most common expression for the variation of wind speed with height is the power law as stated by (Salisu and Garba 2013).

$$\frac{v_z}{v_1} = \left(\frac{h_z}{h_1} \right)^\alpha \quad (7)$$

For Maiduguri the value of α used is 0.41, the value for smooth surface and sand as reported by Medugu and Markus (2011).

According to Muhammad et al., (2015) the wind energy potential of Maiduguri can be evaluated or predicted by using the model presented in equation 8.

$$E_u = 3240.6 \times \eta \times C_p \times V^{3.6} \quad (8)$$

Solar Photovoltaic System

Photovoltaic or PV system, known commonly as solar cells, convert the energy from sunlight into direct current (DC) electricity. Photovoltaic is known as the process between radiation absorbed and the electricity induced. Solar power is converted into the electric power by a common principle called photo electric effect. The solar cell array or panel consists of an appropriate number of solar cell modules connected in series or parallel based on the required current and voltage (Godson *et al.*, 2013). The specific solar energy potentials of Maiduguri and its environs is characterized by the high intensity of solar radiation of 6.176kW/m²/day and the average sunshine hours of about 9 hours (Ngala *et al.*, 2013). According to Boneya and Bakele (2012), monthly average solar radiation of a place is computed using the relation presented as equation 9.

$$\bar{H} = \bar{H}_0 \left(a + b \left(\frac{N}{N_s} \right) \right) \quad (9)$$

The monthly mean daily extraterrestrial irradiation (H_0) and the monthly mean day length (N) can be derived by using equations 10, 11, 12 and 13 respectively as reported by Augustine and Nnabuchi, (2009).

$$\bar{H}_0 = \frac{2}{\pi} I_s \omega_s S_0 \cos \phi_s \cos \delta + c_1 \phi_s \omega_s \quad (10)$$

$$\bar{N} = \frac{2}{1} c_1^{-1} (-t_1 \phi_s) \quad (11)$$

$$\delta = 23.45 S \left(\frac{3(N+2)}{3} \right) \quad (12)$$

$$\omega_s = c_1^{-1} (-t_1 \phi_s) \quad (13)$$

The solar cell performance is related with its angle of tilt with the

horizontal. This is due to the fact that the variation of tilt angle changes the top loss coefficient and the amount of solar radiation reaching the cell effective area. Solar photovoltaic systems must be oriented to track the sun so that beam radiation will be directed onto the absorbing surface. The optimum tilt angle of installation is given by Ibrahim, (2011) as;

$$\beta = \phi + 15 \text{ in winter} \quad (14)$$

$$\beta = \phi - 15 \text{ in summer} \quad (15)$$

A model for predicting solar power output in tropical areas like Maiduguri was developed by Hatzigiorgiou (2004) and the equation is presented as equation 16,

$$\mu = \frac{G_t}{G_o} [\mu_m + \mu_p (T_M - T_0)] \quad (16)$$

Since the module temperature T_M is not known a priori, the following approximate relation between T_M , the ambient temperature T_{amb} and the nominal operating cell temperature NOCT, provided by the module supplier, has been employed (Hatzigiorgiou, 2004 and Ross, 1980)

$$T_M = T_a + G_t \frac{N-2}{8} \quad (17)$$

Hybrid Solar-Wind System

The power output from a solar-wind hybrid energy system in Maiduguri can be evaluated by using equation 18 as reported by Muhammad *et al.*, (2016),

$$P_H = \frac{G_t}{G_o} [\mu_m + \mu_p (T_M - T_0)] + 3240.6 \times \eta \times C_p \times V^{3.6} \quad (18)$$

Note: This equation is valid for wind velocity range of 2.02m/s to 8.65m/s and solar radiation range of flux of 225W/m² to 960W/m² and module temperature range of 3°C to 47°C.

