MODELING AND SIMULATION OF WIND-SOLAR HYBRID ENERGY SYSTEM FOR POWER SUPPLY TO FACULTY OF ENGINEERING TEACHING WORKSHOP IN UNIVERSITY OF MAIDUGURI

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Abstract

Modeling and simulation of a PV-Wind hybrid electric power generation system is presented in this paper. The system generates power from wind and solar energy sources and also supplies power to the Faculty of Engineering Teaching Workshop, University of Maiduguri, Nigeria. Ten years meteorological data (wind speed and solar irradiation) for Maiduguri was collected from the National Metrological Agency (NIMET) and analyzed using statistical and simulation software (HOMER). Theoretical models for predicting the electrical power generation potential of the hybrid system was developed and the wind and solar energy potentials of the desired site was investigated and analyzed. According to the results obtained through the analysis, the site has abundant solar energy and wind energy potential, about 2-5MWh/m^2/yr of electrical power can be generated by using the hybrid system under ideal condition. The electric load of the workshop obtained from the energy audit carried out was about 370kWh/day and the scaled peak load is 140kW. The modeling, simulations and design has been carried out using the HOMER software based on the promising findings of these two renewable energy resource potentials. The software generates the simulation results which are lists of feasible power supply systems have been and arranged in ascending order according to their net present cost.

Keywords: *Hybrid, Homer, Modeling and Simulation*

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1. INTRODUCTION

Hybrid power system (HPS) 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). Thus, a solar-wind power system takes advantage of wind and solar energy's complementary characteristics. Wind and solar energy sources are the cheapest and available renewable energy and they best complement each other. Solar-wind HPS is made up of solar panels which produce electricity when solar radiation strikes the surface of the panel, and a wind turbine which starts to generates power when the turbine blades are turned by the kinetic energy of the wind. In this study, faculty of engineering teaching Workshop (FETW) University of Maiduguri is taken as case study area, it lies on the latitude 11˚ 51′ 0″ and longitude 13˚ 9′ 37″. FETW is a unit in the Department of Mechanical Engineering, University of Maiduguri and is used for academic activities and its sources of energy are the national grid and a diesel engine generator. Maiduguri is a region where industrial activities are very low due to lack of electricity as such there is the need to put in place implementable energy solutions. The renewable energy sources of the region are not being exploited due partly to ignorance and partly to high cost of the conversion technologies involved (Awogbemi & Komolafe, 2011). The specific potentials of the region is characterized by the high intensity of solar radiation of 6.176kW/m^2/day in Maiduguri and the average sunshine hour in the arid region is about 9 hours (Ngala *et al.*, 2013). Wind resources is available at annual average speeds of about 4.0 m/s at the far northern region of the country, with an air density of 1.1 kg/m^3 (Sambo, 2009). The main aim of this study is to model and simulate a wind-solar hybrid energy system for the workshop.

2. THEORETICAL DESIGN CALCULATIONS

The design of renewable energy system starts with feasibility study, determining the available renewable energy resource of the site under study.

A. Theoretical Background of solar energy

Photovoltaic (PV) system also known commonly as solar cells, convert the energy from sunlight into 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). According to Boneya and Bakele (2012), monthly average solar radiation is one of principal parameters used in HOMER software as input.

$$\overline{H} = \overline{H}_O\left(a + b\left(\frac{n}{N}\right)\right) \tag{1}$$

Where:

$\bar{H}$: is monthly average daily radiation flux on horizontal surface (mJ/m^2)

$\bar{H}_O$: is monthly average daily extraterrestrial radiation on a horizontal surface (mJ/m^2),

N: is the maximum possible daily hours of bright sunshine,
n : is monthly average daily number of hours of bright sunshine,

a and *b* are regression coefficients having average value of *a* =0.33 and *b*=0.43

The monthly mean daily extraterrestrial irradiation H_o and monthly mean day length N can be derived from the following formulae: (Augustine & Nnabuchi, 2009).

