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# Modeling and Optimization of Renewable Energy Sources for Power Distribution System

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**Abstract**
This paper presents modeling and Optimization technique for investigating the performance of power networks using renewable energy sources, basically PV (Solar) and wind technologies. Newton Raphson load flow solution in conjunction with Monte- Carlo simulation method is used. Additionally, the optimization formulation is presented. It features a traditional loss minimization objective for the distribution system subject to network constraints. Results showed that there is an improvement in the voltage profile with minimum power loss. Also, the optimum site and size of the renewable Energy sources were obtained.

Keywords: - *Renewable Energy, Probability Density function, Solar Radiation, Wind Speed, Monte-Carlo Simulation, Newton Raphson Load Flow Technique.*

## 1. Introduction

Energy is an important input in all sectors of any country's economy. The standard of living of a given country can be directly related to its per capita energy consumption. Energy crises are usually due to the following reasons; firstly, the population of the world has increased rapidly and secondly, standard of living of human beings has increased [1].

Today, every country draws its energy needs from two or more varieties of sources. This could be via commercial sources such as fossil fuels (coal, oil and natural gas), hydro electric power and nuclear power or via non-commercial sources such as animal waste, solar, wood and agricultural waste.

Alternative energy is a term that refers to any source of re-usable energy intended to replace fuel sources without the undesired consequences of fossil fuels such as high carbon dioxide emissions, which is considered to be the major contributing factor of global warming according to the inter governmental panel on climate change[2]. Deregulation in the power market has encouraged the move towards distributed generation, where many smaller generating plants located close to a few large centrally located power stations are penetrating interconnected power systems.

The renewable energy sources have proven to be of great help in reducing the amount of toxins which are by-products of the energy exploits. Increased population growth and economic development are accelerating the rate at which energy, and in particular electrical energy is being demanded [3]. All methods of electricity generation have consequences for the environment, so meeting this growth in demand, while safe guarding the environment poses a growing challenge.

Nowadays, generating electricity using decentralized generators of relatively small scale is attracting a great interest from electric energy researchers. Such kind of generation is known as distributed generation systems (DGS) [4] There are two types of distributed generation systems: interconnected and independent. The reliability of the distribution system as well as the quality of the electrical energy can be improved by placing the sources close to the consumers and the efficiency is improved by locally generating electrical and thermal energy [5].

The presence of renewable energy resources at the distribution level allows for improvement of power network performance for meeting the required energy balance between supply and demand, with reduced investment in generating resources and transmission system.

## 2. Methodology

Wind speed, temperature and solar radiation parameters basically categorized into three seasons, namely; cold (December, 2008 and December, 2010), hot (April, 2010 and April, 2011) and Rainy (August, 2010 and July, 2011) seasons; obtained from

Nigerian Metrological Department (NIMET) are used as input to the probabilistic solar and wind models and simulated using Monte-Carlo simulation technique to obtain the optimum site of the DG on an existing power system network within Maiduguri city. Similarly, load flow data obtained from Power Holding Company of Nigeria (PHCN) are used as input to Newton Raphson load flow analysis to obtain power output values. The outputs of Newton Raphson in conjunction with Monte-Carlo simulation techniques are combined in a general power balance equation in which the optimal site and size of the DG are obtained. These processes are achieved using MATLAB 2012 graphical user Interface (GUI).

For this study, PV and wind energy technologies are assumed as the only sources available for injection. Furthermore, the study considers the impact of these sources for the performance of power distribution networks with attention on the variability of the sources.

2.1 Wind Energy Resource

wind is a variable source of energy as is known to fluctuate within seconds therefore, for many of the uses to which electricity is put, the interruption of supply may be highly inconvenient and as such, there should be a form of back up to cover periods when there is insufficient or too much wind available. Various researchers have studied many local wind sites around the country to determine the potentials of wind power for electricity generation. As reported in [6], the annual mean wind speed in Nigeria was found to vary between 2 and 9.5 m/s with an overall annual mean wind speed of 4.62 m/s. for Maiduguri, as reported by [7], the maximum monthly wind speed was found to be 15.78 m/s and the annual mean wind speed was 11.63 m/s. also, the monthly mean power output and accumulated annual energy output were obtained as 15.91 MWh and 13.61 MWh/year respectively.

