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Design and Performance Evaluation of Wind-Solar PV Energy System for Kola Village at Birnin Kebbi, Nigeria

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ABSTRACT

This paper presents the results from a designed and simulated wind - solar PV hybrid energy system for residential power requirements of Kola village in Birnin Kebbi, Nigeria. The components designed comprised of wind energy conversion and solar photovoltaic (PV) subsystems, storage batteries and charge controller. 20kW PV array and 10kW wind turbines were integrated in a hybrid arrangement with a battery bank of 12V/200Ah and an average daily energy consumption of 4100 Wh. The Hybrid Optimization Model for Electric Renewables (HOMER) software as well as wind and solar resources data from the Nigeria Meteorological Agency (NIMET) were utilized for the analysis. The total generated power (141,162kWh/yr) meets the load requirement of the location. The wind energy resource contributed 75.25% electrical energy to the system while the solar PV resource (24.25%). The simulated most cost effective system configuration was found to have a total Net Present Cost (NPC) of $236,415 and a levelised Cost of Energy (COE_L) of 0.413 $/kWh.

Key Words: *Hybrid, Solar photovoltaic (PV), Wind energy.*

1. INTRODUCTION

Energy is one of the crucial inputs for socio-economic development of any society. According to [1], energy may also be seen as one of the fundamental instruments to drive any nation from developing to become developed or from stable to a more stable position. Various sources of energy are utilized in meeting the global energy demand. However, although Nigeria is endowed with various energy sources ranging from conventional to renewable resources, there is still energy poverty in the country despite the huge resource potentials due to the fact that activities in the energy sector are not properly coordinated because of inadequate lack of an integrated comprehensive energy policy [2]. It was further observed that only about 40% of households in Nigeria are connected to the national grid. Expansion of renewable energy across the globe, particularly solar and wind powers can also be attributed to the urgent need to develop renewable energy sources aimed at reducing carbon dioxide (CO_2) and other greenhouse gases (GHG) emission. Furthermore, renewable energy development is enhanced by favorable global political climate due to increasing global awareness of climate changes. Even though naturally, all renewable energy sources have some shortcomings [3]. Wind and solar sources depends on some uncontrollable and unpredictable factors such as weather and climatic conditions. But since both sources are complementary in nature, the problem can be reduced by utilizing the weaknesses of one with the strengths of the other. This is the principle behind the idea of hybrid wind-solar PV power concept [4]. Hybrid energy systems have proved to be advantageous over wind or solar alone for decreasing the depletion rate of fossil fuels, as well as supplying energy to remote rural areas, without harming the environment [5].

1.1 Geographical Location of the study area

The study area, Kola village, is a small community village very close to Birnin Kebbi, the capital of Kebbi State with latitude $12^{0}32'$ N, longitude $4^{0}12'$ E and elevation of 235 m. It is located in the North-West of Nigeria. The vegetation of the area is mainly Sudan savannah. The climate of the region is controlled largely by the two dominant air masses affecting the sub- region like the rest of West Africa, [6]. The targeted location was estimated to have a population of around one thousand people and about 100 main households. It is not connected to the national grid as such depends largely on different sources of energy for their domestic energy requirements.

Long term wind speed and solar radiation data records for the area were obtained from NIMET and was imputed into the HOMER software [7] for the determination of optimum system configuration.

1.2 Methodology

The Wind-Solar PV Hybrid System Description

The hybrid system considered in this study is a combination of wind and solar PV subsystems, intended for use for residential applications. The proposed system is composed of 20kW PV panels and 10 kW wind turbine interconnected to a DC bus through converters. The power from the wind - solar PV hybrid system is coupled to battery storage. PV panels transform solar radiation into direct current (DC), and the alternating current (AC) generated by the wind turbine, which is transformed to direct current (DC) by the use of rectifier. The DC voltage obtained at the output of the wind and PV subsystems are connected to the inputs of the hybrid system charge controller. For this system design, a 30kW converter is proposed between the hybrid charge controller and the AC loads, to convert DC into AC. The block diagram of the proposed system and its components are shown in Figure.1, The wind and solar resources data for one year were obtained from the Nigeria Meteorological Agency, (NIMET). These parameters together with the estimated load requirements of the targeted community were imputed into the software for simulation.