$$\bar{H}_O = \frac{24}{\pi} I_{sc} \omega_s sin\emptyset sin\delta + cos\emptyset cos\delta sin\omega_s \quad (2)$$

$$\bar{N} = \frac{2}{15} cos^{-1}(-tan\emptyset tan\delta) \quad (3)$$

$$\delta = 23.45 Sin\left(\frac{360\,(N+284)}{365}\right) \quad (4)$$

$$\omega_s = cos^{-1}(-tan\emptyset tan\delta) \quad (5)$$

Where:
δ = is the solar angle of declination
I_{sc} = is the solar constant (4.921MJm^{-2} day^{-1})
N = is the characteristics day number
Ǿ = is the latitude angle
ω_s : Sunset hour angle (^{0})

B. Theoretical Background of Wind Energy

The wind is a moving mass of air, it possesses a kinetic energy which can be harvested by a rotor or a wheel and transferred to a rotating shaft to derive mechanical mechanisms to produce electricity. This kinetic energy (K) is given by: (Lawan, 2012)

$$K.E = \frac{1}{2} M V_f^2 \quad (6)$$

Where
M= mass of the air passing/striking the wheel,
V is the velocity (free stream velocity).
The available theoretical power is expressed as (Onawumi and Olaoye, 2011)

$$P_T = \frac{1}{2}\rho AV.V^2 = \frac{1}{2}\rho AV^3 \quad (7)$$

Electrical power of the wind turbine is expressed mathematically as

$$P_{el} = \frac{1}{2}\rho AV^3 C_P \eta_g \eta_m \quad (8)$$

Where:
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 (%)
C_P : Beltz constant (%)

3. RESULTS AND DISCUSSION

The load profile of FETW was obtained through energy audit of the workshop; the electricity consumption of FETW is divided into; Lightings, Ventilation/comfort, Office equipments and Machining sections. The daily load profile of the workshop according to Homer calculation is presented in figure 1, the daily primary load profile of the workshop is about 370kWh/day and the scaled peak load is 140kW with a load factor of 0.110. The peak of energy utilization is between the hours of 10am-13pm.

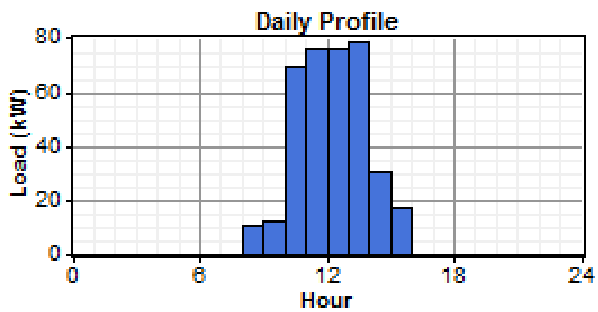

Figure 1: Data map of Daily Load Profile of the Workshop

Figures 2 and 3 depicts that solar energy resource is available in abundance in Maiduguri throughout the year and a substantial amount of electricity could be generated using PV panels. The maximum solar insolation for Maiduguri is obtained in the month of May, where a daily solar radiation of 6.96kWh/m^2/day is recorded, whereas the minimum solar radiation occurred in the month of December with radiation of 5.28kWh/m^2/day. An average of 6.02kWh/m^2/day was obtained for whole of the year. This value depicts a very good electricity generation potential of Maiduguri using solar radiation. The value of clearness index as shown in figure 3 varies from 0.52 in August to 0.69 in February; this indicates that Maiduguri is having a sky that is clear from clouds for larger period of the year

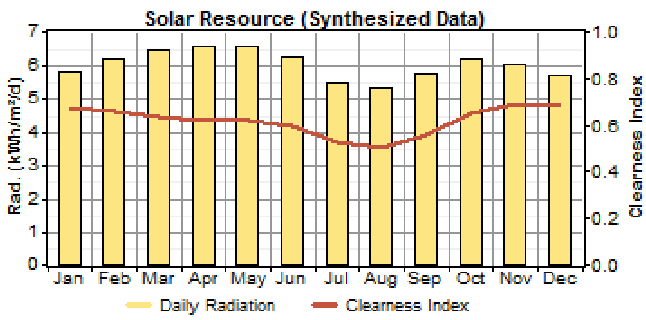

Figure 3: Homer generated monthly average solar radiation and clearness index

Figure 4 shows the data map of solar radiation formulated by HOMER from the raw measured solar data of Maiduguri. It shows that the highest solar radiation occurs approximately between the hours of 10:00 to 14:00 as such more electricity will be generated at that time.

