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Modeling and Analysis of Hybrid Solar/Wind Power System for a Small Community

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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 Standalone Hybrid Power System. This Paper Is Aimed At Modeling Of Hybrid Solar And Wind For Power Generation Using Matlab/Simulink Soft Ware. A Case Study Of Maiduguri Is Presented With Data Obtained From A Meteorological Station For A Period Of Five Years. A Model Was Developed To Simulate A Combination Of A Wind Turbine And Solar Photovoltaic Array To Satisfy The Maximum Load Of 2.015kw And To Charge A Battery Bank. The Battery Bank Supplies The Load In The Event Of Hybrid Power Deficiency. The Result Shows That The Low Wind Resource Can Be Hybridized With The High Solar Profile To Generate Firm Power For Standalone System.*
Keywords: *Solar resources, wind resources, hybrid system, load demand.*

I. Introduction

In hybrid power systems, a number of power generators and storage components are combined to meet the energy demand of remote or rural area, or even a whole community. In addition to PV generators, diesel generators, wind generators, small hydro plants, and others sources of electrical energy can be added as needed to meet the energy demand in a way that fits the local geography and other specifics. Before developing a hybrid electric system for a specific site, it is essential to know the particular energy demand and the resources available at that site. Therefore, energy planners must study the solar energy, wind, and other potential resources at the site, in addition to the energy demand. Solar energy is the most promising of the renewable energy sources in view of its apparent limitless potential. Most of the energy radiated by sun is transmitted radially as electromagnetic radiation which comes to about 1.5kW/m^2 at the boundary of the atmosphere. After traversing the atmosphere, a square metre of the earth‟s surface can receive as much as 1 kW of solar power, averaging to about 0.5 over all hours of day light.Nigeria is also having some cold and dusty atmosphere which is experienced during the harmattan in the northern part which usually occurs for four months period (November to February) annually. The dust from the harmattan has an attenuating effect on the radiation intensity of the solar, Studies relevant to the availability of the solar energy resources in Nigeria have fully indicated its viability for practical use (Nwosu et al,2012).

Nigeria is endowed with daily sunshine that is ranging between about 12hrs and 8hrs in the northern region and southern region of the nation respectively. It also has an annual average daily solar radiation of about 3.5 KWm^2/ day in the coastal area which is in the southern part of the country and 7.0KWm^2/ day at the northern boundary [1]. The country also receives average annual sum of 2200kWh/m^2 in Sokoto, Gusau, Kano, Yobe and Maidugri in the far north, to 600kWh/m^2 in Port Harcourt, Calabar, Aba in Abia and Warri all in the Southern part of the country. Nigeria also receives about 4909.212 kWh of energy from the sun which is equivalent to about 1.082 million tons of oil; this is about 4000 the current crude oil production per day, and also put at about 13 thousand times of daily natural gas production based on energy unit (Chendo,2002).

1.1 Modeling of Hybrid Solar - Wind System

A hybrid solar-wind system consists of PV array, wind turbine, battery bank, inverter, controller and cables [2]. The PV array and wind turbine work together to satisfy the load demand. When energy sources (solar-wind) are abundant, the generated power from the solar, in the day time will continue to charge the battery until it is fully charged. On contrary the when energy sources are poor, the battery will release energy to assist the PV array and wind turbine to cover the load requirements until the storage is depleted [3]. The hybrid solar-wind system modeling is mainly dependent on the performance of individual components. In order to predict the system performance, both sources of power generation should be modeled separately and will be combined to meet the demand reliability [4]. If the power output prediction from these individual sources is accurate enough, the resultant combination will deliver power effectively [2]. A hybrid system could be designed to operate either in isolated mode or in grid connected mode, through power electronic interface.

Marain [6] presented a standalone hybrid power system model for remote telecommunication system on the black sea coast in Romania. They used monthly average data for modeling the hybrid system and concluded that solar and wind power systems proven to be good alternative to power supply. However, they did not explain how the hourly data status was obtained. In this study the monthly average solar and wind data obtained from the Nigerian Meteorological Agency Maiduguri are used. Pragya [7] modeled a solar-wind hybrid system with diesel generator as backup for a site located in isolated areas of central India; The Author used Homer simulation for carrying the feasibility of standalone system, but their model uses diesel as backup system. However, it is noticed that transportation and refueling of the diesel generator is not feasible and economically viable at the remote station. However, in this study battery will be use as backup which does not need unnecessary transportation.

