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Development of a Site Assessment Scheme for Hybrid Wind/Solar Electricity Generation

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Abstract: *The restrictive electricity transmission laws in Nigeria have inhibited the optimal performance of the country's electric power industry resulting in inadequate supply of electricity to her citizenry. To this end, alternatives to centralized, grid-based production of electricity are desirable. The depleting fossil fuels coupled with their green-house gas emissions necessitated channelling research efforts towards the renewable energy particularly wind and solar energy. However, every location has its peculiar wind speed and solar irradiation characteristics. Thus prior to implementing a proposed hybrid wind/solar energy system in a given location, adequate resource reservoir for a satisfactory period of the year must be ensured to justify the commitment of scarce resources. Conventionally, this is done by computer simulation applications which solely depend on local meteorological data that are largely unreliable or unavailable in many third-world regions. In this work, we have developed a scheme for the direct assessment of the prevalent wind and solar resources by fabricating a prototype hybrid wind/solar electricity generator and deploying it in two locations within University of Lagos. And our results show that the wind/solar hybridization will make a veritable renewable energy system in the University of Lagos campus. The aim of this project is to provide a pedestal for the development of system which annihilates the deficiency in power supply to hoi polloi.*

Keywords: *Rural populace, power sufficiency, renewable energy, energy consumption, energy conservation.*

1.0 INTRODUCTION

The chronic situation of inadequate supply of electricity in Nigeria is an endemic problem with unmatched enormity. This has caused the Federal Government of Nigeria to make several attempts to provide reliable electric power supply for its citizens through the construction of thermal power plants powered by natural gas. Other steps taken by the Government include the restructuring of the country's electric power industry along the lines of privatization. The application of these measures has so far, not yielded satisfactory and reliable electricity supply in the country [1]. In addition, the domination of natural gas production and distribution by the Federal Government's Natural Gas Company and the constraining laws governing electricity transmission in Nigeria, have inhibited ideal operation of the country's electricity industry. Thus, economically viable substitutes to centralized, grid-based production of electric power are necessary [1].

Furthermore, the depleting nature of crude oil with the associated green-house gas emissions, and the resultant global warming with its negative consequences, necessitate the channelling of adopted alternative forms of energy required towards the utilization of renewable and environmentally friendly sources. This advocates the concept of solar and wind electricity generation technologies [1]. Production of electricity from sunlight is very attractive due to the continuous reduction in the cost of harnessing the resource as a result of improved manufacturing technology for the required components [2 – 3], and their enhanced reliability [4], as well as low maintenance costs, absence of carbon or noise pollution [5], and an input source that is abundant in nature, especially in the tropics. Nigeria, which is situated within latitudes 4° and 14° with an annual average daily radiation of about 5.25 $kWh/m^2/day$ lasting for about 6.25 hours daily [6 – 7], can be regarded as a country that is rich in solar energy. The kinetic energy inherent in the wind appears, from human perception, to be abundant in some parts of Nigeria, especially near large water bodies like the Atlantic Ocean, and in parts of the far north where large stretches of open land or hills and valleys exist [8 – 9]. Due to improved technology, the cost of harnessing wind energy has experienced a steady decline over the years [10 – 11] and in addition to its non-emission of carbon [12], wind can be considered to be a viable source of renewable energy. Both wind energy availability and solar irradiance naturally complement each other since during the day sunlight is available, sometimes without much perceivable wind. At night, when solar resource is unavailable, availability of wind is much more evident. This phenomenon of nature can be exploited in a hybrid solar/wind energy power generation system.

1.1 Necessity for Wind/Solar Electricity Generation Site Assessment Tools

Each location on earth has its peculiar wind profile and solar irradiation characteristics, thus a hybrid system must be specifically designed for each given location [13]. Policy makers and project financiers require a fast and straightforward means of assessing any given site of a proposed hybrid wind/solar photovoltaic electricity generation project to determine its practicability and viability within the constraints of the available resources, their stochastic nature, and limited capital and time [14 – 16]. In addition, there are various kind of solar photovoltaic and wind technologies with several hybrid configuration possibilities which could be deployed, therefore thorough analysis and design optimization is essential for effective and efficient implementation of a hybrid wind/solar photovoltaic power generation programme [17 – 18]. The results of these would determine the merits of further investments in the project.

