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Investigating Wind-Solar Hybrid Power Potential over Akure, Southwestern Nigeria

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Abstract

Depleting oil and gas reserves, combined with the growing concerns of global warming, have made it inevitable to seek alternative/renewable energy sources. The daily and seasonal variations in solar and wind energy distribution has spurred the need for a complimentary source of power supply. In this research work, we intend to look at the wind-solar hybrid potential in Akure (7.151N, 5.121E), South-West Nigeria for the year 2010. Data for the work were obtained from the Integrated Sensor Suite (ISS) weather station located at Iju area of Ondo state. The statistical correlation of wind and solar thermal power availability and performance of the hybrid system will be presented.

Keywords: hybrid, Power, wind and Solar.

1.0 Introduction

It is universally accepted that fossil fuels are finite and it is only a matter of time before their reserves become exhausted. Estimates of fossil fuel reserves all reach the same conclusion. Extended use of these reserves globally, at the current rate will continue for no more than a few decades to come. The attendant political instability, environmental pollution associated with overdependence of an economy on the world oil price, exploration and utilization has further spurred the quest for alternative source of power. Nigeria, a developing African country, is faced with other issues such as poor maintenance culture, high cost of maintenance, vandalism, high population growth leading to higher energy demand and corruption which currently ravages the energy and power sector.

Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth's surface. Growing concern over the need for alternative power supply has spurred various researches in wind energy. Some authors focused on wind speed measurement over a city [1 – 5], while others reported wind speed measurement across the country [6 - 11]. Most wind data presented by these authors were measured at different heights (varied from about 5 to about 15 m) but were adjusted to a common height of 10 m. This allowed comparison to be made among different locations[12].

Solar energy is the most promising of the renewable energy sources in view of its apparent limitless potential. Given an average solar radiation level of about 5.5 kWhm–2day-1, and the prevailing efficiencies of commercial solar-electric generators, then if solar collectors or modules were used to cover 1% of Nigeria's land area of 923,773km^2, it is possible to generate 1850x10^3 GWh of solar electricity per year. This is over one hundred times the current grid electricity consumption level in the country [13]. Abe and Adetan [14] estimated that if solar appliances with 5% efficiency are used to cover 1% of the country surface area, 2.541 x 10^6 MWh of electricity will be produced. The power generating unit is the solar module which consists of several solar cells electrically linked together on a base plate. On the whole the major components of a photovoltaic system include the arrays which consist of the photovoltaic conversion devices, their interconnections and support, power conditioning equipment that convert the dc to ac and provides regulated outputs of voltage and current; controller, which automatically manages the operation of the total system; as well as the optional storage for standalone (non-grid) systems. In recent times, the commercial viability of photovoltaic systems has led to renew interest and research in its development.

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Solar and wind energy resources are often complementary in nature. The wind is caused by the temperature differences in the atmosphere due to solar radiation heating. The directional, diurnal, and nocturnal characteristics of wind depend also on the effects of local topographic conditions, which complicate the relationship between wind and solar radiation. Therefore, the peak power potentials due to solar and wind do not occur at the same time. Various studies have been carried out on the hybrid potential of many locations across the world such as Saudi Arabia [15 - 17], Palestinian Territory [18], Greece [19], England [20]. Other forms of hybrid systems studied or investigated include solar/wind/diesel [16, 21], solar/wind/biogas [22].

The aim of this research is to investigate the possibility of a hybrid solar-wind power scheme in the town of Akure, an optimized wind/solar ratio for a steady and efficient power output.

2.0 Methodology

The weather in Akure is characterized by high rainfall and low temperature. The data for this study is obtained from simultaneous in-situ measurement of wind speed and solar radiation carried out in the year 2010. The site of the measurement was the old site of the Nigerian television authority (NTA) Akure, located at Iju, a few kilometres from the city of Akure. The sensors were mounted on a 220 m high communication mast, while the receiver (console), together with the data-logger, was located in a measurement room on the ground and adjacent to the communication mast. The device used for the measurement was the Davis 6162 wireless Vantage Pro Plus, manufactured by Davis Instruments, California, United States of America. It is equipped with the integrated sensor suite (ISS), a solar panel (with an alternative battery power source) and a wireless console, which provided the user interface, data display and analogue-to-digital conversion.