RESULTS AND DISCUSSION

Figure 2 presents the wind energy potential of Maiduguri and its environs at 10 m and 30 m heights all-round the year. It was observed that the wind velocity at 30m height is much better than at the height of 10m. The months of August, September, October, November and December recorded lowest wind speed profile is indicated;

whereas the months of April, May, June and July are the windiest months of the year. The daily average wind speed whole round the year is approximately around 5m/s. According to Muazu *et al.*, (2009) the rates of wind speed for effective power generation ranges between 3.5 –

25 m/s. Therefore, the wind speed obtainable in Maiduguri is within the range specified by Muazu *et al.*, (2009), as such the Maiduguri has a good potential of generating electricity using wind energy.

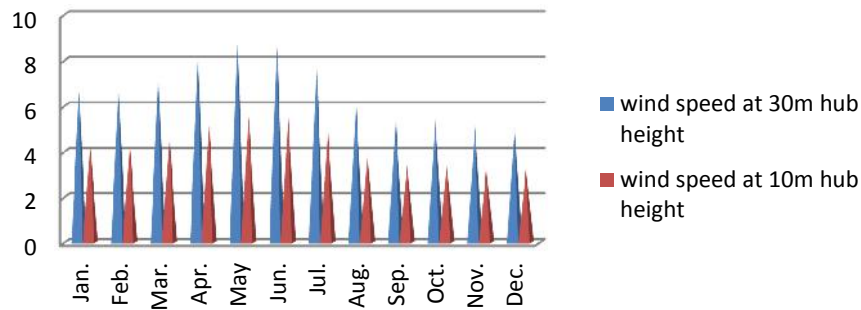


Figure 2: Mean monthly wind speeds of Maiduguri at 10m and 30m heights

Figure 3 depicts the magnitude of electrical energy generations potentials of Maiduguri from wind speed at 30m height. At an average lower wind speeds of around 5-6m/s, the wind speed of the study area

has the potential of generating around 1MWh/yr of electricity and with wind speed around 7-8m/s, there is the potential of generating up to 3MWh/yr of electricity.

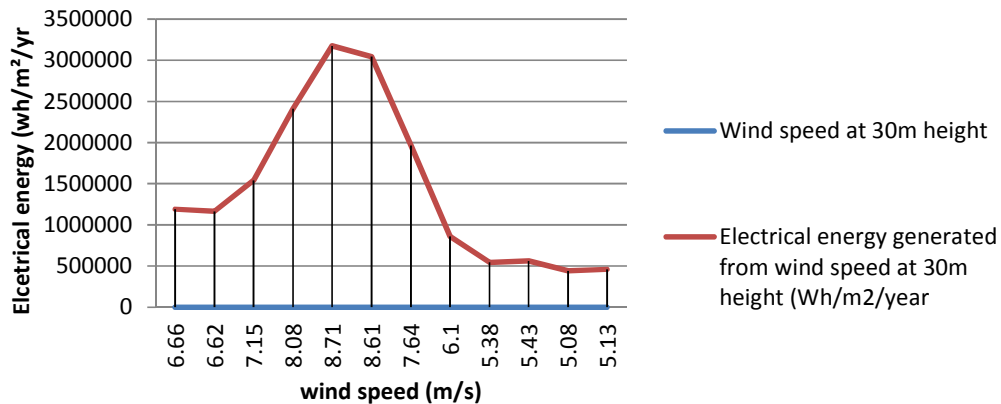


Figure 3: Electrical energy generated using average monthly wind speeds at 30m heights

Figures 4 depicts the solar energy potential Maiduguri and its environs all year round. The figure depicts that maximum solar insolation for Maiduguri was observed to be in the month of May, where a average solar radiation of 6.96kWh/m²/day was

recorded, whereas the minimum solar radiation was also observed in the month of December with radiation of 5.28kWh/m²/day. An average of 6.02kWh/m²/day was obtained for whole of the year.