In the process of generating electricity from wind power, the energy available to the wind turbine is dependent on the local average wind speed. Also, wind availability and speed vary with terrain, time of the day, season of the year, elevation, and it varies from year to year. For wind technology to function optimally, there must neither be too small nor excessive wind at the site of interest for most of the time, thus making the resource difficult to exploit [19]. It is known that the human sensory perception of the wind is generally based on short-term observations of climatic conditions, implying that human judgement of wind speed would be quite inaccurate, and an error of 1% in measurements of wind speed would lead to almost 2% of error in energy output [11]. Thus a scientific means of wind resource assessment is crucial as this plays a very significant role in determining the cost of wind energy production [11, 16].

Solar photovoltaic electricity generation depends, most importantly, on available insolation and less critically, on the ability of the photovoltaic panels to efficiently capture and convert the available insolation to electrical energy. Therefore any inaccurate estimate of average available insolation at a given site would lead to a poorly designed solar power generating system, and consequently, inadequate power output or over-estimated quantities of required components and unnecessary expenditure. Hence, reliable assessment of solar irradiation at a typical location must be effected before commencing the implementation of a solar electricity generating system. In addition, without assurance of the ability of a proposed hybrid wind/solar photovoltaic electricity generator to meet required load demand, it would be impossible to convince a potential investor to commit scare funds to the project [12, 20].

Efficiency of the system is of utmost importance to ensure that a larger quantity of photovoltaic panels, wind turbines and storage batteries than actually required is not deployed, thus minimising equipment procurement costs and physical space requirements and consequently the overall system cost. This clearly demands some form of modelling, simulation and optimization to be conducted at the pre-feasibility stage, the process of which could be quite costly, since conventional simulation software applications for the purpose are majorly under proprietary, for example, PVsyst and PolySun [21 – 22], even though some widely available and freeware like RETScreen exist. However, site assessment software tools depend entirely on locally available measured weather data, which in many underdeveloped countries, could be grossly inaccurate, thus resulting in correspondingly inaccurate results.

To circumvent the problem of inaccurate data, modelling of solar irradiation and wind speed is a choice, however such models still depend on measured data for their validation, thus returning to the initial problem of ascertaining the integrity of data obtained from secondary source [23]. Therefore a direct means of assessing a given location for its suitability for the siting of a hybrid wind/solar energy generating plant, without relying on ambiguous data, is of immense and urgent necessity in socioeconomically underdeveloped societies. To this end, the study has developed a site assessment scheme to meet this need. The scheme has the ability to comprehensively assess the suitability of any chosen location for the implementation of a hybrid wind/solar photovoltaic power generation project, without depending on meteorological data. The scheme involves the deployment of a locally fabricated hybrid wind/solar photovoltaic power generating system to the site of interest (Figure 4), applying a known electrical load to the output of the power generating system, intermittent logging of terminal voltages of the wind and solar components of the generator, the battery terminal voltage and corresponding wind speeds, and the analysis of the data obtained in terms of output power and Loss-of-Load probability.

2.0 MATERIALS AND METHOD

The experimental hybrid wind/solar photovoltaic electricity generating system is composed of seven broad subsystems namely: wind turbine and alternator, photovoltaic solar panel, rectifier, battery charger/controller, battery, the inverter and the mounting pedestal. These components are connected in accordance with the system block diagram of Figure 1:

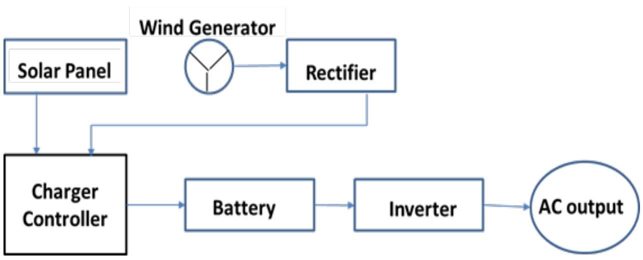

Figure 1: Schematic of hybrid wind/solar electric power generating system.

In accordance with Figure 1, the photovoltaic solar panel generates DC voltage while the wind powered generator produces AC voltage which is rectified to DC voltage by the rectifier IC module. This is necessary because DC voltage is required to charge the system's backup battery. With both voltage generators in parallel, the net voltage produced is regulated by the battery charger controller to ensure that only voltage within an acceptable range is supplied for charging the backup battery. The charged battery then supplies the inverter, which is an electronic circuit that converts the battery's DC voltage to AC output voltage.

