



Wind-Solar Hybrid Power System for Rural Application in Kebbi State

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ABSTRACT

A combination of wind and solar resources offers a unique possibility in generating electricity either as grid-connected or as stand-alone hybrid power system. This paper investigates the marrying of the two resources where one, solar, is in abundant and the other, wind, is in limited supply. A case study of Aliero local government is presented with data obtained at the Ibtech emerging mechatronics Ltd, Aliero (Kebbi state). The model power plant simulates a combination of a variable speed wind turbine and 12 by 2 solar PV array with the aim to satisfy the load demand 1.5kva and to charge a battery bank during the period of excess power. The battery bank supplies the load in the event of hybrid power deficiency. The model at the end gives hope that the low wind resource can be hybridized with the high solar profile to generate firm power for standalone or grid-connected systems.

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INTRODUCTION

An average wind speed of 5.8 m/s and above are considered good wind resource, while average wind speed below 4.5 m/s is considered a small wind resource. Nigeria with average wind speed ranging between 2.5 m/s at the coastal areas to 4.5 m/s at the northern boundaries, therefore, falls within the low wind resource zone. But by no means does this natural placement constitute any threat to the application and utilization of wind energy in Nigeria's electric power system. But then what nature may deny Nigeria in wind resource it endows it abundantly in solar energy resource. The latitude and longitude of Nigeria is 10° N and 8° E, while for Kebbi they are approximately 12.4376° N and 4.2078° E. Photovoltaic Geographical Information System insolation data scaled to summer equivalent months was used to establish the relationship between solar energy and solar power output in Kebbi State NorthWestern Nigeria. It was observed that if storage option is coupled in the system, 1kWp of solar PV is capable of satisfying

a typical household electricity demand in Kebbi. The output of the research also shows that, solar system can be a reliable system of renewable electricity generation in supplying based load in rural locations in the Northwestern Nigeria where solar energy resources are in abundant and significant percentage of the dwellers are living completely off grid without any hope of being connected to national grid. The finding of the research reveals that, with government fiscal incentives as a payment to the individual's investment in renewable energy, Nigeria has potential of becoming the leading renewable solar electricity country in the globe since 1kWp system can power a typical household electricity demand against the 3kWp which is considered to be typical household PV installation across the globe [1-2].

A combination of the two resources, wind and solar, therefore offers a unique possibility in generating electricity in Nigeria, either as grid-connected or as stand alone. Research studies have been carried out by several authors in the past to prove the unique

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possibility in combining renewable resources, wind and solar, in conjunction with backups to provide not just firm but green power [3], [4], [5], and [6]. These studies and many others focus on the regions where the wind speed variation may range from 5 m/s to 25 m/s with moderate sunshine. Published literature addressing the hybrid system in a region of small wind resource with high profile for sunshine is scanty [7], [8]. This paper, therefore, focuses on the applicability of wind-solar hybrid power system in a small wind and high sunshine region of North Western Nigeria, using Aliero as a case study.

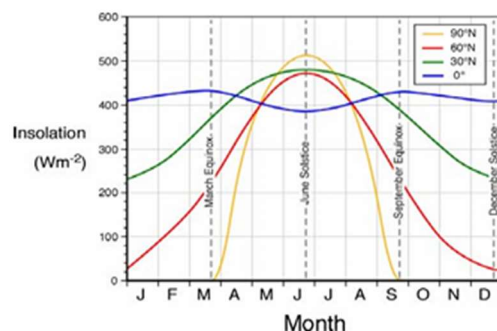


Fig.1: Global traces of solar insolation between latitudes 0° to 90° [2].