2.2 Solar Energy Resource

Globally, the amount of sunlight reaching the earth's surface is 6000 times more than the average power consumed by humans [8]. In most places in northern Nigeria, (located at longitude 11.5 degree North and latitude 13.0 degree East), insolation is between 7.2kWhr and 8.3kWhr/m$^2$ per day for about 8 months in a year. Such amount of energy can be harnessed for diverse applications. The states comprising the north east zone of Nigeria have vast land masses that receive huge amount of solar radiation, with a daily average of 5.6kWhr/m$^2$ per day. [9]

2.3 The Wind Energy System Model

The real power output of the wind Energy technology is expressed as:

$$P_m = \frac{1}{2}(\rho.\pi R^2.V^3.C_p) \qquad (1)$$

Where ρ is the air density in (kg/m$^3$), R is the turbine radius in (m), $C_p$ is the turbine co-efficient power conversion efficiency of a wind turbine and V is the wind speed in (m/s). [10]

The introduction to variability of the wind is achieved by statistical analysis of historical data of wind speed over a period of time. This information was sourced from Nigerian Meteorological department (NIMET), Maiduguri international Airport. The wind speed is truly variable depending on the location and time. There are many probability distribution functions that describe wind speed distribution in a particular location. Raleigh and Weibull distributions are the two most widely used [10]. The Weibull distribution is adopted in this study because of its versatility and found to give a better fit with experimental data [10]. Parameters of weibull model can be determined by simultaneously solving the mean and variance equations given as:

$$\bar{v} = \int_0^\infty v f(v)dv = \beta.\Gamma\left(1+\frac{1}{\alpha}\right) \qquad (2)$$

$$\sigma^2 = \int_0^1 (v-\bar{v})^2 f(v)dv = \beta^2\left[\Gamma\left(1+\frac{2}{\alpha}\right) - \Gamma^2\left(1+\frac{1}{\alpha}\right)\right]$$

(3)

The probability density function (PDF) is as expressed in equation (4)

$$f(v) = \frac{\alpha}{\beta}[v/\beta]^{\alpha-1} e^{-(v/\beta)\alpha} \qquad (4)$$

Where α and β are the Weibull shape and scale factors and V is wind speed (m/s), $(\bar{v})$ is the mean and Γ is the gamma function. [10]

2.4 The Solar Photovoltaic System Model

The equation used to model the output of PV panels is as expressed in equation (5).

$$p_{mp} = s/s_{ref}\, p_{mp.ref}\left[1+\gamma(T-T_{ref})\right] \qquad (5)$$

Where s is the incident angle, $p_{mp}$ is the maximum power output, $p_{mp.ref}$ is the maximum power output under standard testing conditions, T is the temperature, $T_{ref}$ is the temperature for standard testing conditions, reference $S_{ref}$ is the Solar reference angle under Standard testing condition = 1000 $Wm^{-2}$ , $T_{ref}$ = $25^0C$ and $\gamma$ is the maximum power correction for temperature.

The variability of the PV source is a function of the solar insolation which is modelled using a beta distribution function [10]. Using historical data obtained for the purpose of this research, parameters of Beta model are obtained by solving equation (6) and (7).

$$\alpha = \mu\left(\frac{(1-\mu)\mu}{\sigma}-1\right) \qquad (6)$$

$$\beta = (1-\mu)\left(\frac{(1-\mu)\mu}{\sigma}-1\right) \qquad (7)$$

Where $\mu$ is the mean and $\sigma$ is the standard deviation of the solar radiation. The corresponding PDF is as expressed in equation (8)

$$f(s_i) = s_i^{\alpha-1} - \frac{(1-s_i)^{\beta-1}}{\Gamma(\alpha)\Gamma(\beta)}\Gamma(\alpha+\beta) \qquad (8)$$

Where $s_i$ is the solar radiation data, $\Gamma$ is the gamma function, $\alpha$ and $\beta$ are parameters of beta distribution obtained by solving equations (6) and (7). [10]

2.5 Load and Feeder Model

Loads in this study are modelled in the form: $S = P + jQ = VI^*$ [11]. Where $S$ is the complex power, $P$ is the real power and $Q$ is the reactive power.