The basic idea of this design is to operate the system while applying a load of known value, which is large enough to completely deplete the battery within a half-day period, to the output. A half-day period is chosen due to the fact that in the tropics, approximately half of a typical day experiences solar irradiation, implying that the battery is likely to receive adequate charge during day time. If the battery is depleted within the remaining half of the day when no sunlight is available, i.e. at night, then it implies that no wind was experienced during the night and thus, a hybrid system would not be effective at the location of operation. If this behaviour is continuously experienced for a significant percentage of the total period of interest, the location can be adjudged unsuitable for generating power of that load value, within the period of evaluation, in a hybrid wind/solar configuration of the evaluation system's specification. On the other hand, if the storage battery is not depleted throughout the period of darkness (half of the day), it implies that the prevailing wind and solar resources at the site of evaluation are adequate for sustaining the battery while it supplies the specified load. The concept of Loss-of-Load Probability [24] is used as the basis for calculating the amount of power obtainable from the system [25 – 27].

2.1 The Wind Power Generator Subsystem

The wind power generator subsystem consists of the wind turbine and the alternator. The wind turbine serves as the prime mover for the alternator, and both working together, produce an electric power generator fuelled by the wind. The wind turbine is made up of the blades carved from light, hard wood, the metal nacelle which houses the alternator, and the yawing mechanism consisting of a metal tail boom, the yaw bearings and an acrylic tail fin. The alternator comprises of a single phase, permanent magnet synchronous generator with the permanent magnets mounted on the rotor to create a magnetic field of adequate strength for generation of significant voltage at the prevalent average wind speed, considering that the stronger the magnetic field, the more sensitive would the generator [19]. Several sets of 22 swg copper coils, with their terminals connected to create additional positive electrical voltage, were wound into the rotor slots. Experimenting with a test coil of 40 turns produced an output voltage of about 1.6V with a hand spin. This implied that more turns per coil, and a total of ten coils positively connected together, would produce a voltage of well over 15V, which is adequate for charging a 12V battery at average wind speed of about 3 m/s.

2.2 The Solar Power Generator Subsystem

The solar power generator subsystem consists of the solar panel, and the control circuitry. The photovoltaic solar panel selected for use in this work is the mono-crystalline type due to its relatively high efficiency, though it is more expensive than other types because of the process required for its manufacture [28]. Under standard test conditions, it has a maximum peak power rating of 75W, a maximum voltage capacity of 17V, a maximum current capacity of 4.4A, and a rated irradiance of 1 kW/m^2 at 25°C, enclosed in a solid rectangular structure of 50 cm × 70 cm, with an aluminium frame, and protective glass surface, having its positive and negative terminals attached to the back of the structure.

2.3 The Battery Charger/Controller

The battery charge controller regulates the amount of voltage allowed to reach the terminals of the battery from both the wind generator and the solar panel, utilizing a simple voltage regulator IC and the comparators contained in a 555 timer chip, with associated output transistors and a switching relay, cutting of the voltage supply at 11.7V and 14.9V. Voltages within this margin are safe for charging the battery.

2.4 The Inverter Subsystem

The inverter is comprised of an oscillator, MOSFET switching power transistors, and a centre tapped step-up transformer. The oscillator circuit generates continuous pulses by virtue of its arrangement in a stable multivibrator configuration using two pnp BJTs, and ancillary resistors and capacitors. The transformer has a laminated iron core with a centre tapped primary side, and a secondary side having an appropriate turns ratio to step up the 12V primary voltage to about 240 V output for powering the desired load.

2.5 The Backup Battery

The storage battery chosen for this work is the deep cycle lead-acid type, due to its relative low cost and its fairly good ability to provide long duration supply with irregular recharge rates [2, 6].

2.6 The Mounting Pedestal Subsystem

The mounting pedestal is essential for bearing the wind turbine and alternator. It is necessary to lift the turbine off the ground to enable its blades rotate freely without obstruction. A firm base is also required to hold the turbine, which would experience considerable vibrations in winds of moderately high speeds, ensuring its stability and safety. Thus the structure must be strong, sturdy and firm. Due to the fact that the equipment must be continuously moved from one location to another when in use, portability of the mounting pedestal is a critical factor. It was therefore designed as a central pole mount of minimal height, with a detachable tripod stand to facilitate portability. A height of 6 feet (1.8m) was chosen to give room for the tripod stand also facilitate stability, to be mounted at about 2 feet from the base, and the turbine blades, which extend 3 feet downwards from the top of the central pole, with a mounting plate on top of the central pole to mesh with the base of the nacelle. Its minimal height enables individuals of average height to place and secure the nacelle on the mounting plate without much difficulty.