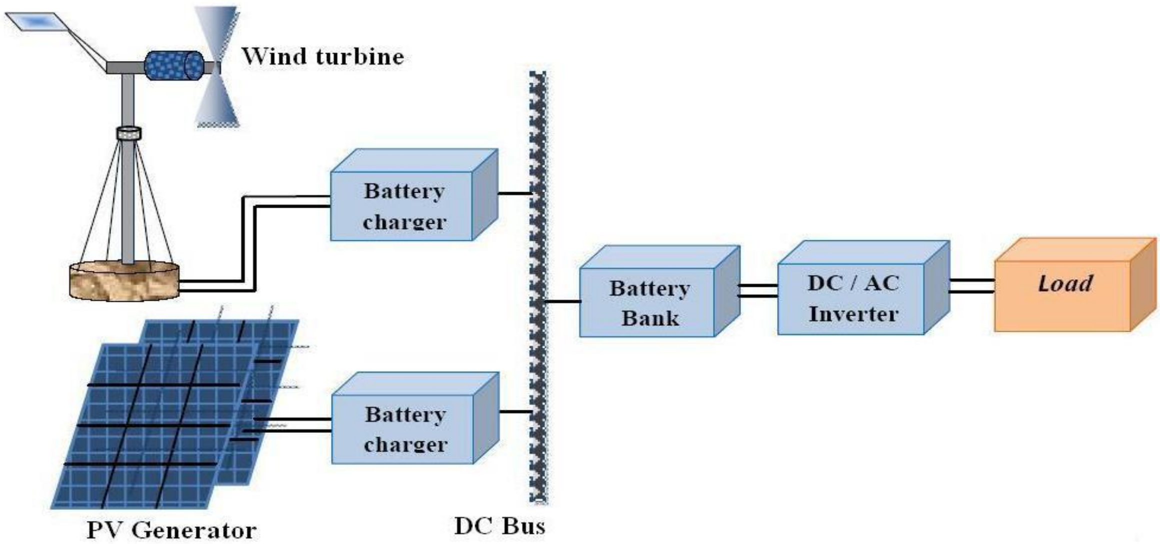

Figure 1: Block diagram of the Standalone hybrid PV-Wind system

2 EXPECTED LOAD REQUIREMENT

A hypothetical model community village comprising of about 100 main households (families) are to be provided with electrical power by the hybrid set up. Electric loads to be powered were for domestic usage such as; lighting, ceiling fans, TV, and radio for the households, health clinic and school. There is also water pumping activity for the community as part of the load requirement. The calculation of the load involved selection of appliances which are readily available as well as relatively efficient. Thereafter the power rating of each appliance was multiplied with the quantity to obtain the electrical load profile. Table 1 represents the total energy consumption for the village under study.

Table1. Calculated Energy Consumption for Kola village

Appliance	Power (W)	Used hours/day	Used energy/day in Wh
Lighting	160	15 h	2400 or 2.4kWh
Other appliances	340	5h	1700 or 1.7kWh
Total	500	20h	4100 or 4.1kWh

For all the households (100) = 410kWh
Annual consumption of community = 410×365=149,650kWh/yr
Figure 2 illustrates the hourly mean electricity consumption values of the load charges. The estimated loads along with the previous specifications were fed into HOMER software before the simulation was carried out.