Various probability density functions have been used to model load. The probability distribution function used in this work is the Gaussian/normal probability distribution function which is in the form of equations 9 and 10.

$$P_L \sim N\ (\mu_p, \sigma_p) \qquad (9)$$

$$Q_L \sim N\ (\mu_q, \sigma_q) \qquad (10)$$

Where N represents the normal distribution function, $\mu_P$ and $\sigma_p$ are the mean and standard deviation function with respect to real power; and $\mu_q$ and $\sigma_q$ are the mean and standard deviation function with respect to reactive power.

The distribution feeder model adopted is shown in figure 1. Each branch has the following properties: origin bus, destination bus, impedance per unit length, apparent power installed and load power factor. The source (from the substation) is considered as the swing bus, while the others are considered as load or PQ busses.

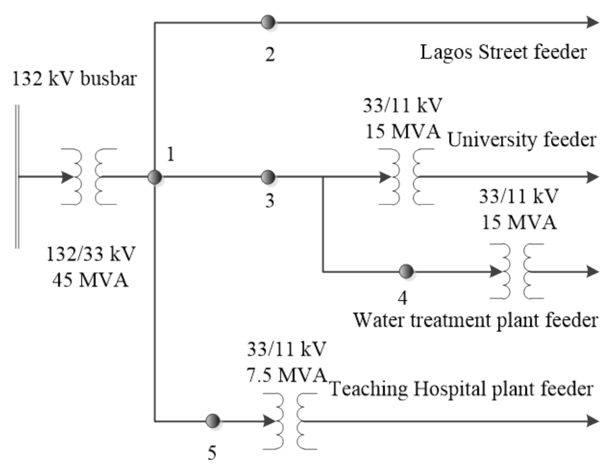


Figure 1: Single line diagram of 33kV line. [12]

*2.6 Monte Carlo Simulation*

In a Monte Carlo simulation, a random value is selected for each of the tasks, based on the range of estimates. The model is simulated based on this random value. The result is then recorded, and the process is repeated. A typical Monte Carlo simulation calculates the model hundreds or thousands of times, each time using different randomly-selected values [13]. When the simulation is completed, one obtains a large number of results from the model, each based on random input values. These results are used to describe the likelihood, or probability, of reaching various results in the model. The flow chart of algorithm for the Monte- Carlo simulation technique is as shown in figure 2

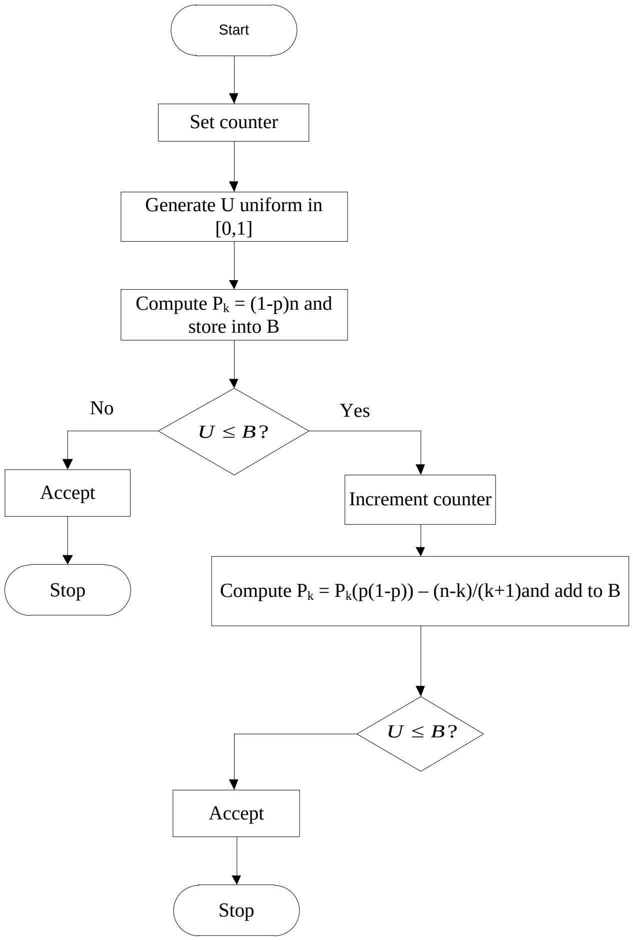


Figure 2: Flow chart of algorithm for Monte Carlo simulation.