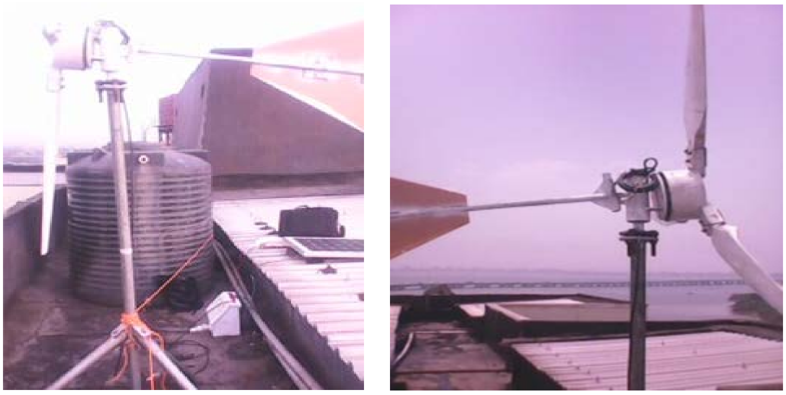

Figure 2: Deployment and operation of the site evaluation scheme at Education Library (Left) and High-rise (right) buildings

2.7 The Site Evaluation Process

The scheme was utilized in the evaluation of two sites on the University of Lagos campus on the 20th/21st of March and 8th//9th of April, 2015, in order to determine their suitability for hybrid wind/solar power generation implementation (Figure 2). The evaluated sites were Block B of the High Rise residential area at a height of about 24.38 m and the Faculty of Education Library at a height of about 10.68 m, respectively. The evaluation period was 24 hours, with a load of 12 W applied at the system's output terminals. The rationale behind this is to find out how long a load of 12 W can be sustained by the wind and solar resources prevalent at the site of interest in a period of 24 hours or one day, and determine its Loss-of-Load Probability, which is a reflection of the proposed system's reliability [26, 25, 23]. A 12 AH battery supplying the inverter, can sustain a load of 12 W at its output at 240 V, by supplying a current of

$$I = P/V$$

$$\Rightarrow \quad 12/240 = 0.05 \text{ A}$$

at the secondary side of the transformer, and hence a current of 0.05 × 20 = 1 A would be drawn from the battery at the primary side. This amount of current would be continuously drained from the battery per hour. Thus theoretically, in 12 hours the battery would be fully discharged if it does not get supply form either the solar or the wind generator, and would therefore cease to sustain the load for the remaining 12 hours of the day. This situation is termed Loss-of-Load and can be defined as the amount of time the load is unsustainable during site evaluation divided by the total period of evaluation [26]. In reality, a 12 AH battery being discharged at a rate of 1 A per hour, would be completely discharged in less than 12 hours due to losses in the cabling and inverter circuitry. In addition, a lead acid battery should not be completely discharged to avoid irrecoverable damage to the battery cells, and so a discharge value of about 50% – 70% is usually recommended [28]. Hence, a 12 AH battery utilized with this site evaluation scheme should not be depleted to a voltage value beyond about 10.5 V before cutting off the load from the supply. By experimentation, it was observed that a fully-charged 12 AH battery with a terminal voltage of about 12.9 V, with a load of 11 W at its output, would be depleted to a safe level of 10.5 V in 4.5 hours. Therefore, a 12 AH battery employed in this site evaluation process would result in a Loss-of-Load of 24 - 4.5 = 19.5 hours, without any input form wind or solar resources.

A readily available close approximation to a load of 12 W is a lamp of 11 W. Thus a current of I_2 = 11/240 = 0.0458 A would be required at the secondary side of the output transformer, and a current of

$$I_1 = 0.0458 \times N_2/N_1$$

$$\Rightarrow \quad I_1 = 0.0458 \times 20 = 0.917\ A$$

would be drawn from the battery at the primary side, and continuously drained from the battery every hour, where N_2/N_1 is the ratio of the number turns of cable in secondary to primary coils in a step-up transformer. Three sets of voltage values were observed and logged at various intervals during the evaluation period, namely: the battery terminal voltage, the solar panel terminal voltage, and the wind generator terminal voltage with the corresponding wind speed (Figure 5). The system was loaded with a 12 W light bulb at the start of the evaluation period with a battery terminal voltage of 13.91 V. This load was cut-off as soon as the battery terminal voltage reduced to a value of 10.78 V, and was reinstated as soon as it had recharged to a value of about 11.71 V. At the High Rise Residential Area, Block B, a Loss-of-Load of 10.5 hours or 43.75% was realized during the period of evaluation and adequate power supply was obtainable for 56.25% of the total time of 24 hours under consideration. Consequently, 19.5 - 10.5 = 9 hours of power capacity was added by prevalent wind and solar resources. At the Faculty of Education Library, the system was observed to have a Loss-of-Load of 3.5 hours or 14.58% within the evaluation period of 24 hours (Figure 4 and Figure 5), i.e., 19.5 - 3.5 = 16 hours of power capacity was added to the system due to the harnessing of available wind and solar resources, and the results obtained are detailed and analysed below