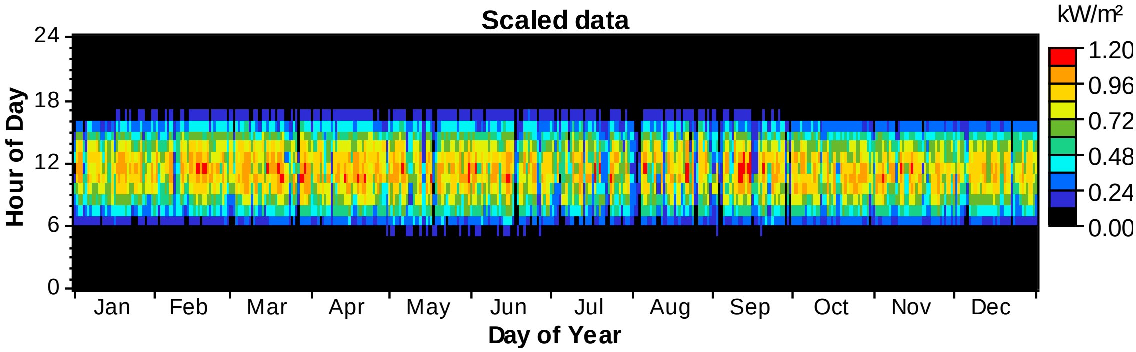

Figure 4: Data map of daily solar resource pattern

The PV module use for this study is poly-crystalline silicon, TSM 250-PA05 model with an efficiency of 14 to 15 % and capacity of 250W. The operation and maintenance (O&M) cost of fixed tilted PV systems is taken as 0.17% of the total installed cost (Lisell and mosey, 2010). The designed PV energy system is modeled as fixed tracking and Figure 5 depicted the electricity generation via solar PV. Electricity generation is high during the months of November, December, January and February the rated power output is 60kW when sky is clear enough, while from May till end of September PV power generation is lower than the other months which are below 48kW due to cloud coverage of the sky. Mean power output is about 12.3kW. The total hours of operation of the PV system is 4,380 hours per annum, thus it shows that almost more than 10 hours per day is working.