2.7 Newton Raphson Load flow Technique

There are basically four types of load flow solution techniques. These are: Gauss Siedel, Newton Raphson, Decoupled and Fast Decoupled load flow techniques. The load flow technique considered for this paper is the Newton Raphson Load flow technique. This is because Newton Raphson method is found to be more efficient and practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluation are required at each iteration.[11] The flow chart algorithm for the implementation of the Newton Raphson load flow technique is as shown in figure 3.

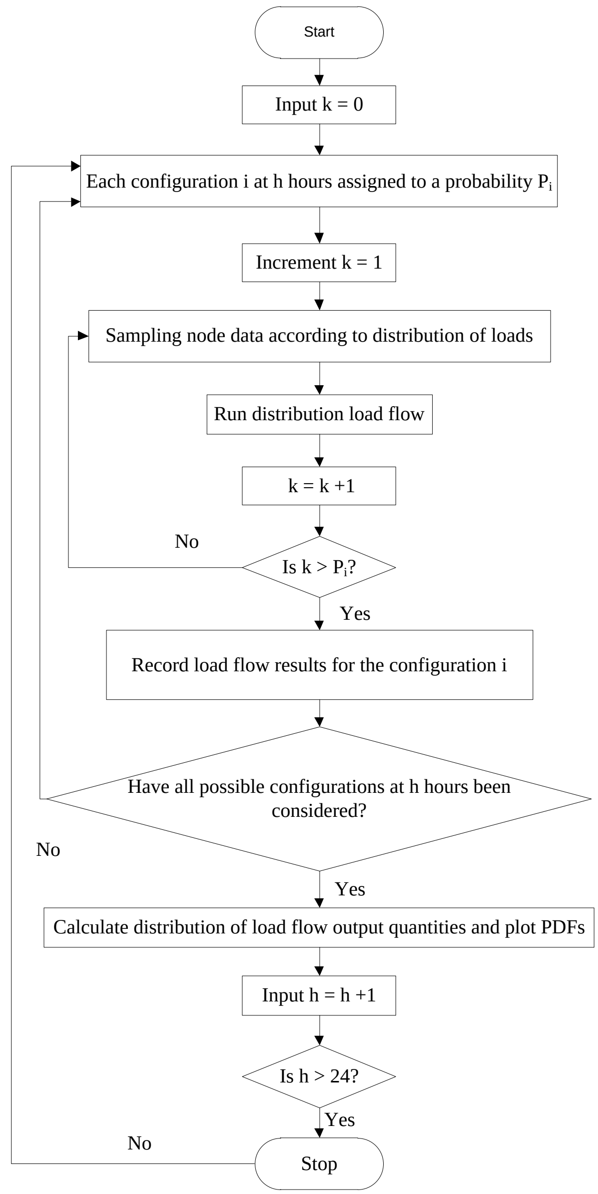


Figure 3: Flow chart of the algorithm for the implementation of Newton Raphson load flow technique

2,8 Loss minimization formulation

A system loss depends on line resistance and currents and is usually referred to as thermal losses. Loss on any distribution system for an N number of busses can be calculated as:

$$P_L = \sum_{K=1}^{N} I_{ij}^2 r_{ij} \qquad (11)$$

Subject to:

Power balance

$$P_{dg.pv.j} + P_{dg.wind.j} - P_{D.j} - P_{loss.j} = 0$$

(Total capacity of DGs)

$$P_{dg.pv.j}^{\min} \le P_{dg.pv.j} \le P_{dg.pv.j}^{\max}$$

$$P_{dg.wind.j}^{\min} \le P_{dg.wind.j} \le P_{dg.wind.j}^{\max}$$

(Voltage constraint)

$$/V_i/^{\min} \le /V_i/ \le /V_i/^{\max}$$

(Current constraint)

$$/I_{ij}/ \le /I_{ij}/^{\max}$$

Where $I_{ij}$ is the current flowing from branch i to j, $r_{ij}$ is the line resistance, $P_{dg.pv.j}$ , $P_{dg.wind.j}$, are the generating output of the PV and wind technologies respectively, $P_{D}$.$_j$ is the real power demanded, and $P_{loss.j}$ is the power loss at bus j in the network[10].