3.0 RESULTS AND DISCUSSION

From the above, the total Loss-of-Load period for the Faculty of Education Library site was approximately 3.5 hours, i.e. from 2:54 AM to 6:24 AM (Figure 4). This implies that, with a load of 11 W at the system's output terminals, and a battery storage capacity of 12 AH, a Loss-of-Load of 3.5 hours or 14.58% resulted at this location, during the period of evaluation. In other words, power was obtainable from available wind and solar resources prevailing at this location during the evaluation period for 85.42% of the total time. If solar radiation alone had been harnessed, the Loss-of-Load period would have increased to

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at least 3.5+1.08=4.58 hours i.e. 19.01% of total time (power availability of 80.99% of total time), since between 6:05 AM and 7:10 AM (1.08 hours), the voltage generated by available solar radiation was below 12 V and the presence of wind energy resulted in an adequate charging voltage of above 17 V within that period (Figure 4). In addition, the solar radiation available during the day, form about 5:54 PM to 7:36 PM, a total of about 1.7 hours, would have been insufficient for battery recharge without any augmentation form wind generated voltage, however this may not have made a significant increase to the Loss-of-Load period.

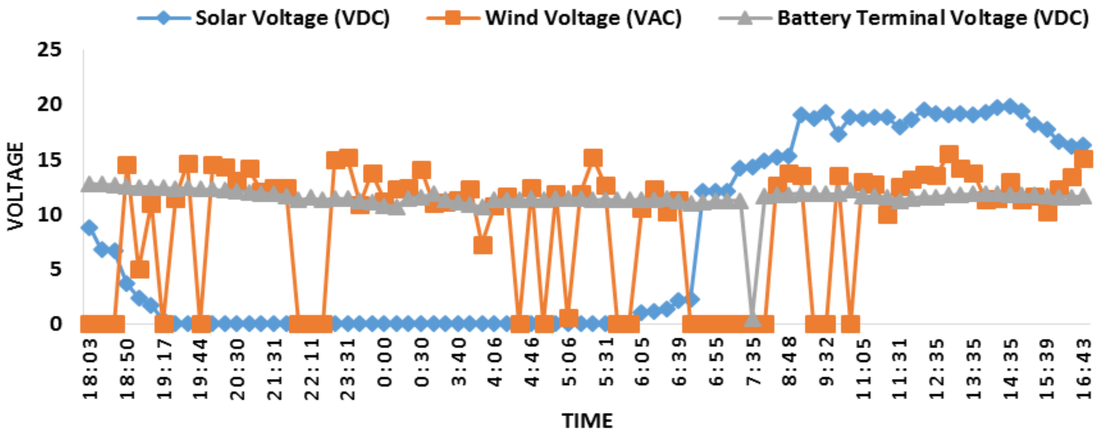

Figure 3: Observed generated voltages with time at High-rise Building Site 1

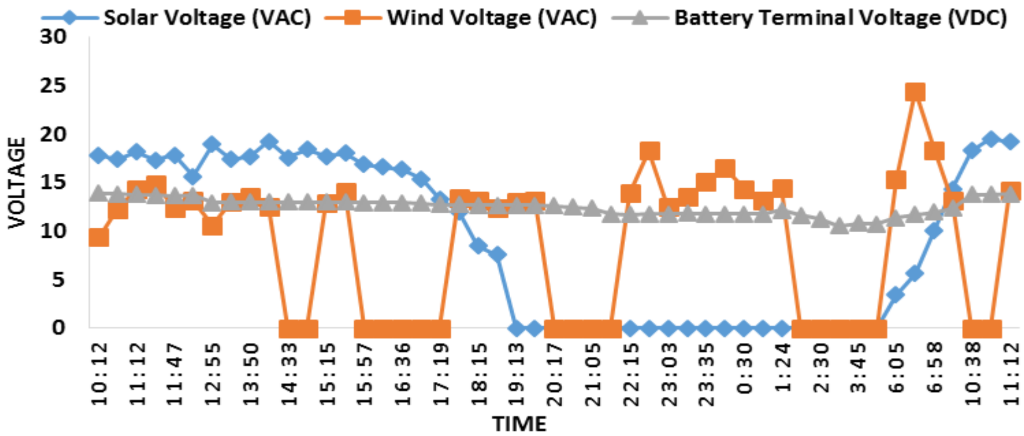

Figure 4: Observed generated voltages with time at Education Library Site

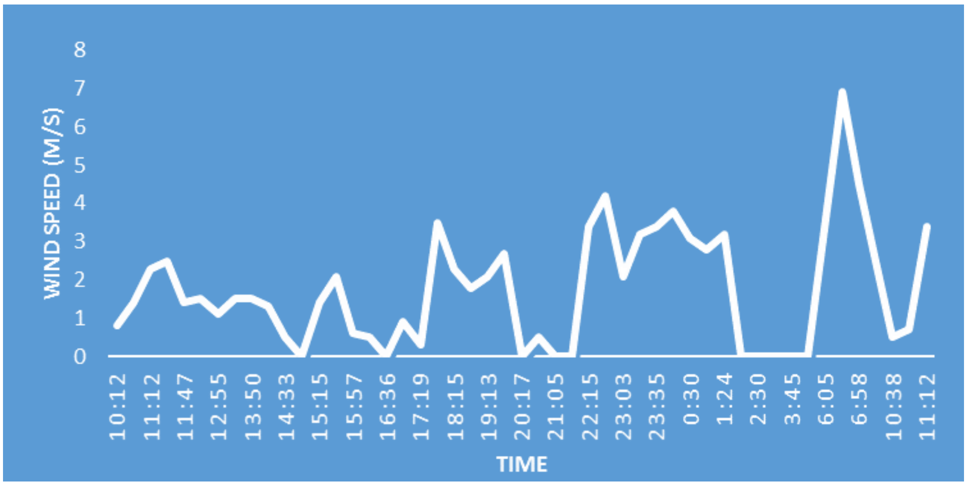

Figure 5: Observed wind speed with time at Education Library Site

In comparison, if the wind resource had been used in isolation, the battery would not have received any charge between 3:57 PM and 5:19 PM (1.37 hours), between 8:17 PM and 9:42 PM (1.75 hours), and from 2:05 AM to 5:08