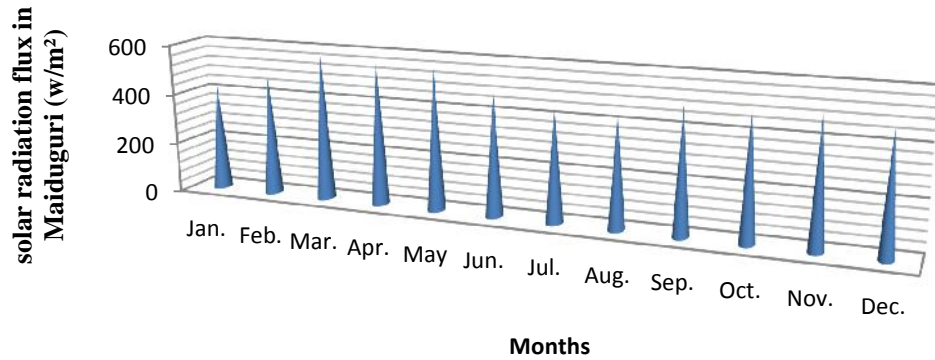


Figure 4: Average monthly solar radiations in Maiduguri

The solar energy resources of Maiduguri and its environs has the potential of generating between 1.2-1.4MWh/m²yr in the months of January and August as depicted by Figure 5 and also the figure shows that an average of

1.6-1.8MWh/m²yr power can be obtained during the remaining months of the year. This value depicts a very good electricity generation potential of the study are using solar radiation.

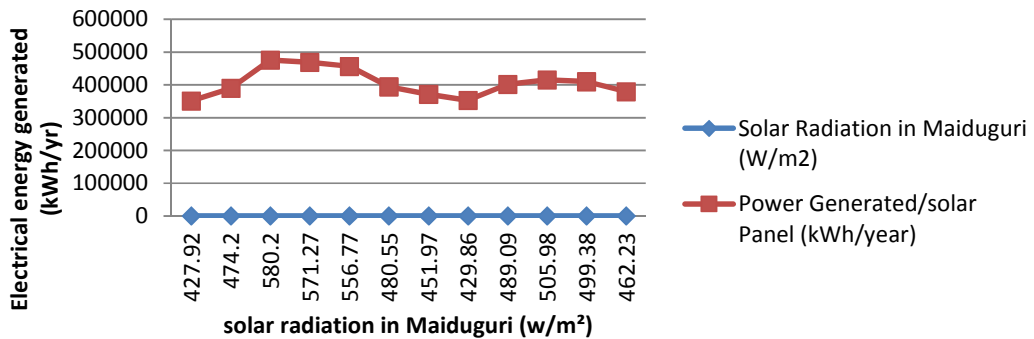


Figure 5: Average monthly solar radiations and the predicted electricity generation potentials of Maiduguri

Figure 6 depicts the electrical energy generation potentials of the study area using solar-wind hybrid energy system. The predicted power generation potentials using the solar-wind hybrid power system all year round is about 2-5MWh/yr of electricity can be generated as depicted by

figure 6. This result shows that the energy output from the hybrid system is so promising; it can be used for water pumping, battery charging or electrifications of rural settlements that are not connected to the grid.