### 2.9 Performance Measure

For the optimal utilization of the Renewable Energy Resources (RERs) within the distribution network, the identification of performance measures is necessary. For this study, the power balance ($P_{bal}$ ) is considered as the primary performance measure. $P_{bal}$ is a derived index which is calculated as the difference between the generation and demand in the network. It is calculated as:

$$P_{bal} = P_{dg.pv} + P_{dg.wind} - P_D - P_{loss} \qquad (12)$$

Where $P_{dg.wind}$ , $P_{dg.pv}$ are the generation output of the wind and pv technologies respectively. $P_D$ is the real power demanded, and $P_{loss}$ is the power loss in the network.

If $P_{bal}$ is negative, this indicates that the demand exceeds the present generation and as such, the loss minimization algorithm will be implemented for the optimal utilization of RER.

The Algorithm for implementation of this research work is as shown in figure 4:

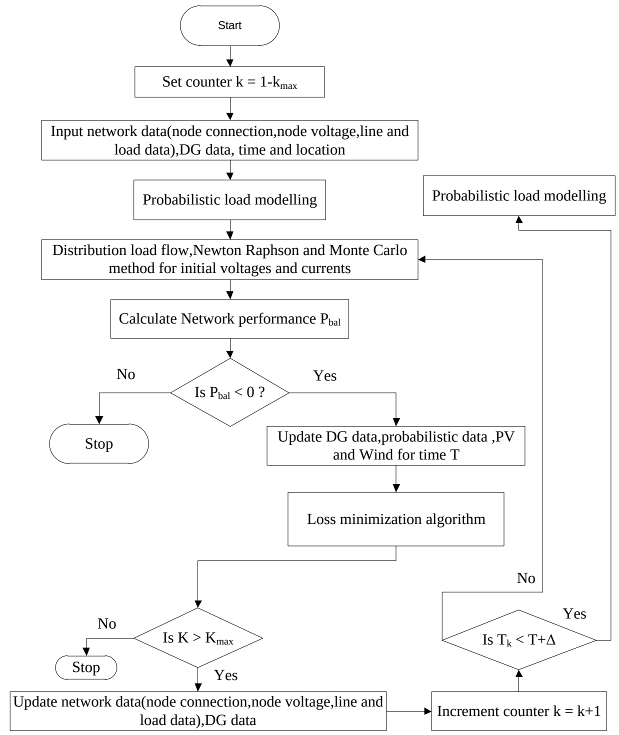


Figure 4: Flowchart of Algorithm for Operational tool

The flow chart algorithm is summarized in the following way:

1 Set counter k=1, kmax, ΔT

2 Input network data which include node connection, node voltages and load data, DG/RERs Data as well as time and location.

3 Probabilistic load modeling by equations 9 and 10.

4 Run monte carlo distribution load flow simulations to determine initial values for voltages, currents, power loss, etc.

5 Calculate network performance index, equation 12

6 If $p_{bal}$<0, then

-update DG data for PV and wind technologies available.(eqns 1-8)

-run loss minimization optimization

Else, End.

7 Check k>kmax, if no, go to 8, else END.

8 Update network data.

9 Increment k, k=k+1.

10 Update time, if TK>T+ΔT, update DG data for time TK, else, go back to 4.

### 3. Results and Discussion

The distribution system used is a 5 bus radial power distribution systems shown in figure 4 with a total load of 30MW and 4.33MVar.The initial total real power loss and reactive power loss in the system are 723.24kW and 430.10kVar, respectively.

In order to locate the best site for the distributed resources in the network system, Monte Carlo simulation technique in conjunction with the Newton Raphson load flow solution were used. After 3 iterations, an optimum position was obtained as shown in detail in table 1

Table 1: Best location, size and power losses

| BUS NODE | RER SIZE (MW) | INITIAL POWER LOSS (KW) | FINAL POWER LOSS (KW) | % POWER LOSS REDUCTION |
|---|---|---|---|---|
| 1 | 15 | 723.24 | 604.0 | 16.49 |
| 2 | 1.0 | 723.24 | 604.0 | 16.49 |
| 3 | 2.33 | 723.24 | 52.0 | 92.81 |
| 4 | 2.0 | 723.24 | 5.0 | 99.31 |
| 5 | 2.0 | 723.24 | 2.0 | 99.72 |