AM (3 hours) and the load would most probably not have been sustained, thus the Loss-of-Load period would definitely have increased by at least about 1.67 hours (between 2:05 AM and 3:45 AM), resulting in a total of 3.5+1.67=5.17 hours or 21.54% Loss-of-Load, i.e. adequate power would have been obtainable for 78.46% of total time. Loss-of-Load could indeed have been more than this since for about 3.12 hours (1.37 + 1.75) earlier than 2:05 AM, the battery would not have received any charge since no wind or solar power was available [28]. This fact is corroborated by the graph of wind speed in Figure 5. Compared to the above discussion on an isolated solar system, a wind-only system would result in inferior power production capability at this particular location during the period of evaluation. These observations have been summarized in Table 1.

Table 1: Loss-of-Load/Obtainable Power Supply Summary

System Configuration	**Loss-of-Load %**	**Period of Obtainable Power Supply %**
Isolated Battery	81.25	18.75
Hybrid Wind/Solar	14.58	85.42
Solar alone	19.01	80.99
Wind alone	21.54	74.46

As an illustration, if this information is utilized in planning for an 11 W hybrid wind/solar power generation system of similar capability for the evaluated site, assuming the observed conditions of resource availability remained unchanged, and with the empirical knowledge that a 12 AH battery would be safely depleted in 4.5 hours by an 11 W load without any form of recharge, it can be deduced that, within an evaluation period of 24 hours, without any wind or solar resources to recharge the battery, the Loss-of-Load would have been 24 - 4.5=19.5 hours, or 81.25%. This means that an additional 19.5 - 3.5=16 hours of capacity has been added to the backup battery due to the presence of wind and solar resources within the period of evaluation. If this scheme was deployed in a prefeasibility study for a proposed hybrid wind/solar photovoltaic power generation system with a load requirement of 110 W at 240 V, a current of $I_2 = 110/240 = 0.458$ A would be required at the secondary side of the output transformer, and $I_1 = 0.458 \times N_2/N_1$