The hybrid system under study relies on solar and wind energies as the primary power resources and it is backed up by the batteries (see Figure 1). Batteries are used because of the stochastic characteristics of the system inputs. Namely, it is used to meet the electricity demand while the solar and wind energies are not adequate. The basic input variables of the hybrid model are: solar radiation, wind speed and temperature.

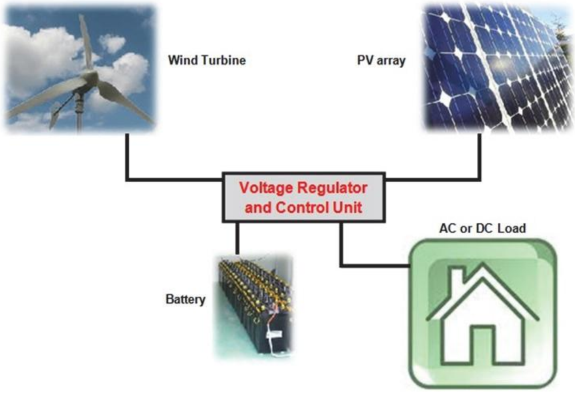

Figure 1: solar and wind power system(Orhan E,2010)

II. Methodology

This section outlines the methodology applied to carry out the modeling and analysis of hybrid solar and wind power generation under Maiduguri weather. The first step of the methodology is the formulation of relevant equations and implements these equations into MATLAB/SIMULINK software to observe the power generation. Solar radiation, temperature and wind speed are used as input to the SIMULINK block to generate solar power output, wind power output and hybrid solar and wind power output. The appropriate PV array model and Wind Turbine model is chosen to produce the power generated from these renewable sources. The second step of methodology is to analyze the Hybrid Solar and Wind Power System based on output characteristics.

PV Array Modeling

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar radiation.

Figure 2 shows the equivalent circuit of a solar module, 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 [12]. 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 below [12]. 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 [11].

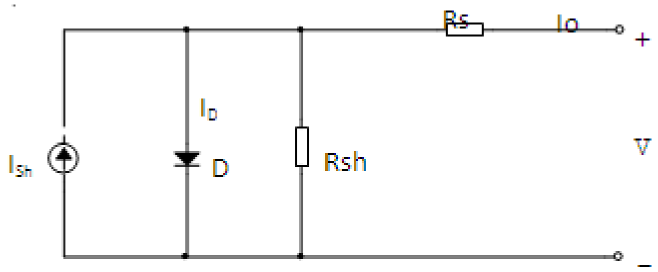

Figure 2: Equivalent circuit of PV module

The voltage-current characteristic equation of a solar cell is given as

$$I = I_{ph} - I_{sh}\left(exp^{q\left(\frac{v+IR_S}{nkT}\right)} - 1\right) - \frac{V+IR_S}{R_{sh}} \qquad (1)$$

Where I_{ph} is a light-generated current or photocurrent,
I_{Sh} is the cell saturation of dark current,
q = 1.6 $\times 10^{-19}$C) is an electron charge,
k = 1.38 $\times 10^{-23}$J/K) is a Boltzmann's constant,
T is the cell's working temperature,
n is an ideal factor, R_{sh} is a shunt resistance, and R_S is a series resistance.
The ideal factor n is dependent on PV technology [8].

Thus, once the solar radiation on PV panels and ambient temperature are known, the power output of the PV module can be calculated easily and accurately. Making use of the definition of fill factors the maximum power output delivered by the PV module can be written as [13].

$$P_{modul} = \frac{voc - ln(voc+0.72)}{1+voc} \cdot \left[1 - \frac{RS}{VOC/ISC}\right] \cdot \frac{Voc1}{1+\beta ln\frac{Go}{G}}$$

$$\frac{V_{OC1}}{1+\beta ln\frac{G_0}{G_1}}\left[\frac{T_0}{T1}\right]^{\gamma} .Isco\left[\frac{G1}{GO}\right]^{\alpha} \qquad (2)$$

α = is the factor responsible for all the nonlinear effects that the photocurrent depends on;
β= is a PV module technology specific-related dimensionless coefficient;
γ= is the factor considering all the nonlinear temperature–voltage effects.
G_0= is the standard solar radiation
G_1= is solar radiation on the site, while T0 and T1 represent two PV module temperatures. The five parameters (α, β, γ, and Rs) are introduced to take into account all the nonlinear effects of the environmental factors on PV module performance.

PV modules represent the fundamental power conversion unit of a photovoltaic system but a single PV module has a limited potential to provide power at high voltage or high current levels. It is mandatory to connect PV module in series and in parallel in order to scale up the voltage and current to tailor the PV array output.