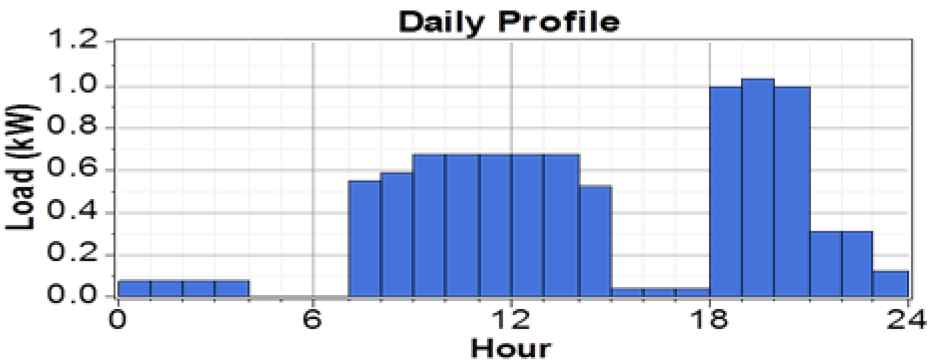

Figure 2: Hourly average electricity demand for Kola Village

3. RESULTS AND DISCUSSION

Figures3 and 4 presents respectively the wind speed distribution and the extrapolated wind speed. The monthly variation of the wind speed measured at 10m and extrapolated to 30m height can be observed. It confirmed that wind speed increases with height [8]. Also, the monthly variation shows relatively that higher winds occur between the months of December to March in the area, while lower values prevail in the rest of the months

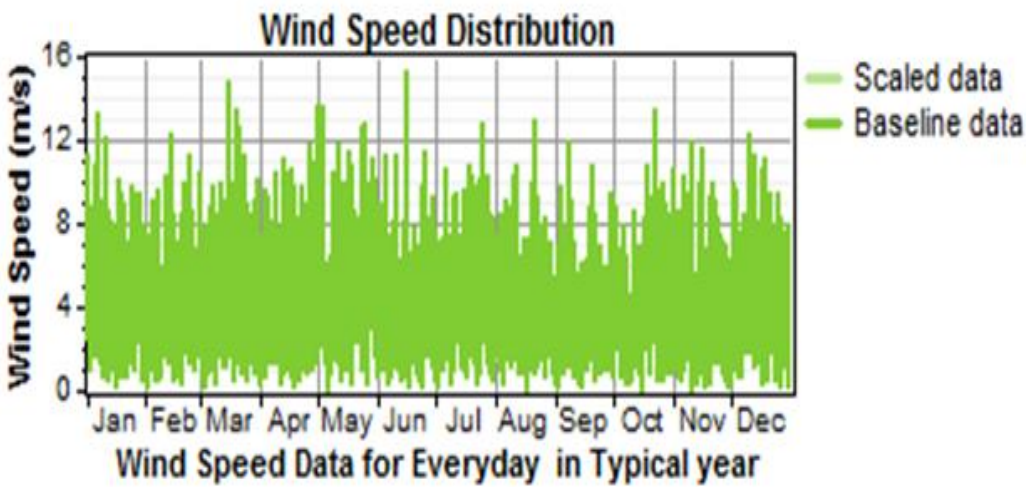

Figure 3 Daily Wind Speed Distribution for Kola village

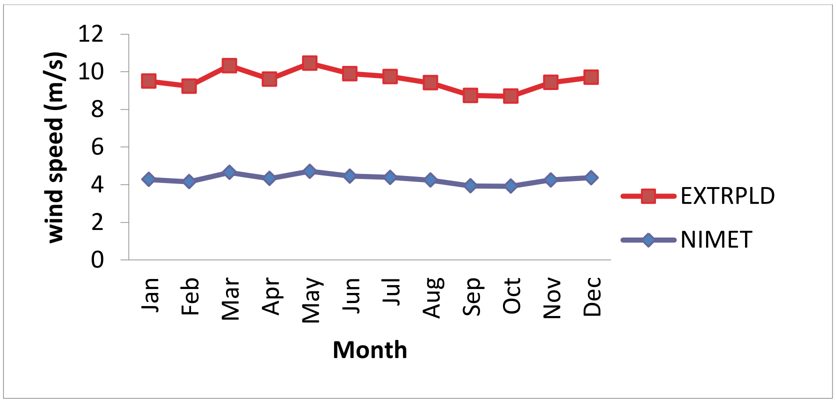

Figure 4; Monthly Average Wind Speed data at 10 m height, extrapolated to 30 m

The annual wind power output is presented in Figure 5, which depicts the monthly variability of wind speed. The hourly variation further shows that relatively higher winds occur in the morning hours between 09:00h and 17:00h