From the output values shown in table 1, the optimum location for the Renewable Energy resources (RER) is node 5 and the corresponding size of RER unit and the total system losses for the given load values are 2.0MW and 2.0kW respectively. The loss was reduced by 99.72% and the voltage profile was improved as shown in figures 5, 6 and 7 for the three seasons. Also, from the NR load flow solution after 3 iterations, the total load of the system is 23.384MW and 13.489MVar. Also, the total real power loss and reactive power loss in the network is 0.662MW and 13.464MVar respectively.

Figures 5, 6 and 7 show the voltage profile waveforms at the compensated node with the RERs inserted in the network, and without the RERs in the network. The waveforms of the three seasons clearly shows the difference in the voltage profile when the RER is not inserted in the network, with the cold season showing the most significant difference. These waveforms are obtained with the two RERs applied to the network. These waveforms clearly indicate that the presence of the RERs in the network certainly improves its voltage profile.

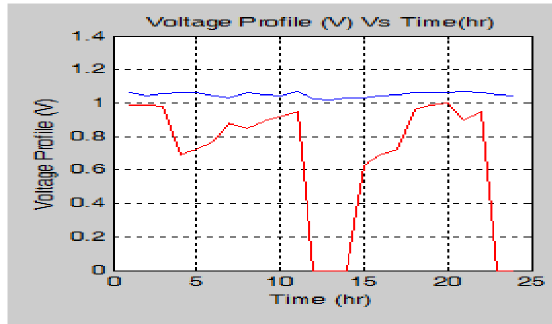


Figure 5: Voltage profile waveform at the compensated node with and without DG with respect to time for cold season.

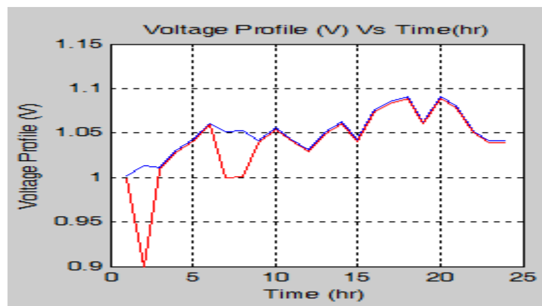


Figure 6: Voltage profile waveform at the compensated node with and without DG per unit time for hot season.

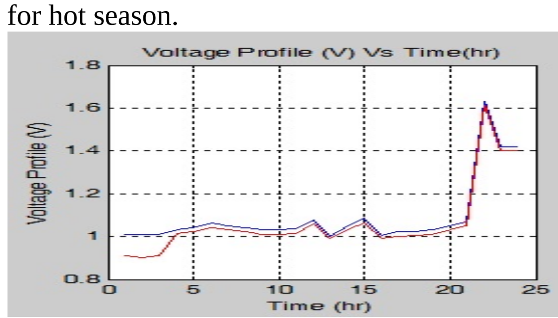


Figure 7: Voltage profile at the compensated node per unit time with and without DG for rainy season.

Figures 8, 9 and 10 show the Probability Density function (PDF) of the wind Energy Technology for Cold, Hot and rainy seasons respectively with respect to time. It shows clearly that the output falls within 10 to 20 on the horizontal axes of the three graphs. These values fluctuate in accordance with the variation of the wind speed, indicating minimum value when the condition is calm and gradually increases with an increase in the wind speed.

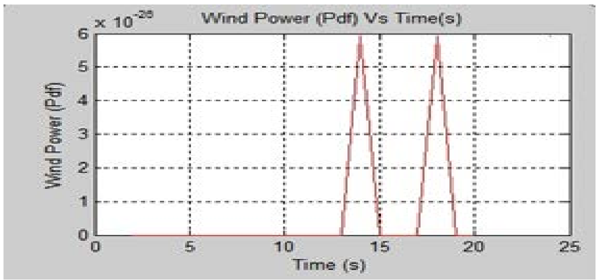


Figure 8: Waveform of PDF of the wind technology with respect to time for cold season