Assume that the fill factor of a PV array, composed of a string of identical PV modules, equals that of single PV module [2].The maximum power output of the PV array can be calculated by:-

$$P_{pv} = N_p.N_s.P_{module}.\ \eta_{oth}.\ \eta_{mppt} \qquad (3)$$

Where η_{mppt} is efficiency of the maximum power point tracking, although it is variable according to different working condition, a constant value of 95% is assumed to simplify the calculations[13]. η_{oth} is the factor representing the other losses such as losses caused by cable resistance and accumulative dust, P_{pv} is power generated by the pv array, N_p is the number of pv module connected in parallel and $N_s$is the number of pv module connected in series.

Thus, once the solar radiation on the module surface and the PV module temperature are known, the power output of the PV system can be predicted.

2.2 The electrical power generated by wind turbine

The electrical power generated by the wind turbine is given by:

$$P_w = \frac{1}{2} C_e \rho A v_1^3 \quad (4)$$

Where, P_w is power extracted from wind turbine with changes in wind speed, C_e is the fraction of upstream wind power, which is captured by the rotor blades and has theoretical maximum value of 0.59, it is also referred to as the power coefficient of rotor or rotor efficiency.V_1 is the wind velocity in m/s, ρ is the air density in (kg/m^3) and A is the area swept by the rotor blades in (m^2).

V is the wind speed in m/s (find in data table)

ρ is the density and equals to 1.225kg/m^3 (constant)

C_e = 0.59 (constant)

.A = 9.6m^2 (constant)

2.3 Power from the hybrid

The total energy of the hybrid system will be the energy supply from the solar PV and the wind turbine. As shown in the equation below;

$$P_{HY} = P_{PV} + P_W \quad (5)$$

Where P_{HY} is the total power generated by the hybrid system, P_{PV} is the power generated by the solar PV array and P_W is the power generated by the wind generator.

III. Result and Discussion

The results can be analyzed and discussed in terms of it capability to meet the required load demand of the area . The developed methodology has been applied to simulate standalone hybrid PV/wind system in MATLAB/SIMULINK environment, the result are presented.

Figure 3 shows the monthly average power produced by the PV array, wind turbine as well as monthly power produced by the hybrid system.

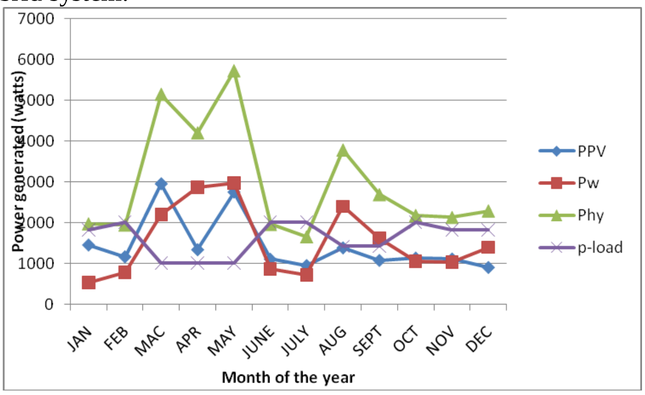

Figure 3: Monthly Average power produced by wind turbine, PV array and the hybrid system in 2002 and the load demand.

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. Figure also show the power generated from the hybrid components in 2002. Therefore it can be seen that the highest month of generation from the PV array was in March, and that could be as a result of large solar radiation of about 27.623w/m^2 recorded in the year. Starting from June through November, this power generated lies between 1109.7W –1151.1W because the season which usually characterized by low solar radiation with very high temperature, and that have high effect on the power generation.These characteristics shows that the combination of power generated by solar and wind yield significant value that can be used for standalone application and is capable to meet the load demand of the area under study except in July, however in that month there is minimal usage of electricity because of the rainy season.

Figure.4 is similar to Figure.3 but with a reduced PV array power in December which explains the difference in solar radiation between the two periods of the year.