LITERATURE REVIEW

Among the wide range of problems facing our world today, there is global consensus that greenhouse gas (GHGs) emissions have the largest negative impact on our environment. GHGs include carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydro fluorocarbons and perfluorocarbons. These gases help maintain the temperature of the earth at comfortable levels for organisms, and a decrease in their levels would result in a temperature that could be too low for us to survive. However, because GHGs allow sunlight to enter the atmosphere, but trap the heat radiated off the earth's surface, an increase in these emissions would result in an increase of the planet's temperature, or global warming, to levels that could be fatal to living organisms. Many scientists also believe that the increase in natural disasters is fueled by climate change, since atmospheric and oceanic patterns shift as the Earth's temperature increases. [Ashish S. Ingole

et al. (2015)] Now a day's electricity is most needed facility for the human being. All the conventional energy resources are depleting day by day. So we have to shift from conventional to nonconventional energy resources. In this the combination of two energy resources is takes place i.e. wind and solar energy. This process reviles the sustainable energy resources without damaging the nature. We can give uninterrupted power by using hybrid energy system. Basically this system involves the integration of two energy system that will give continuous power. Solar panels are used for converting solar energy and wind turbines are used for converting wind energy into electricity. This electrical power can utilize for various purpose. Generation of electricity will be takes place at affordable cost. This paper deals with the generation of electricity by using two sources combine which leads to generate electricity with affordable cost without damaging the nature balance. [Samahir H. Abuarafah (2015)] Energy today, is the need of 21st century. The renewable energy resources therefore are used in tremendous amount as they are easily available and cost free. But these energies in standalone forms have disadvantages such as unpredictability, availability in all time etc. which can be overcome by hybrid energy systems. They are basically consists of combinations of number of renewable energy resources. They provide efficient response against voltage and frequency fluctuations, harmonic measures and power issues in standalone systems. Hybrid power system provide reduction in complexity, maintain lowest unit cost, energy fluctuations due to DPSP (deficiency of power supply probability), with the help of proper design, advanced fast response, good optimization and control feasibility. This paper provides review of hybrid solar and wind power system. The technical feasibility of PV wind hybrid system in given range of load demand was evaluated and economical evaluation of standalone PV, standalone wind and PV wind hybrid system have been developed using the model. [Muhammad Zeeshan Malik (2015)] Energy is essential for the economic growth and social development of any country. The world facing the problem of power generation. The fossil

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energy sources are limited and needed to use properly. This power generated increases the greenhouse effect. The used of the combined solar and wind power system can be more benefits in order to make useful throughout year.

Hybrid Power System Components Modeling

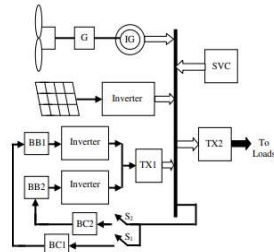


Fig. 2: The system structure for the proposed hybrid power plant

The operational modes of the hybrid system may be divided into three principal modes: normal mode, complementary mode, and back-up mode. In the normal mode of operation, the load is powered by a combination of the PV power unit and the wind turbine power unit. In this mode and in other modes, battery bank BB2 acts both as a power source and a power sink as it constantly supplies power to the bus through the VSCC and is charged through BC2. In the complementary mode, BB1 is switched into the system to complement the hybrid power from PV and wind units. This however will depend on the SOC of BB1; else an alternative power source like diesel generator (though outside the scope of this work) may be resorted to. In the back-up mode, BB1 is switched into the system to share the load with BB2. Most times, battery banks are typically sized to supply the electrical load for up to three days, to complement for hours/days during which neither solar nor wind power is produced. Hence, hybridization ensures that should any of the units not perform at a particular time/day like solar on cloudy days or no wind days, for any reason, there will be a backup means of providing the plant power.

Wind Power Unit

The mechanical power extracted from the wind [10] is obtained as:

$$P_{mec} = 0.5\rho\pi R^2 V_w^3 C_p(\lambda) \quad (1)$$

where P_{mec} is the power extracted from the airflow [W], ρ is the air density (about 1.225 at sea level or 1.168 at standard ambient temperature & pressure) [kg/m³], R is the radius of the turbine blade [m], V_w is the wind speed upstream the rotor [m/s], C_p is the turbine power coefficient which represents the power conversion efficiency of a wind turbine, and λ is the tip speed ratio given by:

$$\lambda = \frac{\omega_r}{V_r} R \quad (2)$$

with ω_r the rotor angular speed [rad/s]. For every wind speed, there exists a rotor speed ω_r , at which maximum power can be extracted from a given turbine and this power is dependent upon the turbine's power coefficient $C_{p(\theta, \lambda)}$. This maximum power corresponds to maximum power coefficient $C_{p,max}$ and at this $C_{p,max}$ there exists a corresponding optimum tip-speed ratio λ_{opt} . Thus, for a variable speed wind turbine (variable ω_r), the optimum tip-speed ratio λ_{opt} is maintained constant by varying ω_r in relation to the change in wind speed V_w . By this process, a variable speed wind turbine follows the $C_{p,max}$ to capture the maximum power up to the rated speed by varying the rotor speed to keep the system at the optimum tip-speed ratio λ_{opt} . For variable speed wind turbines, the following generic equation [10] may be used to approximate the power coefficient:

$$C_p(\theta, \lambda) = 0.5176 \left(\frac{116}{\lambda_i} - 0.405 \right) e^{\frac{-21}{\lambda_i}} \quad (3)$$

where θ is the pitch angle. The electrical output power of the induction generator may be obtained as:

$$P_{el} = \eta_{gen} P_{mec} \quad (4)$$

where η_{gen} is the generator efficiency. In eqn. (1) and hence eqn. (4) the only variable factor is the wind speed. Thus, while different values of turbine rotor speed will be established for each speed, the λ and hence C_p are maintained constant for the wind speed variations. In this research, an appreciable value of R will be chosen in order to an extent cushion the effect of the small wind resource in this region.

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PV Power Unit

A photovoltaic array (PV system) is an interconnection of modules which in turn is made up of many PV cells in series or parallel. The power produced by a single module is seldom enough for commercial use, so modules are connected to form an array to supply the load. The connection of the modules in an array is same as that of cells in a module [11]. Modules can also be connected in series to get an increased voltage or in parallel to get an increased current. PV arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model such as the one given in Fig. 3 [11], [12], [13], and [14].

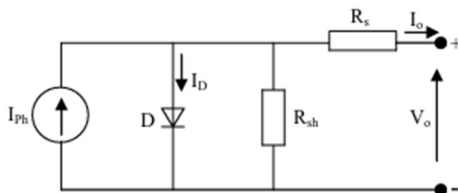


Fig. 3: Simplified Equivalent Electric circuit of a PV cell.

The power generation simulation model for the PV system is composed of three parts: PV array power model, solar radiation on PV module surface and PV module temperature model [8]. Models relating the current and voltage of a PV cell and hence PV array abound in literature [11, 15, 16]. It is clear that for the maximum power production of the PV generator, the models describing the PV module's maximum power output behavior become more practicable. This work focuses on the PV array power model that relates the PV array power with the solar radiation and PV module temperature. The resulting relationship is obtained as [12]:

$$P_{\text{module}} = \frac{\frac{V_{oc}}{n_{MPP}KT/q} - \ln\left(\frac{V_{oc}}{n_{MPP}KT/q} + 0.72\right)}{1 + \frac{V_{oc}}{n_{MPP}KT/q}} \cdot \left(1 - \frac{R_s}{V_{oc}/I_{sc}}\right) \cdot I_{sc} \left(\frac{G}{G_0}\right)^\alpha \cdot \frac{V_{oc0}}{1 + \beta \ln \frac{G_0}{G}} \cdot \left(\frac{T_0}{T}\right)^\gamma \quad (6)$$

Case Study Area

The feasibility of a standalone wind-solar hybrid power system in a low wind region is

investigated using the real data obtained from Ibtch emerging mechatronics Ltd, Aliero (Kebbi State). The data of the First March and First July 2010 are used. They consist of the hourly wind speed, solar insolation, and ambient temperature. Figs. 5 and 6 show the hourly wind speed variations for March and July respectively. Figs. 7 and 8 show the hourly solar insulations for March and July respectively while Fig. 9 displays the hourly temperature variation for the two months.

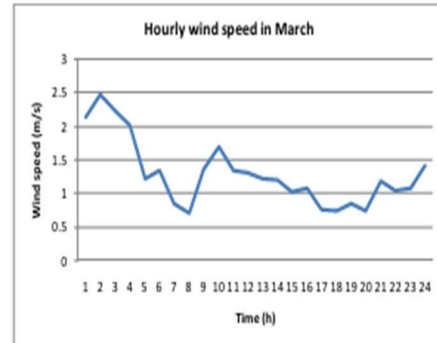


Fig. 5: Hourly wind speed variation in March.