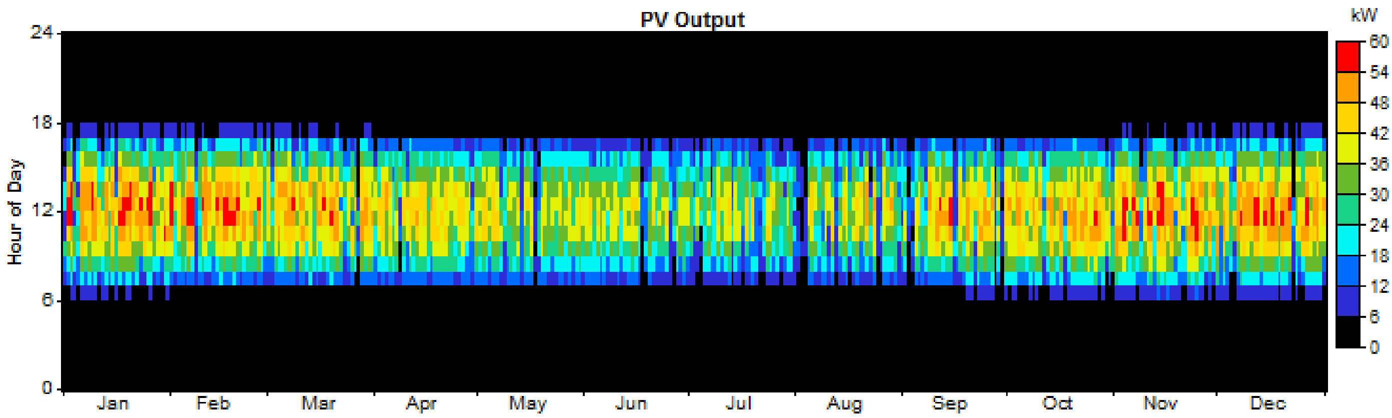

Figure 5: PV System electricity generation distribution profile

The wind turbine used in this study is PGE 20/25 is a three bladed 3 phase wind turbine, it has a cut in speed of 3m/s and its capacity is 25kW. It is designed for high reliability, low maintenance, and automatic operation in adverse weather conditions. Operation and maintenance cost is 1.5% of the total installed cost. As noticed from figure 7, the energy production by wind turbines is relatively higher in summer season. Maximum wind power output is registered from January till July, whereas in the other five months it is below this value. The wind turbine can generate up to 26kW as its maximum output, it will operate for 7586hrs/yr and produce 121,558kWh/yr.

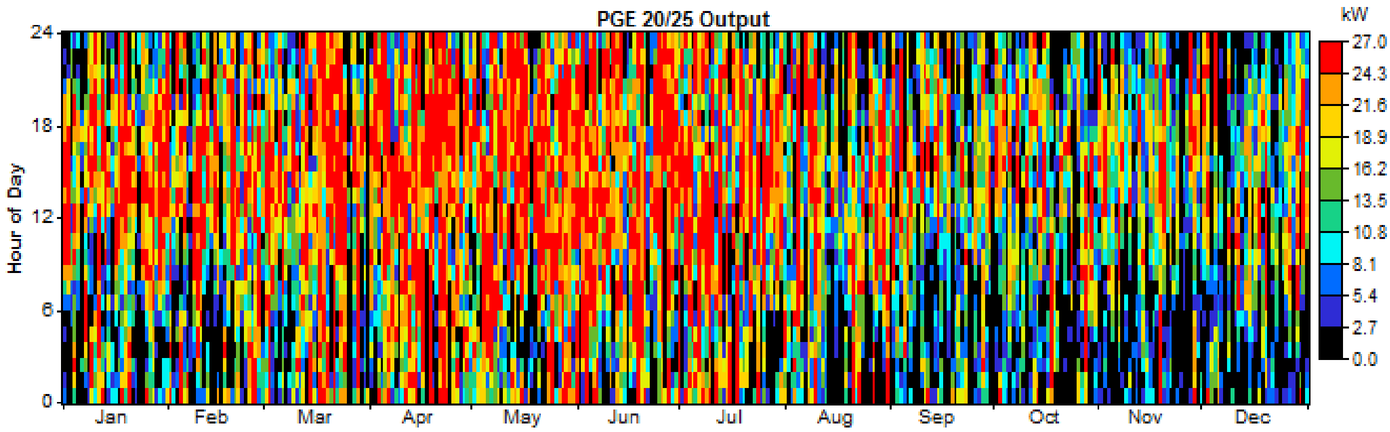

Figure 7: wind turbine electricity generation distribution profile

The total electricity to be generated by the solar and wind units of the hybrid system is 229,712kWh/yr. PV array power production accounts for 47% (108,153kWh/year) while the wind turbines accounts for 53% (121,558kWh/year) of the total electricity produced as shown figure 8. The wind energy system is the primary generator of power in this hybrid system because the magnitude of the power generated by the wind energy system is more than that of PV system and hence the wind energy system is considered as the base load of the hybrid assembly.