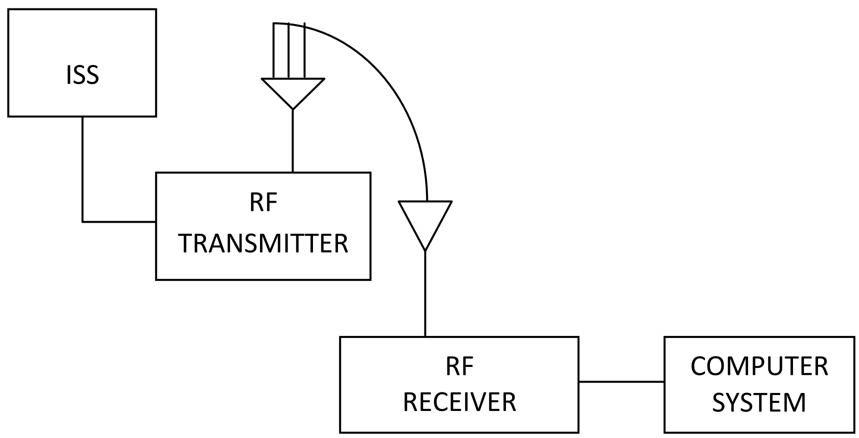

Fig 1: Block diagram of the equipment set up

The ISS housed the external sensor array for measurements of wind speed, solar radiation, pressure, temperature, relative humidity, UV index and rainfall rate among others. The console was connected to a computer through the data-logger from which the stored data are downloaded. The frequency of transmission of the ISS is 868.0–868.6 MHz. The block diagram of the instrumentation set-up is shown in Fig. 1.

The measurement covers a 24-hour window from midnight at 30 minutes interval. From the half-hourly data, the daily and monthly means were evaluated.

In order to compare and correlate the potentials of the solar and wind power, these power potentials are calculated per unit surface area (W/m^2). The total solar radiation (W/m^2) on a horizontal surface is considered. The wind energy potential is calculated from

$$W_w = \frac{1}{2}\rho V^3 \qquad (1)$$

where W_w is the wind power (W/m^2), ρ is the density of ambient air in Kg/m^3 and V is the velocity of wind in m/s.

The efficacy of the hybrid system is determined from the correlation between the solar power availability and the wind power availability which can be expressed as [24]

$$P_{s,w} = \frac{\mathrm{cov}(W_s, W_w)}{\tau_s, \tau_w} \qquad (2)$$

where the covariance cov(x,y) is given as

$$\text{cov}(W_s, W_w) = \frac{1}{n}\sum_{t=1}^{n}\left[(W_s)_t - \overline{W_s}\right]\left[(W_w)_t - \overline{W_w}\right] \qquad (3)$$

standard deviations (τ_s, τ_w) are

$$\tau_k = \left\{\frac{1}{n}\sum\left[(W_k)_t - \overline{W_k}\right]^2\right\}^{1/2} \qquad (4)$$

Where $\overline{W_k}$ are mean powers and k takes values s and w.

The best correlation for complementary data such as solar and wind power would be -1. As the correlation approaches +1, the complementary nature of the data disappears.

Power output from the solar-wind hybrid generator, W_H is given by

$$W_H = A_S W_S + A_W W_W \qquad (5)$$

where coefficients A_S and A_W are used to account for the size and overall efficiency of the individual solar and wind power generators, respectively. The main goal in designing the hybrid power generator is to select the optimum values of A_S and A_W for minimum cost and to produce a total power output W_H to meet the demand of power (assumed to be 100W) throughout the year.

3.0 Results and Discussion

The total power available from the hybrid system is given as

$$W_H = W_s + W_W \qquad (6)$$

W_S = power available from the solar panels

W_W = power available from the wind system.

The scatter plot of the contribution of the individual power (W_S and W_W) and total power (W_H) from the system is shown in Figure 2. The hybrid power is seen to be far more than the individual power. The highest daily mean global solar radiation of 38.62 W/m^2 was recorded on November 20. The monthly averages of solar, wind, and total power potentials are shown in Figure 3. The complementary characteristics of solar and wind power availabilities are clear, and the total power potential shows less variation throughout the year. This suggests that using a solar–wind hybrid generator, a continuous and nearly constant power output could be obtained which can utilize the solar and wind power potentials in an optimum way.

The correlation analysis shows -0.1495 which portrays a weak complimentary characteristics of solar and wind power. This may be attributed to the windy nature of the site giving rise to the dominance of wind component of the hybrid system. The size of the component system to give optimum output is given by (7) and the estimated output is shown in Figure 4.