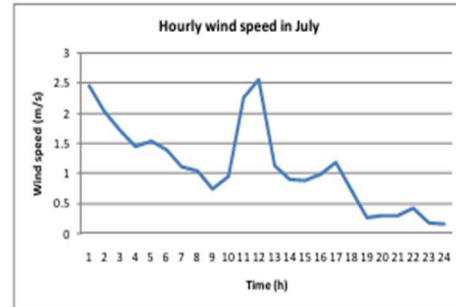


Fig. 6: Hourly wind speed variation in July.

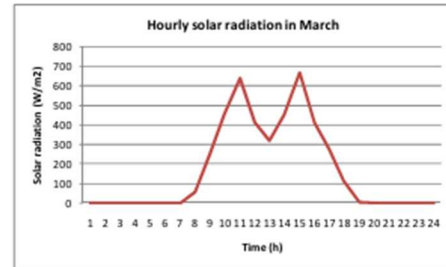


Fig. 7: Hourly solar insolation in March.

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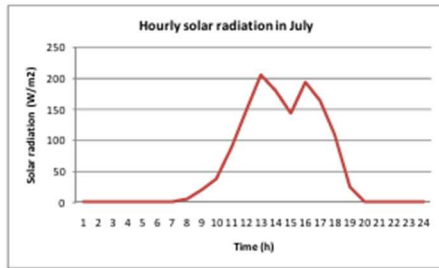


Fig. 8: Hourly solar insolation in July.

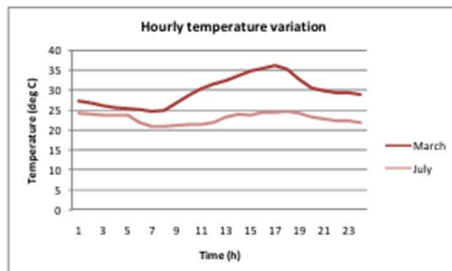


Fig. 9: Hourly temperature variations in March and July.

Data applications

The acquired data as represented in Figs. 5 to 9 are processed with a view to generating electric power to meet a sample load. The load profile is patterned after a load demand of an average 3-bedroom flat apartment.

Wind power

It is usual to specify the operating wind speed range, the cut-in wind speed and the rated wind speed. In this feasibility analysis, however, all the extractable wind power within the resource region are shown. A 25m turbine rotor radius is used in the variable speed wind turbine. In generating the mechanical wind power using eqn. (1) and hence the electrical power using eqn. (5), only the hourly wind speed is utilized from the three data comprising the wind speed, solar insolation, and air temperature. From each wind speed data, the maximum power coefficient $C_{p,max}$ is derived with the aid of the rotor radius. At the $C_{p,max}$ the maximum power at any given wind speed is extracted.

Solar power

In order to generate the PV array solar power using eqns (6) and (7), the three recorded

data are involved. They are further processed through eqns. (8) to (11) in order to generate the solar insolation G , and the temperature T , for the PV module power in eqn. (6). In determining the amount of solar radiation incident on a tilted module surface, the chosen tilt 312 J. Electrical Systems 8-3 (2012): 304-316 angle of the PV module is used in conjunction with the angle of elevation which in turn depends on the day of the year being considered. The solar radiation incident on a tilted module surface, the ambient temperature T_a , and the wind speed data are used to obtain the PV cell operating temperature. Table 3 shows all the data needed for the generating of the PV array power.

Table 2: are used in conjunction with the module parameters to estimate the PV power output.