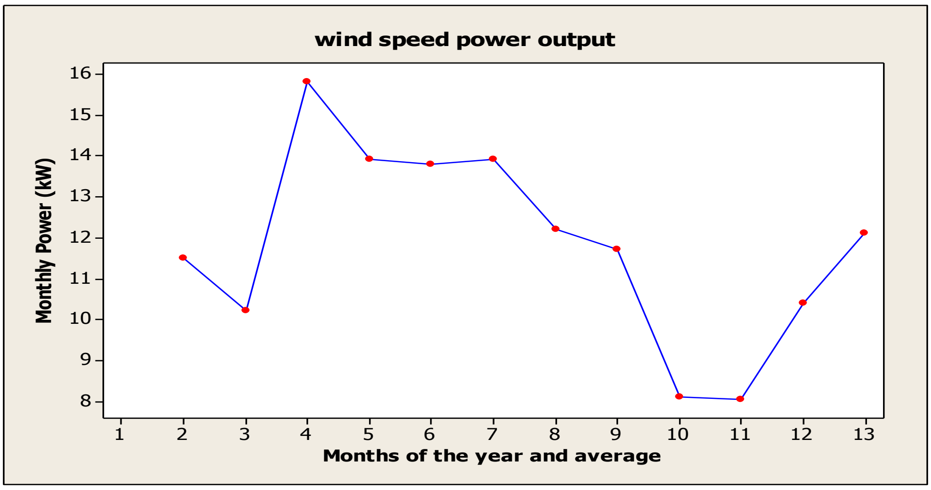

Figure 5 Wind speed Power Output

Figures6 and 7 shows the plot of the global irradiance distribution and solar PV power output respectively. The generated power of PV panels is a function of temperature, when the temperature increases, the efficiency of the panel decreases. The surface temperature of the PV module is approximately the same as the ambient temperature at night; however, it can exceed the ambient temperature by 25 °C or more at noon. Thus, the highest solar PV power was produced in the month of June when the temperature was at its peak.