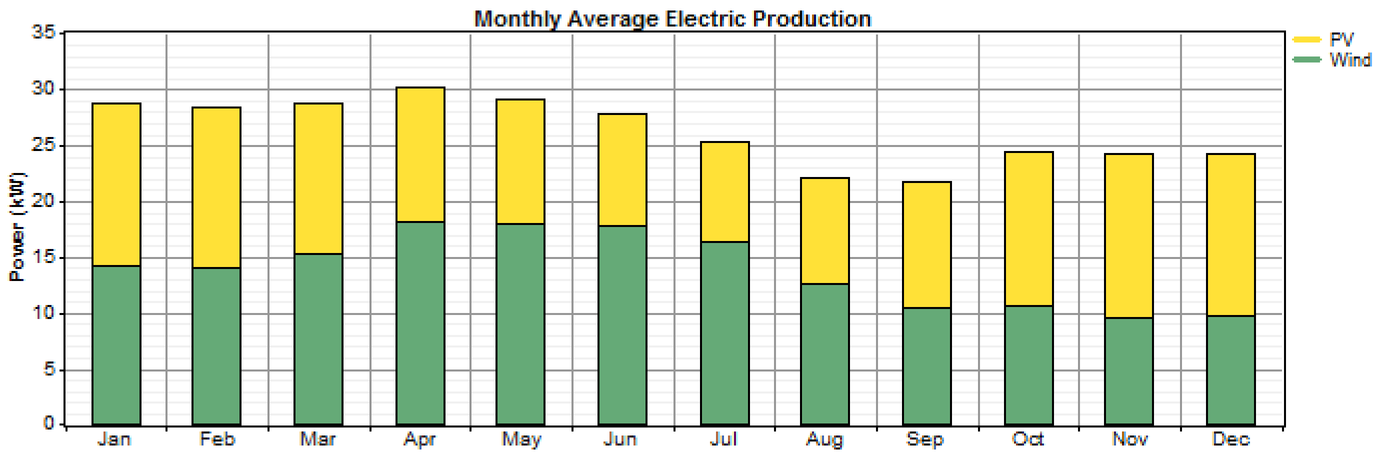

Figure 8: Monthly average electricity production

Surret 4KS25P is the energy storage battery considered in this research work due to its moderate cost, maturity, high performance over cost ratio. It has nominal capacity of 1156Ah (9645kWh) with nominal voltage of 6V for single battery with a lifetime throughput of 10,569kWh, the battery has an efficiency of 90. The annual maintenance cost is 0 % for the batteries storage (dry cell) (Diaf *et al.*, 2007). Figure 9 show that the battery bank (Surret 4KS25P) state of charge of the system has a minimum state of charge of 40%. According to the simulation result, the storage system will be made up of 80 batteries strings in parallel with 608kWh nominal capacity. The batteries will have autonomy of 23.7hr with lifetime throughput 845,488kWh and life expectancy of 12 years.

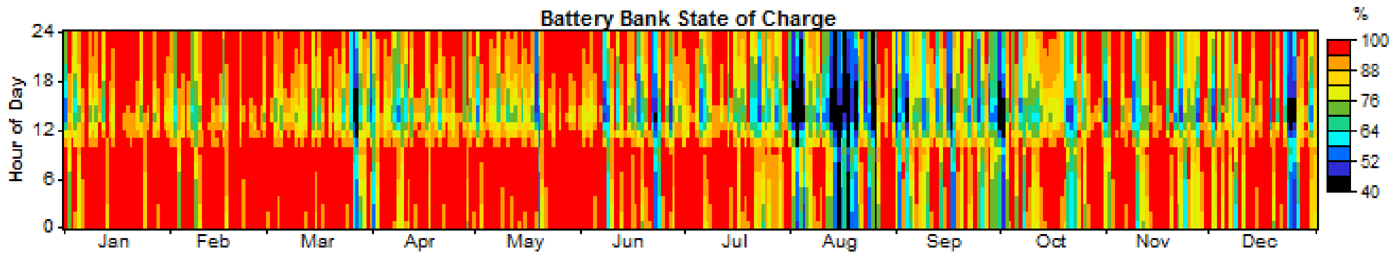

Figure 9: storage system state of discharge profile

A converter is required for changing the DC current into AC and supplies it for consumption because all the machines use AC type of current. The selected converter is 100kW power one aurora PV central 208/480VAC, 60Hz 3-phase converter. As shown in figure 10, the operational periods of the converter are between the hours of 8:00 to 16:00. The operation of the unit is zero between the hours of 17.00-7.00 because the energy requirement at these hours is zero. Also most of the time when the converter in used, the rate of conversion is between 50-70kw most of the times.