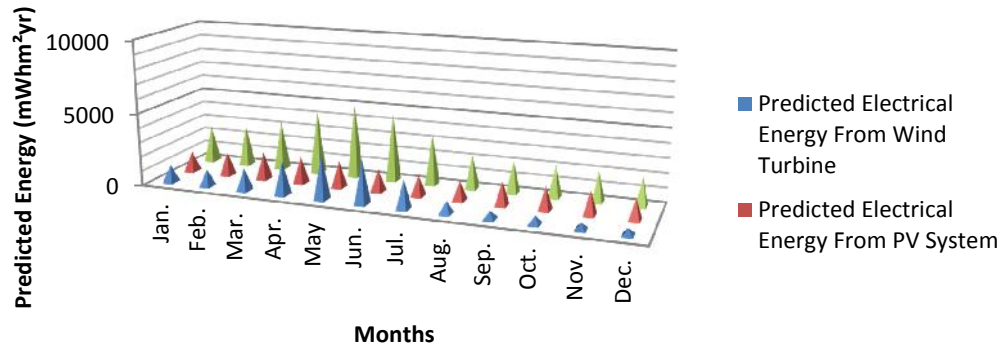


Figure 6: Solar-wind hybrid system electricity generation potentials

CONCLUSION

This research work was devoted to investigating the potentials, scopes and viability of using solar-wind hybrid energy system for power generation in Maiduguri and its environs. From the research conducted, the solar and wind energy potentials of Maiduguri and its environs are good for harnessing and when harnessed, an appreciable quantity of electricity can be generated. Also a solar-wind hybrid power system can effectively operate effectively and supply power for utility applications such as water pumping, battery charging and for domestic applications.

Nomenclature

P_{el} wind turbine electrical power (kW)
 P_m : wind turbine mechanical power (kW)
 η_m : The mechanical (gear box) (%)
 η_g Electrical generator efficiencies (%) condition (1000W/m²)
 v_1 wind speed at reference height h_1 (m/s)
 v_2 wind speed at estimated hub height h_2 (m/s)
 h_1 reference height above ground level (m)
 h_2 hub height (m)
 α depends on factor such as surface roughness or atmospheric stability.
 η efficiency (%)
 C_p Beltz constant (%)
 V Wind velocity (m/s)

\bar{H} Monthly average daily radiation on horizontal surface (MJ/m²)
 \bar{H}_0 Monthly average daily extra-terrestrial radiation on a horizontal surface (MJ/m²),
 N The maximum possible daily hours of bright sunshine,
 n Monthly average daily number of hours of bright sunshine,
 a Regression coefficients having average value of 0.33
 b Regression coefficients having average value 0.43
 δ Solar angle of declination
 I_{sc} Solar constant (4.921MJm⁻² day⁻¹)
 N Characteristics day number
 ϕ The latitude angle
 ω_s Sunset hour angle (°)
 Φ Latitude angle of the setting position (for Maiduguri is 11.51°).
 G_i Solar radiation (W/m²)
 G_o Solar radiation in standard
 P_m Power at maximum power point
 μ_{pmax} Temperature coefficient of power
 T_M Cell temperature inside diode (°C)
 T_o Operating temperature (°C)
 T_{amb} Ambient temperature
 $NOCT$ Nominal operating cell temperature