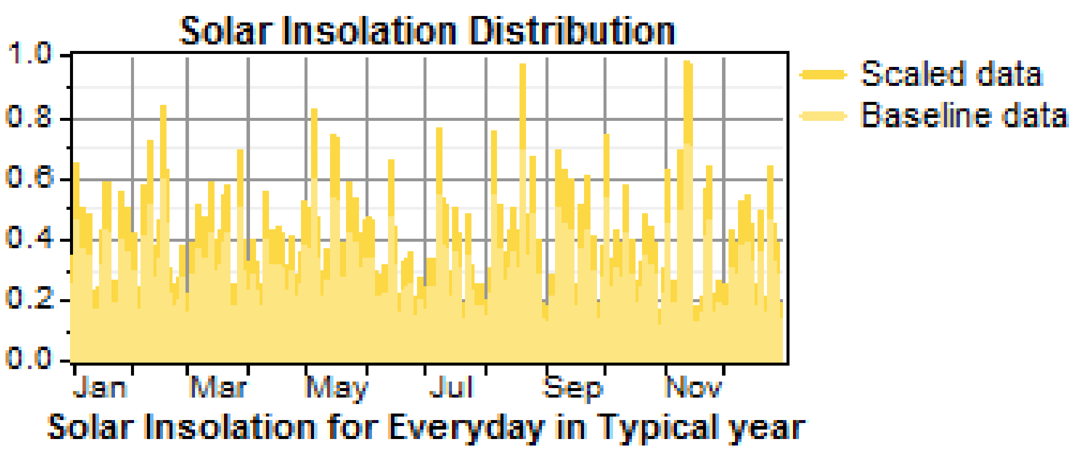

Figure 6: Daily Solar Insolation Distribution for Kola village

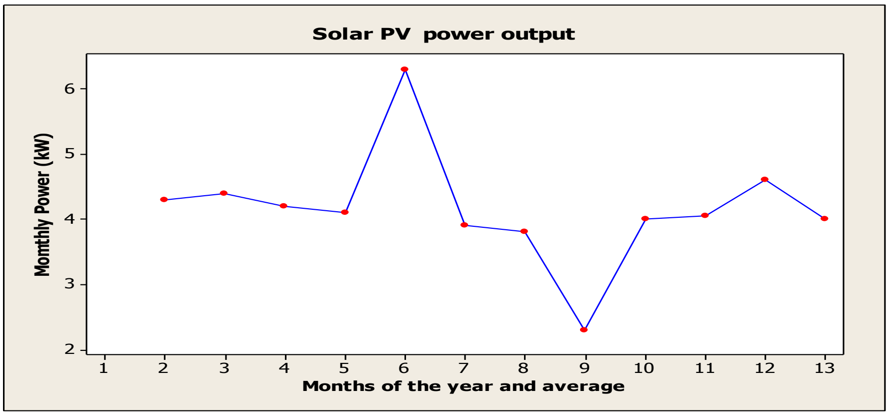

Figure 7: Solar PV Power Output

Figure 8 illustrates the distribution of the daily load consumption. The load consumption for everyday in a typical year shows the load variations and power consumptions at different hours in each day of the month that were considered in the methodology. The sun starts to be significant at 09:00h and decreases at 16:00h

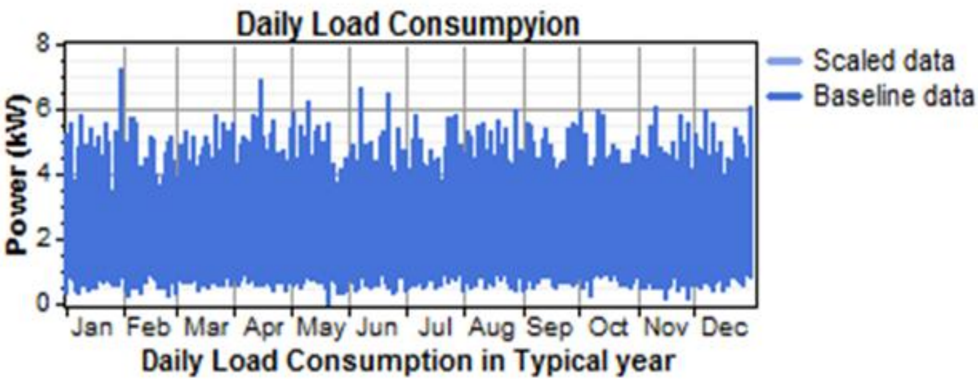

Figure 8: Average Load Consumption in Typical Year for Kola village

Figure 9 describes the contribution of the wind speed and solar radiation in the monthly average electrical power production of the simulated hybrid power generation project. It can be observed that the power supplied by the wind turbine is higher than PV array. However, the initial design assumption was that solar resource contributes more than wind and this informed the choice of the components.

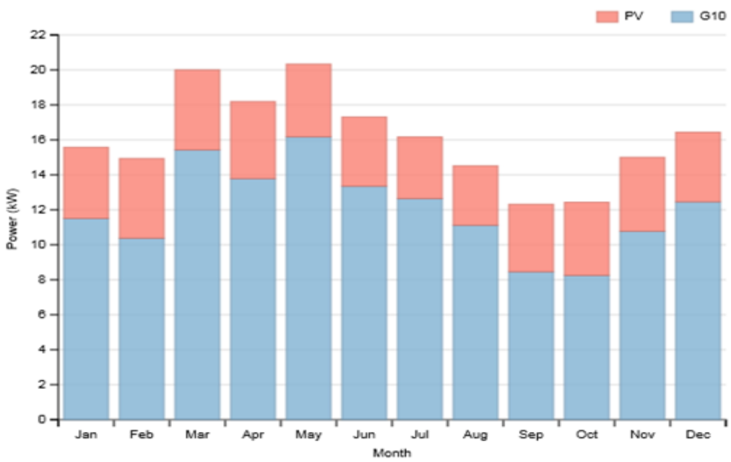

Figure 9: Contribution of the wind speed and solar radiation in the monthly average electrical power production