$$\Rightarrow \quad I_1 = 0.458 \times 20 = 9.17 \text{ A}$$

would be drawn from the battery at the transformer primary, and continuously drained from the battery every hour. Thus, for instance, a battery of size of 100 AH would theoretically be depleted in 100/9.17=10.91 hours by a load of 110 W, with a hybrid wind/solar photovoltaic electric power generator of similar capacity. Considering the empirical result of 4.5 hours obtainable from a 12 AH battery of similar chemical configuration, delivering a current of approximately 1 A (which implies a theoretical value of 12 hours battery depletion time) the theoretical value of 10.9 hours of a 100 AH battery can be scaled down to a more practical value of (4.5/12)×10.91 hours = 4.09 hours. However, Figure 3 gives a clear indication that the hybrid system worked perfectly in the high-rise block B where residents may experience a Loss-of-Load of less than 2 hours between 9:34pm and 10:18pm, later in the night between 4:20am and 5:10am, and at dawn between 5:24am and 6:05am. The advantages derived from site altitude and direct location of high-rise building by Lagos lagoon with no obstruction to wind flow favoured the deployment of the hybrid system at that site. It becomes obvious that with further investigations, windmill will be sufficient to generate enough electricity for a section of the University community if a windmill is properly sited on any of the high-rise buildings.

With an addition of 16 hours of electric power capacity by the prevailing wind and solar resources at the specified location within the period under study, the total time of battery supply to the proposed load would be increased to 4.09+16 =19.09 hours and the Loss-of-Load would be 24-19.09 = 4.91 hours or 20.46%. From the above, it is clear that within the evaluation period at the sample site, an isolated solar power system would yield less Loss-of-Load than an isolated wind resource scheme [28 – 30]. However, a scheme utilizing a hybrid of both resources would always yield much better results than any one of the resources harnessed alone. This illustrates the judiciousness in the idea of a hybrid configuration and clearly demonstrates how the fabricated equipment could be used in assessing the power generating capability of the wind and solar resources available in a given location within a chosen period. Without doubt, the benefit of a scheme for direct assessment of a locality for its hybrid wind/solar electric power generation potential, without depending on unreliable or unavailable meteorological wind speed and solar irradiation data has been exhibited in this research. The fabricated contraption utilized in this work reliably converts any available magnitudes of wind and solar resources to their equivalent voltage values for electric power assessment, and it is relatively easy to assemble and deploy by a team of two or three people [4]. With this scheme, hitherto un-appraised sites can be easily assessed within any given period of interest, and several such sites within close proximity to each other could be evaluated concurrently, thus improving the speed and efficiency of such prefeasibility projects.

4.0 CONCLUSION

In this work, we have developed a site assessment scheme for determining the suitability of deploying a hybrid solar/wind electricity generating system as a panacea to the impending energy crisis that may plague Nigeria and by extension Africa in the near future when fossil fuel will be nearly completely depleted and the cost of exploring available fossil fuel becomes unreachable. The proposed scheme is also applicable to the current situation in Nigeria. In addition to the aforementioned, this study successfully constructed the hardware components involved in the study. An indication that an entrepreneurship drive can be successful in Nigeria even with the prevailing circumstances.

REFERENCES

[1] Ajibola, O.O.E., Ibidapo-Obe. O. & Balogun, O.J. 2017. Developing Sustainable Renewable Energy for Rural

Dwellers' Energy Sufficiency. *ABUAD Journal of Engineering Research and Development*. 1(1), 1-7.

[2] Wasfi, M. (2011). Solar Energy & Photovoltaic Systems. *Journal of Selected Areas in Renewable and Sustainable Energy*, pp. 1-2.

[3] Moner-Girona, M., Ghanadan, R., Jacobson, A., & Kammen, D. M. (2006). *Decreasing PV costs in Africa: Opportunities for rural electrification using solar PV in sub-Saharan Africa*. *Refocus*, 7(1), 40-45.

[4] Kakulu, M. 2015. *Development of a site assessment scheme for hybrid wind/solar electricity generation*. M.Sc. Thesis. University of Lagos, Lagos, Nigeria.

[5] Komor, P. (2009). *Wind and solar electricity: challenges and opportunities*: *Pew Center on Global Climate Change*. University of Colorado at Boulder, USA.

[6] Oji, J., Idusuyi, N., Aliu, T., Petinrin, M., Odejobi, O., & Adetunji, A. (2012). Utilization of solar energy for power generation in Nigeria. International *Journal of Energy Engineering*, 2(2), 54-59.

[7] Yakubu, D. & Medugu, D. W. (2012). Relationship between the Global Solar Radiation and the Sunshine Duration in Abuja, Nigeria. Ozean. *Journal of Applied Sciences.* 5(3), 221-228.

[8] Ajao, K., & Adegun, I. (2009). Development and power performance test of a small three-blade horizontal-axis wind turbine. *Heat Transfer Research*, 5(5), 71-78.