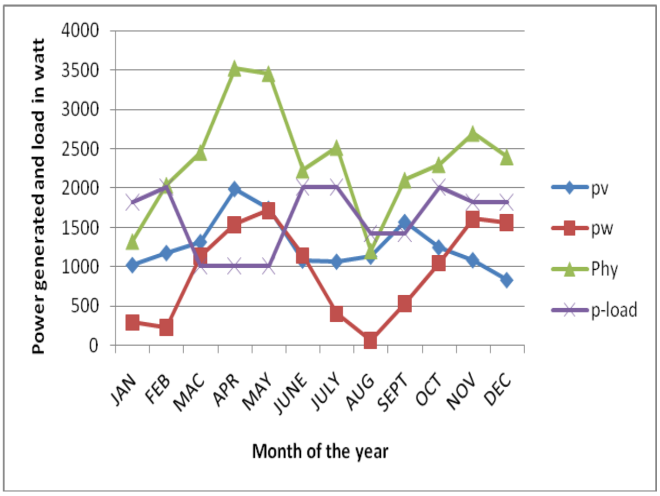

Figure 4: Monthly Average power produced by wind turbine, PV array and the hybrid system in 2003 and the load demand.

Figure.4 Shows the power produced by the solar PV array, wind turbine and hybrid system in 2003, although the weather record shows that almost all the data recorded for ten years looks very similar. Power produced by the PV array in April is higher than what produced in December, this is because, April is the sunniest month of year and it has solar radiation of 20.14w/m^2 while December is a dry season with low solar radiation of 10.12w/m^2. In August least power was produced by wind turbine which has the wind speed of 2.09m/s. Therefore, in 2003 more power is produced by the PV array than the wind turbine. Although the power generated by the wind turbine is low throughout year compared to PV array power it can be used to burst the system when it is hybrid connection. The hybrid power generated in 2003 is low compared with the one generated in 2002. highest generation in 2003 was in April which sunniest month of year with solar radiation of 20.14w/m^2 and moderate wind speed of 5.6m/s, yield the peak hybrid power of 3522.93W for month and that 43% less than hybrid power produced in 2002. From the figure, it can be observed in the month of January, February, July and August.

Fig.5 below shows the solar PV array power and wind turbine power in 2004. The peak power was generated by wind turbine in July and May, and they are both above 2 times the amount generated by solar PV array in the whole year. This demonstrates the fact that large amount of wind speed falls in May and July, while the solar radiation was average throughout the year. From the result it can be seen that, the hybrid system can withstand the required load of the area throughout the year.

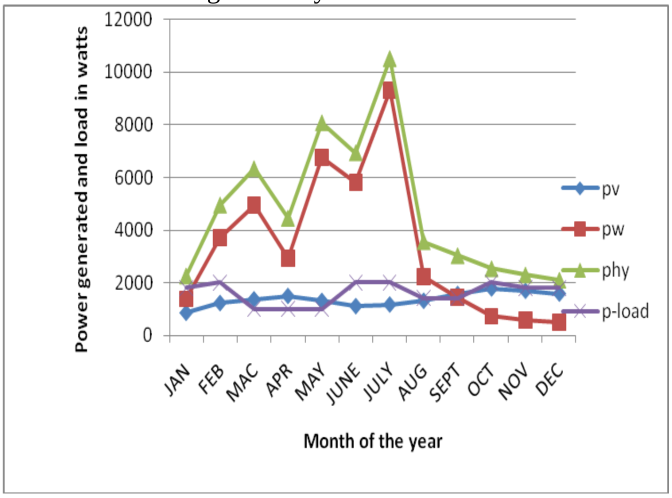

Figure 5: Monthly Average power produced by wind turbine, PV array and the hybrid system in 2004 and the load demand.

Fig 5: presents the hybrid component for the year 2004. The above result shows that from February to July much power is been generated than the other month of the year. the peak maximum power of 9329.5W was generated by the wind turbine in July, this is because there is large power generated by the wind turbine as result of high wind speed recorded in that year, therefore when combined with the power generated by solar PV array the result is very significant and would be capable of proving electricity to consumers with less facilities especially in developing country like Nigeria. It can be seen that, in 2004 the power generated by the hybrid can meet the load demand throughout the without deficiency. the result revealed that more power was generated by wind turbine as a result of higher wind speed recorded in the year, high temperature was recorded which have reduces the voltage output of the PV module and it affect the PV array output coupled with the low solar radiation. Therefore the combination of two sources of power result in yielding good power source that can meet the load demand of the area.