The monthly generated power varies according to the intensity of the wind and solar resources. Nonetheless, the complementary nature of the two renewable energy resources can be observed and the daily load requirement is satisfied. Table 2 describes a Technical Report for the Optimal System at Kola village.

Table 2: Technical Report for the Optimal System at Kola village

System Architecture		Annual Electric Production kWh/yr		
PV Array	20kW	PV Array	35.644	25.25%
Wind Turbine	Generic 15kW	Wind Turbines	105,518	74.75%
Battery	L16P 200Ah	Unmet load	8,488	5.7%
Converter	20kW	Total power	141,162	100%
Dispatch Strategy	Cycle Charging	---------	-----------	---------------

From table 2 above, the total annual electrical power production by the system was 141,162kWh/yr with an unmet load of 8,488kWh/yr, representing 5.7% of the electrical power required by the community. In the hybrid arrangement at this location, the solar PV component produced about 35,644kWh/yr. or 25.25%, while the wind energy conversion system produced about 105,518kWh/yr representing 74.75% of the total electrical power produced. This is against the initial design consideration which assumed that the solar PV will contribute more electrical power to the hybrid system. This can be attributed to the prevailing wind and solar resources at the location during the period of the study. Similarly, the total power produced failed short of the estimated energy requirements of the community by about 5.7%. But this is expected to be covered by reduced power usage in the rainy and cold seasons.

Table 3: Extracts from optimization results for Kola village

PV (kW)	G10	L16P	Conv. (kW)	Initial Capital($)	Operating Cost ($/yr)	Total NPC($)	COE ($/kWh)	Ren. Frac.
20.0	15	100	20	182.125	10.001	236.415	0.413	1.00
20.0	10	100	30	176.625	10.600	240.220	0.431	1.00
20.0	10	100	40	172.688	10.648	242.399	0.435	1.00
20.0	15	100	30	183.688	10.582	245.487	0.417	1.00
20.0	15	100	40	178.188	10.640	247.796	0.420	1.00
50.0	15	100	20	174.250	10.809	321.854	0.536	1.00
50.0	5	100	20	176.625	11.432	324.418	0.553	1.00

It shows that the first row contains the most optimal (feasible) system. Hence the following observations can be made from the results: For the most cost-effective system, the total NPC was $236,415 while the COE_L was 0.413 $/kWh. This system comprised of 20kW PV panel, Generic15kW wind turbine, L16P batteries (200Ah) and 20kW converter in the set-up. The second optimal system has a total NPC of $240,220 while the COE_L was 0.431 $/kWh. This system also had the same number and capacity of PV and batteries components as in the first category but the converter was a 30kW type, while 10kW wind turbine was utilized. However, at this site, the system in the first row had the lowest COE_L as well as the least NPC. Therefore, it was considered the most feasible and optimal configuration obtained at this location.

4. CONCLUSION

The study presents the system components description at the beginning, followed by its technical specification. The system's design considerations were presented thereafter. The simulated results demonstrate the capability of the system to supply the energy demands of the targeted community, with an average annual energy consumption of 149,650kWh/yr. From the results, we can specifically observe that:

- The initial design consideration assumed more power contribution from solar PV in the hybrid arrangement but the results after simulation showed that power supplied by the wind turbine (74.25%) is higher than PV array (24.75%).
- The total generated power of 141,162kWh/yr did not exactly meet the load requirement of the location by about 5.7%.
- The wind speed is higher on average between 10:00h and 18:00h while lower values are recorded during the rest of the day.
- The most cost-effective system from the simulation has a total NPC of $236,415 and COE_L of 0.413 $/kWh

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