$$W_H = 23.0 W_S + 4.03 W_W \qquad (7)$$

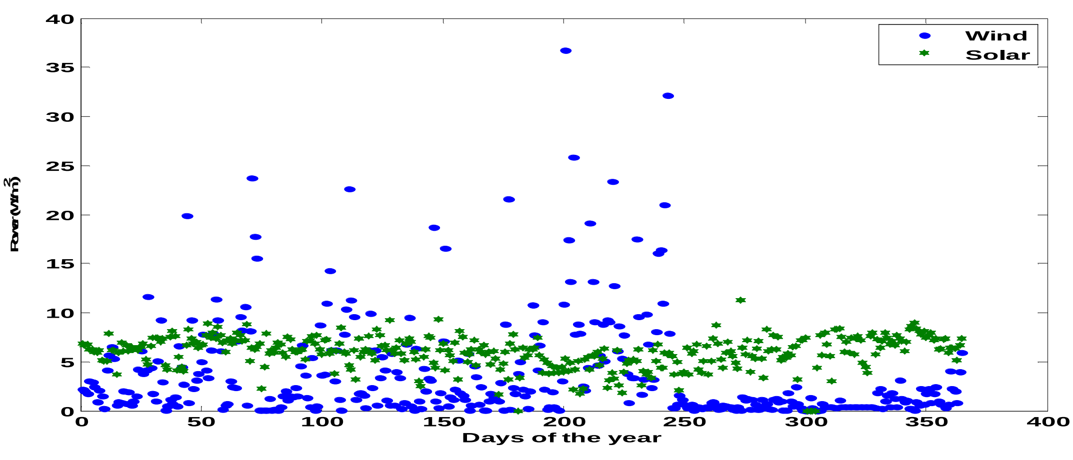

Figure 2: Daily average solar and wind power throughout the year

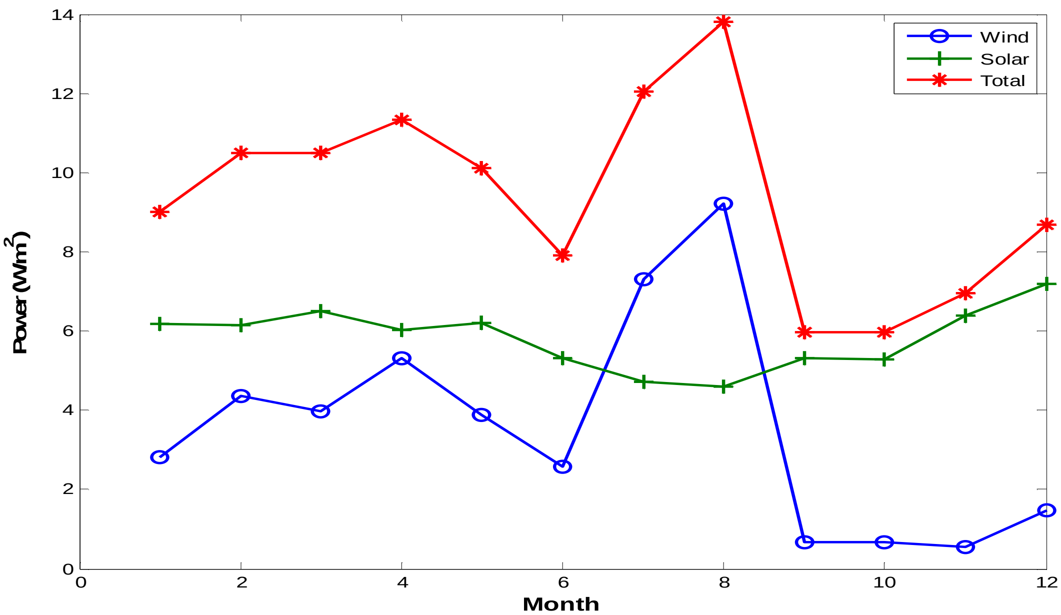

Figure 3: Monthly average wind, solar and total potentials

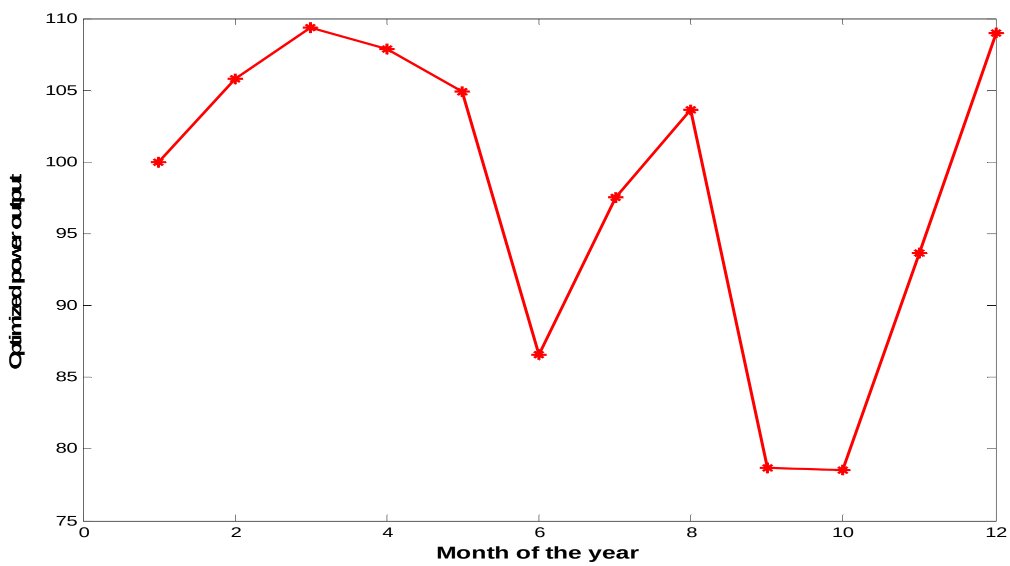

Figure 4: Estimated power output from optimized hybrid system

4.0 CONCLUSION

Hybrid potential of wind and solar power at a local site in Akure, Southwestern Nigeria over a period of one year have been studied. From the results, it can be inferred that the solar power at the site will not effectively compliment the potential wind power given the correlation coefficient. Consequently, the optimum size of the system tends towards large values (15.0) for wind and low (4.03) for solar. This result can, however, be utilized for low power and on-demand systems. A backup system such as national grid or diesel/gasoline engine could be used to further compliment the available hybrid power.

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