REFERENCES

- Adejumobi, I. A., Oyagbinrin, S. G., Akinboro, F. G. & Olajide, M. B. (2011). Hybrid solar and wind power. An Essential for Information Communication Technology Infrastructure and People in Rural Communities, 9:130-138.
- Akinboro, F., Adejumbob, L., & makinde, V. (2012). Solar Energy Installations in Nigeria: Observation, Prospects, Problems and Solutions. *Transnational Journal of Science and Technology*, 2 (4), 73
- Akpu, I. V. (2012). IAIA 12 Conference Proceedings' Energy Future The Role of Impact Assessment 32nd Annual Meeting of the International Association for Impact Assessment 27 May- 1 June 2012, Centro de Congresso da Alfândega, Porto - Portugal . www.iaia.org accessed on 3/7/2014
- Augustine, C. & Nnabuchi, M. N. (2009). Correlation between sunshine hours and global solar radiation in Warri, Nigeria. *Pacific Journal of Science and Technology*, 10(2):574-579.
- Awogbemi, O. & Komolafe, C. A. (2011). Potential for sustainable renewable energy development in Nigeria. *The Pacific Journal of Science and Technology*, 12:161-168
- Boneya, G. (2011) Design of a Photovoltaic-Wind Hybrid Power Generation System for Ethiopian Remote area, PhD thesis, Institute of Technology Department of Electrical and Computer Engineering, Addis Ababa University.
- Dalwadi, P. G. & Mehta C. R. (2012) Feasibility Study of Solar-Wind Hybrid Power System, *International Journal of Emerging Technology and Advanced Engineering*, 3; 125-128
- Eke. K. (2014) Rural Electrification Infrastructure Development in Nigeria Using On-Grid and Off-Grid Sources, World Engineering Conference,
- Felix, A. A., Akinbulire, T. O, Abdulkareem, A., & Awosope C. O. A. (2012). Wind Energy Potential in Nigeria, *International Electrical Engineering Journal* 3 (595-601)
- Godson, J., Karthick M., Muthukrishnan T. & Sivagamasundari (M.S). 2013. Solar PV-wind hybrid power generation system. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 2:5350-5354
- Hatzigiargyriou, (2004). *Modeling of micro sources for security studies*. Paris: CIGRE. 2004.
- Hoque, M. M, Bhuiyan, I. K. A, Ahmed, R., Farooque, A. A. & Aditya S. K. (2012). Design, Analysis and Performance Study of a Hybrid PV-Diesel- Wind System for a Village Gopal Nagar in Comilla, *Global Journal of Science Frontier Research Physics and Space Sciences*, 12(5) 12-17
- Ibrahim, A. (2011). Analysis of electrical characteristics of photovoltaic single crystal Silicon solar cells at outdoor measurements. *Smart Grid and Renewable Energy*, 2:169-175
- Idris, N. A, Lamin, H. S., Ladan, M. J. & Yusuf, B.H. (2012). Nigeria's Wind Energy Potentials: the Path to a Diversified Electricity Generation-Mix, *International Journal of Modern Engineering Research (IJMER)* 2(4) 2434-2437
- Lawan, S.M. (2012). Prospects of Wind Energy in Bagwai for Irrigation Scheme. *Journal of Electrical and Electronics Engineering* 2(1):35-40
- Maijama'a, D., Maijama'a, L. and Umar, M. (2015). Renewable Sources of Energy for Economic Development in Nigeria, *International Journal of*



- Sustainable Energy and Environmental Research*, 4(2): 49-63
- Mayomi, I. and Mohammed, J. A. (2014). A Decade Assessments of Maiduguri Urban Expansion (2002 -2012), *Global Journal of Human Social Science: B, Geo-Sciences, Environmental Disaster Management*, 14(2)
- Medugu, D. W. and Markus, A. (2011). Wind as a Viable Source of Energy for Fluctuation of Electric Power in Yola, *Ozean Journal of Applied Sciences* 4(1) 41-50
- Mu'azu, M. B., Oricha, J. Y. and Boyi, J. (2012). Renewable Energy Resource in Nigeria: An Estimation of Wind Power Potentials, EACWE 5th Florence, Italy 19th – 23rd July 2009
- Muhammad, A. B., Sulaiman, A. T. & Shodiya, S. (2015). A Model for Pre-Assessment Study of Wind Energy Potential for Borno state. University of Maiduguri, Faculty of Engineering Seminar Series
- Ngala, G.M., Sulaiman, A.T., & Garba, I. (2013). Review of Solar Chimney Power Technology and Its Potentials in Semi-Arid Region of Nigeria, *International Journal of Modern Engineering Research (IJMER)*, 3(1283-1289)
- Olaoye, T., Ajilore, T., Akinluwade, K., Omole, F. & Adetunji, A. (2016). Energy Crisis in Nigeria: Need for Renewable Energy Mix, *American Journal of Electrical and Electronic Engineering*, 4(1):1-8
- Onawumi, A. S. and Olaoye, O. S., (2011). A Review of Savonius Wind Turbine as a Source of Energy Generation in Nigeria *International Journal of Emerging trends in Engineering* 3(1) 325-336
- Pecen, R., Salims, M.D. and Timmerman, M. (2000). A Hybrid Solar-Wind Power Generation System as an Instructional Resource for Industrial Technology Students. *Journal of Industrial Technology*, 16: 565-600
- Salisu, L. and Garba, I. (2013). Electricity Generation Using Wind in Katsina State, Nigeria, *International Journal of Engineering Research & Technology (IJERT)*