Table 2: Parameter estimation results for the PV module performance

A	B	γ	R_s	n_{MPP}
1.21	0.058	1.15	1.17	0.012

Specifications of the PV module

$V_{oc}(V)$	$I_{sc}(A)$	$V_{max}(V)$	$I_{max}(A)$	$P_{max}(W)$
21	6.5	17	5.73	100

RESULTS AND DISCUSSION OF RESULTS

Fig. 10 shows the hourly power produced by the wind turbine, as well as the hourly power produced by the PV array. The high power yield of the PV array over the wind turbine is a true reflection of the amount of solar radiation over the wind speed in the region. Fig. 11 shows the power generated from the hybrid components and the power demand by the load in 1st March 2010. Within major part of the day, the hybrid system appear capable of supplying the load, while at some part of the day the load demand exceeds the power from the hybrid components. At these points especially during the sunless hours, a combination of the wind power and the power from the battery bank can effectively supply the load

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with less stress on the battery bank power. The excess power from the PV array during the sun hours and part of the wind power can be channeled to the charging of the battery bank.

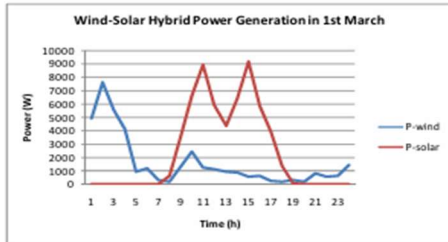


Fig. 10: Hourly power produced by the wind turbine and the PV array in 1st March.

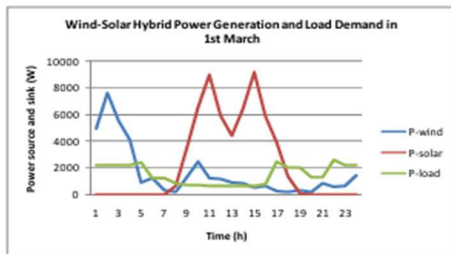


Fig. 11: Hourly power produced by the hybrid plant and the load demand in 1st March.

Fig. 12 is similar to Fig. 10 but with a reduced PV array power which explains the difference in solar radiation between the two periods of the year. Fig. 13 shows a different load pattern from that of Fig. 11 especially during the night period when less power is demanded. Like in Fig. 11, battery bank power can effectively supply the load at periods of hybrid power deficiency. Power from the hybrid plant at the periods of excess are used to charge the battery bank. Fig. 14 shows the solar PV array power in 1st March and in 1st July. The peak and average solar power generated in 1st March are both above 4 times the amount generated in 1st July. This demonstrates the fact that large amount of solar radiation falls in March than in July. Fig. 15 displays the wind turbine power in 1st march and in 1st July.

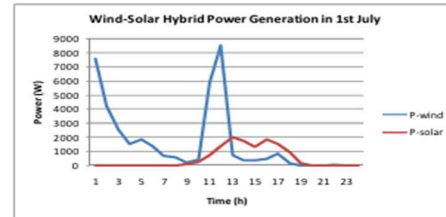


Fig. 12: Hourly power produced by the wind turbine and the PV array in 1st July.

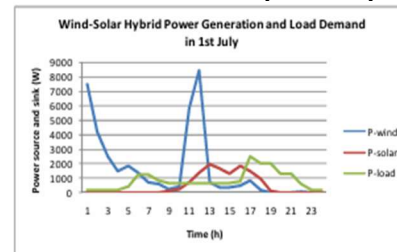


Fig. 13: Hourly power produced by the hybrid plant and the load demand in 1st July.

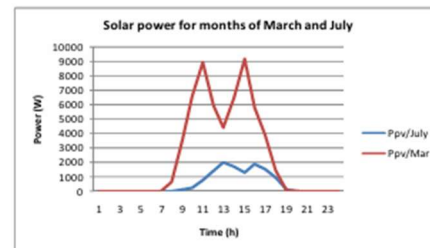


Fig. 14: Comparison of the hourly power produced by the solar PV array in 1st march and 1st July.

CONCLUSION

A feasibility study of wind-solar hybrid power system in South Eastern Nigeria has been presented. Hourly recorded data comprising the wind speed, the solar insolation, and air temperature has been applied to meet the power demand of a typical 3-bedroom flat apartment. It is observed that the hybrid plant is able to satisfy the daily average load demand of about 1.5 kW during hot season and less than 1.0 kW during rainy season. Excess power from the hybrid can be used to charge the battery bank which in turn supplies the load in the event of hybrid power deficiency.



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