[9] Dikko, I. & Yahaya, D.B. (2012). Evaluation of Wind Power Density in Gombe, Yola and Maiduguri, North Eastern Nigeria. *Journal of Research in Peace, Gender and Development*. 2(5), 115-122.

[10] Sasi, K. K. (2005). *Wind Energy-Principles and Applications. Department of Electrical and Electronics Engineering* Amrita Vishwa Vidyapeetham, Coimbatore, India.

[11] CANMET Energy Technology Centre (2004). *Clean Energy Project Analysis: RETScreen Engineering and Cases*. Minister of Natural Resources, Varennes, Canada.

[12] Al-Shemmeri, T. (2010). Wind Turbines: BookBoon. USA

[13] Adejumobi, I.A., Adebisi, O.I., & Matti, S.O. (2017). Development of a Hybrid Solar-Dynamo Powered Charging System. *ABUAD Journal of Engineering Research and Development*. 1(1), 74-82.

[14] Aidan, J., & Ododo, J. (2010). Wind Speed Distributions and Power Densities of Some Cities in Northern Nigeria. *Journal of Engineering and Applied Sciences*, 5(6), 420-426.

[15] Koutroulis, E., Kolokotsa, D., Potirakis, A., & Kalaitzakis, K. (2006). Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms. *Solar energy*, 80(9), 1072-1088.

[16] Rehman, S., El-Amin, I., Ahmad, F., Shaahid, S., Al-Shehri, A., & Bakhashwain, J. (2007). Wind power resource assessment for Rafha, Saudi Arabia. *Renewable and Sustainable Energy Reviews*, 11(5), 937-950.

[17] Kuhn B., Marquis J. & Rotatori H. (2010). *Wind Turbine Design and Implementation*. Worcester Polytechnic Institute, Massachusetts, USA.

[18] Ajibola, O.O.E., Ibidapo-Obe, O. & Sofoluwe, A.B. (2012): Developing a viable renewable energy policy: a pathfinder to millennium goals and vision 20:2020. *International Academy of African Business and Development (IAABD) Conference*, El Jadida Polydisciplinary University, El Jadida, Morocco, pp. 208 – 217.

[19] Grogg, K. (2005). *Harvesting the wind: The physics of wind turbines*. Physics and Astronomy Department, Carleton College, Northfield, Minnesota, USA.

[20] Sinha S., & Chandel, S. S. (2013). Pre-feasibility Analysis of Solar-Wind Hybrid System Potential in a Complex Hilly Terrain. *International Journal of Engineering Technology and Advanced Engineering*, 3(3), 277-282.

[21] Aung K. T. (2011). *Simulation Tools for Renewable Energy Projects*. Lamar University, Beaumont, Texas, USA.

[22] Lee, G. R., Frearson, L., & Rodden, P. (2011). *An assessment of photovoltaic modelling software using real world performance data*. *26th European PV Solar Energy Conference*. Hamburg. Germany.

[23] Myers, D. R. (2005). Solar radiation modeling and measurements for renewable energy applications: data and model quality. *Energy*, 30(9), 1517-1531.

[24] Yang H., Zhou W., Lu L. & Fang Z. (2007). Optimal Sizing Method for Stand-Alone Hybrid Solar-Wind System with LPSP Technology by using Genetic Algorithm. Elsevier Science Direct, *Solar Energy*. 82, 354–367.

[25] Zhou, W., Lou, C., Li, Z., Lu, L., & Yang, H. (2010). Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. *Applied Energy*, 87(2), 380-389.

[26] Yang, H., Lu, L., & Zhou, W. (2006). A novel optimization sizing model for hybrid solar-wind power generation system. *Solar energy*, 81(1), pp. 76-84.

[27] Vijayamohanan, P. N. (2008). *Loss of Load Probability of a Power System. Centre for Development Studies*, Prasanth Nagar, Ulloor, Trivandrum, Kerala, India. Munich Personal RePEc Archive, Paper No. 6953.

[28] Buchmann I. (2015). *Learning the basics about batteries*. Battery University, Texas, USA.

[29] Burger B., Kiefer K., Kost C., Nold S., Philipps S., Preu R., Schindler R., Schlegl T., Stryi-Hipp G., Willeke G., Wirth H., Brucker I., Haberle A., Schacht V. & Warmuth W., 2014. ISE, *Photovoltaics Report*. Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany.

[30] Mohamed B. (2014). Design performance analysis of an automobile-removable solar system for water and cabin heating. *Transactions of the Canadian Society for Mechanical Engineering*, 38(4), 505-515.