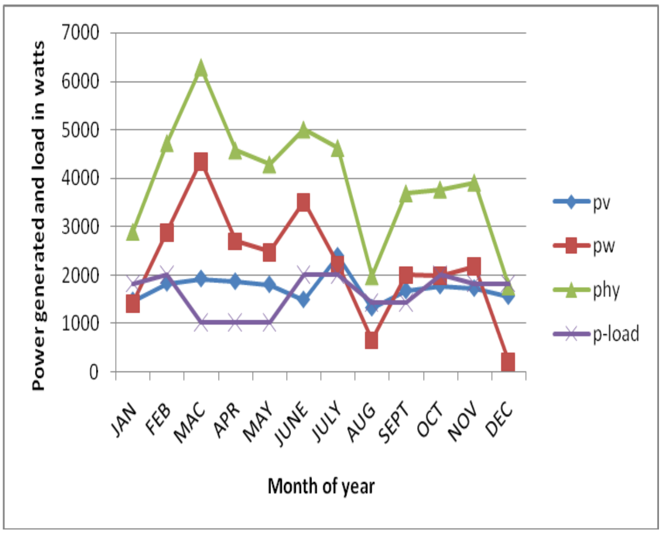

Figure 6: Monthly Average power produced by wind turbine, PV array and the hybrid system in 2005 and the load demand.

In the month January and August power generated by both sources of energy are low, for example power generated by solar PV array and wind turbine in the month of August and 1324.2W and 652.83W respectively, this is largely as a result of low solar radiation and wind speed recorded within the month, therefore from figure, it can be seen that the hybrid generated in that month is lowest power generated in the year.Also, the contribution of solar PV array is higher than of wind turbine in 2005. However, from February to July the wind power produced is high due to the high level of wind speed recorded. Hence the maximum hybrid power is produced in that month.

The result also present that the peak maximum hybrid generation is in March is almost 3-times than the hybrid generation in December. It can be observed that the individual generation may not meet the demand, but the hybrid result shows that the two sources of energy are feasible and can meet the demand.

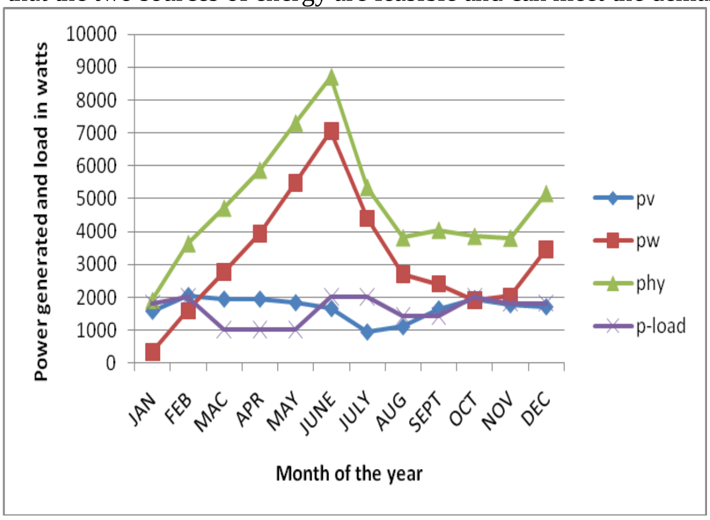

Figure 7: Monthly Average power produced by wind turbine, PV array and the hybrid system in 2006 and the load demand.

In fact the figure revealed that the energy range produced by the wind turbine is included between 1894.1W in October and a maximum value of 7054.7W in June. However for the solar PV array, the energy production reaches it maximum 1962.6W in October. It seems that energy production coming from the wind turbine is higher than this energy produced from solar PV array this year (2006). This fact is meanly due to the higher wind speed in that year and lower solar radiation coupled with high temperatures which in turn affect power out of solar PV array.The figure also Present hybrid power produced from the two sources of energy for the year 2006. It is clear that during February to December, this power generated from this hybrid power system reaches maximum value of 7308.1W and it can be concluded that the hybrid system is feasible throughout the year.

IV. Conclusions

In simple terms what has been accomplished in this work is firstly the determination of solar and wind energy potentials at three typical locations in Maiduguri. Then, based on these potentials, a feasibility study for a standalone electric power supply system for three communities has been conducted. A software (MATLAB/SIMULINK) was used as an aid for the study, however, it can be concluded that, generally-speaking, the potential are sufficient even for a larger power system, the simulation result revealed that solar energy and wind energy will be a viable option if integrated together. The results of this study can be considered to be applicable to most regions in Maiduguri with similar climatic Conditions. It can be concluded the solar and wind are viable in this area and it was found that it will supply more than 90% of the load demand of the study area.

There is a considerable electricity demand for stand-alone/mini-grid Renewable Energy Technologies, both in remote and highly populated areas. To meet this demands, policies have to be implemented to promote Renewable Energy Technologies, and address the problems still connected with them.

Other areas for further investigation are:
i. Village load, RES and related full costs data with accuracies
ii. Hurdles faced by small-scale Renewable Energy Technologies to become sustainable.

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