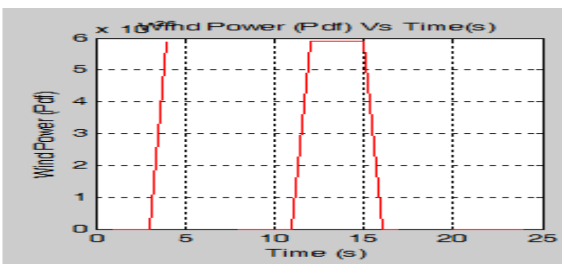


Figure 9: Waveform of wind power PDF per unit time for hot season

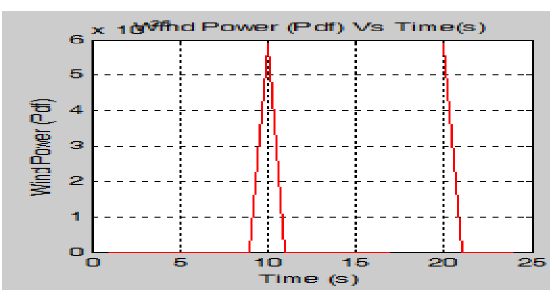


Figure 10: PDF of wind technology versus time for rainy season

Figures 11, 12 and 13 show the waveform of the Probability density function (PDF) of the solar PV with respect to time for cold, hot and rainy seasons respectively. These waveforms clearly shows that the solar PV PDFs all lies on the negative side of the vertical axes (below zero) for the three seasons with most part of that of the rainy season at zero. These waveforms are also dependent on the solar intensity at that particular time. This implies that its almost not possible to obtain an output within the desired region and may not be unconnected with the availability of solar intensity at the particular period being considered for this research.

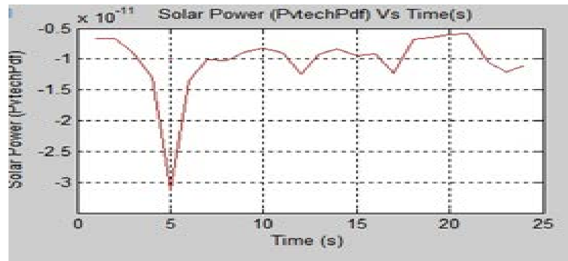


Figure 11: Waveform of PDF of the Solar PV with respect to time for cold season

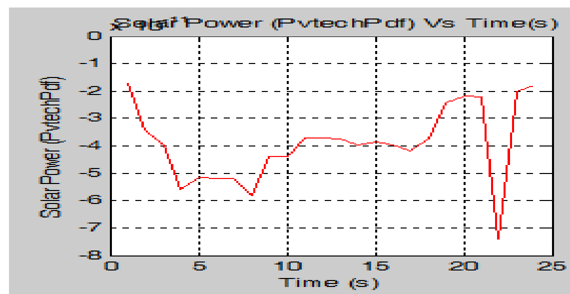


Figure 12: Waveform of Solar PV PDF per unit time for hot season

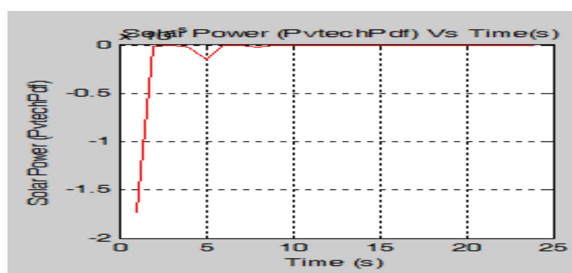


Figure 13: PDF of Solar PV versus time for rainy season

Figures 14, 15 and 16 show the wave forms of the power output by the solar PV per unit time for the cold, hot and rainy seasons respectively. The maximum power output dissipated by the solar PV for the hot and rainy seasons is 2100MW and 1600MW, with a minimum power output of 600MW recorded by the cold season.