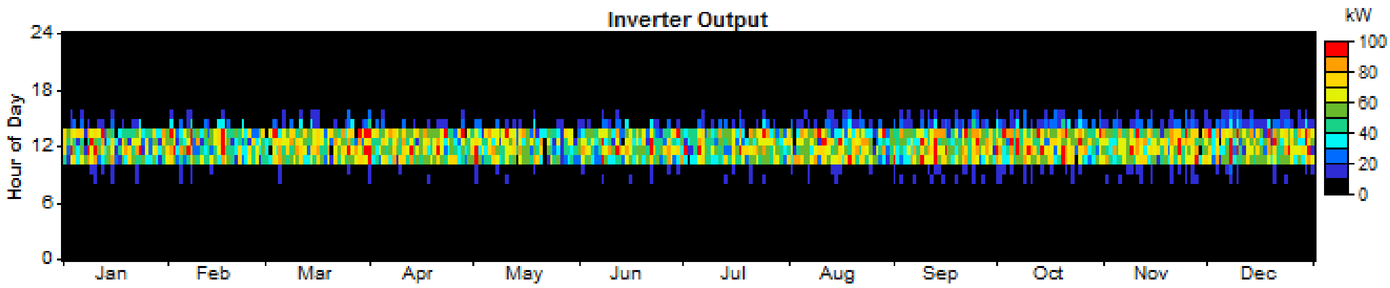

Figure 10: converter/inverter unit output profile

The supply of energy, as well as the load needed, fluctuates and this will create an imbalance within the system and hence the potential for load to be unmet with supply. As shown in table 2, according to the simulation result from Homer, the excess generated by this hybrid system is 71601kWh/yr which is 31.2% of the total energy produced by the system, capacity shortage to be experienced is 6109 kWh/yr 4.5% and the unmet electricity by this hybrid system is 3970kWh/yr is 1.4%. Energy storage is introduced in order to maintain the energy balance within the RES with consistency.

Optimization Analysis of the designed hybrid system

Table 1 presents the truncated simulation results of some feasible hybrid system, in the table, cost effective configurations are displayed and are ranked from the top, the first row is the optimum power system configuration according to Homer (low COE and NPC)

Table 1: Truncated Categorized Optimization Results from Homer simulation

PV (kW)	Wind turbine	Battery	Converter (kW)	Total capital cost ($)	Total net present cost ($)	Cost of energy ($/kWh)	Capacity shortage (%)	Operating cost ($/yr)
60	1	80	100	276,613	342,043	0.201	0.05	5118
70	1	70	100	279,483	343,765	0.202	0.05	5,029
50	1	100	100	285,443	356,364	0.210	0.04	5,548
60	1	90	100	288,313	358,086	0.210	0.03	5,458
50	1	90	150	291,540	358,118	0.211	0.04	5,208
70	1	80	100	291,183	359,808	0.210	0.05	5,368
60	1	80	150	294,410	359,840	0.211	0.05	5,118

4. CONCLUSION

Modeling and simulation of an off-grid renewable hybrid power system for FETW, University of Maiduguri has been carried out. Wind speed and global solar radiation data for ten years (2002-2011) of Maiduguri were obtained from the Maiduguri NIMET office. The average monthly profiles and hourly data for both sources were analyzed using statistical methods and HOMER software to model and simulate the hybrid system, and the result displays wind and solar energy potentials are undisputable to exploit for the provision of electricity. The mean wind speed at 30m height and the mean global horizontal solar radiation flux was 6.716m/s and 6.021kWh/m^2/day respectively. The simulation result displayed the most economical feasible system based on NPC as a set up containing of 1 unit wind turbines with 25kW rating power, 60kW photovoltaic panel, 80 unit batteries, and 100kW inverter. The simulation results showed various feasible hybrid system setups with different configurations but one with least NPC and cost of energy (COE) are chosen as the most feasible.

5. RECOMMENDATION

To improve the energy supply at all levels in Nigeria, grid and off-grid renewable energy technology systems have to be promoted. Hybridization of wind and solar as well as any other renewable energy hybridization techniques should be given due merit.

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