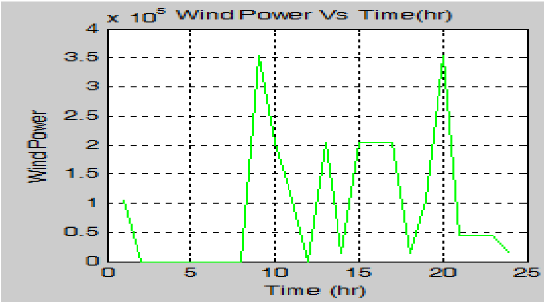


Figure 14: Waveform of power output by the wind turbine with respect to time for cold season

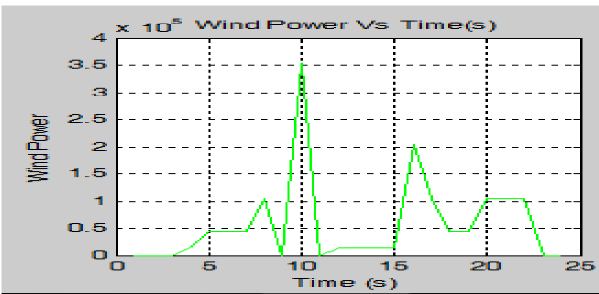


Figure 15: Waveform of wind technology power output per unit time for hot season

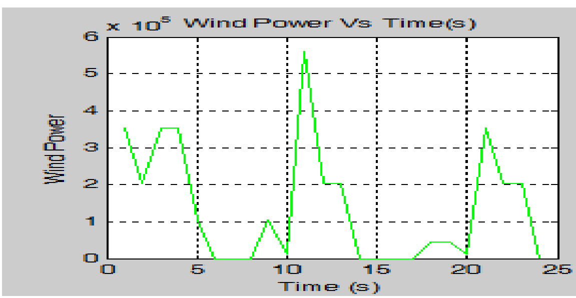


Figure 16: Waveform of wind power per unit time for rainy season

Figures 17, 18 and 19 show the wave forms of the power output by the wind technology with respect to time for cold, hot and rainy seasons respectively, with Wind power output for the cold and hot seasons both approaching 350,000MW and recording a massive 550,000MW for the rainy season.

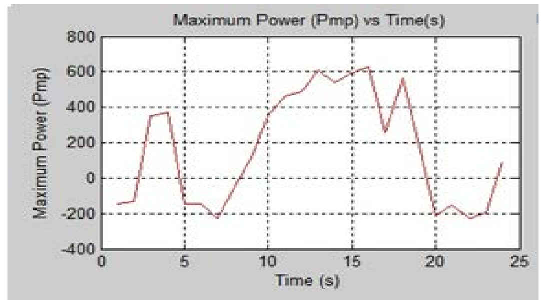


Figure 17: Waveform of power output by the Solar PV with respect to time for cold season

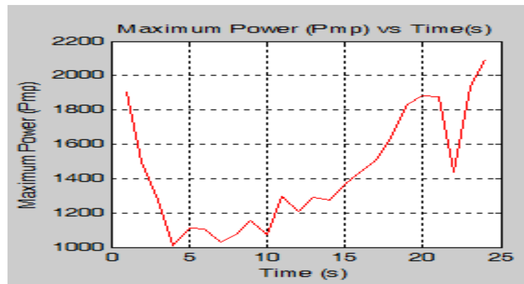


Figure 18: Waveform of Solar PV power output per unit time for hot season

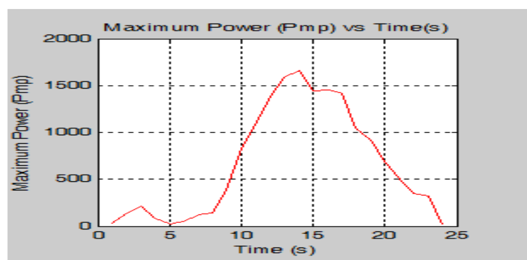


Figure 19: Solar PV power per unit time for rainy season

## 4. Conclusion

This research work has presented an optimization technique for investigating the performance of power networks using renewable energy sources, basically PV and wind technologies. Also, the objectives of the work has been achieved which are to investigate the following

i. Stochastic modeling approach of the PV and wind technologies
ii. Power flow to minimize power losses thereby improving power quality

iii. Power system optimization technique that will be used in the placement and sizing of DG in a power distribution network.

The feasibility and effectiveness of the developed tool has been demonstrated on an existing 33kV line within Maiduguri Metropolis via simulation. The study revealed that the proper placement and sizing of the RERs can have a significant impact on system loss reduction and voltage profile improvement. It also revealed how improper choice of site will lead to higher losses.

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