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Wind Energy Resource Assessment for Selected Locations in Nigeria

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Abstract- Presently, the electricity demand in Nigeria far outweighs the available supply; this imbalance has negatively affected the economy of the country and the social-economic well-being of the population. The country is expected to harness the abundant renewable energy potentials available for the generation of electricity. The electricity market is expected to co-integrate both the conventional generators and the renewable generators into the day wholesale electricity market. This paper carried out a wind assessment study for six selected locations in the Northern Nigeria for the purpose of electricity generation. It is shown from the simulation results that the selected areas have sufficient wind speed in varying capacity but adequate for the generation of electricity.

Index Terms- Deregulation, Renewable energy, Weibull distribution

I. INTRODUCTION

Presently there exists a huge gap between the electricity demand and supply in Nigeria. Nigeria's electricity demand presently is estimated to be about 20GW compared to the meager available generation that fluctuates between 2500MW and 3000MW [1] In an attempt to improve the electricity supply in the country, an electric power sector reform act (EPSRA 2005) was established and passed into law in 2005 and now serves as the roadmap for power sector restructuring and deregulation. Electricity generation in Nigeria dated back as early as 1896 when the first generating station was established in Lagos by the British Colonial Government [2]. Ever since, the electric power sector has evolved through many stages covering a long period of time of more than a century. The Electricity Corporation of Nigeria (ECN) established in 1962 to oversee the generation, distribution and retail of electricity. The Niger Dam Authority (NDA) equally serves the hydroelectric power development in the country. These two institutions were merged together in 1972 to form a new organization known as National Electric Power Authority [3]. NEPA from inception was a vertically integrated public utility with the monopoly of electricity generation, transmission, and distribution within and outside the country. But, with the increase in economic activities over the years as a result of industrial growth, population increase and improve lifestyle; energy demand began to increase steadily without a corresponding increase in supply. Current electricity demand in the country far exceeds the supply from NEPA and this shortfall causes recurrent outages and unreliable power supply to the customers [4]. Nigeria presently has a total installed capacity of 7876.4 MW with only less than 4000 MW available capacity. Poor maintenance, inadequate transmission and distribution networks are some of the factors responsible for the discrepancies in the installed and the available capability in the country. Nigeria has fourteen generating stations located in various parts of the country.

The transmission network is made up of 5000km of 330kV lines and 6300km of 132kV lines with 6098MWA transformer capacity for the 330/132kV network and 8090MWA transformer capacity for the 132/33kV network. The transmission network coverage is very poor with most parts of the country, not covered; the current maximum wheeling capacity is 4000MW. The distribution network is characterized by a weak and inadequate network coverage and overloading of the transformers and lines [5].

The drive for the integration of renewable energy sources (RES) and investment trend has increased over the years [6]. The renewable energy sources available include: solar, wind, hydro, geothermal and biomass [7]. In this paper, we are mainly concerned with the assessment of wind energy in six selected locations in Nigeria. Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth's surface. Seasonal and locational variations in the energy received from the sun affect the strength and direction of the wind. It is possible to convert wind energy to rotary mechanical energy and electrical energy for a variety of uses. In view of the energy available in the wind, there is a need to embark on a wind energy development program. Wind energy is the energy contained in the movement of air in the form of the wind, which can be used to turn the blades of windmills or wind turbines, which in turn could drive electrical generators to produce electricity [8]. Large modern wind turbines operate together in "wind farms" to produce electricity for utilities, while smaller ones can meet localized and smaller energy needs.

The renewable energy development of Nigeria has gone through various policy generations in the last decade with well documented intentions of the government to generate electricity from wind and other renewable sources [9], [10]. The country is geographically divided into the Northern and Southern parts. Wind speed is generally weak (approximately less than 3m/s) on the southern part with the exception of the offshore and coastal regions. The offshore region includes Lagos, Ondo, Delta and Rivers State. The other locations in this region have low wind projection and are generally unsuitable for the development of the wind at commercial quantities. The Northern region experience very strong wind mostly in the hilly parts and this made the region most appropriate for the siting of wind farms for generation of electricity in commercial quantities [11] Hence, the studies of wind assessment and resource of six selected cities, namely: Jos, Kano, Kaduna, Bauchi, Katsina, and Maiduguri were carried out in this paper with the aim of determining the suitability of these locations for the sitting of wind farm for electricity generation.

The key developmental processes to drive the exploitation of the renewable energy in Nigeria includes: the formulation of renewable energy policies for the various RES, the set obejectives of such policies and the strategies for its realisation.

Wind energy policies in Nigeria includes the commercial development of its wind energy resource and the integration of this with other energy resources into a balanced energy and electricity mix. Also, necessary measures shall be taken to ensure that this form of energy is harnessed at sustainable costs to both suppliers and consumers in the rural areas. The nation shall ensure the development of indigenous small-scale wind generating devices and energy storage devices.

The set objectives of the wind energy policies are the development of wind energy as an alternative renewable energy resource. To develop local capability for the country in the wind energy technology and use wind energy for provision of power to rural areas and remote communities far removed from the national grid. The application of wind energy technology in areas where it is technically and economically feasible to feed into the grid.

The strategies for the realization of the wind energy policies and objectives are to encourage research and development in wind energy utilization. Developing skilled manpower for the provision of basic engineering infrastructure for the local production of components and spare parts of wind power systems. Intensifying work in the wind data acquisition and development of wind maps and implement a web-based wind prospecting tool to encourage the implementation of wind projects. Also, the provision of appropriate incentives to producers, developers, and consumers to facilitate the development of wind energy in Nigeria and to promote its usage. [12]

II. MATHEMATICAL MODELLING OF WIND SPEED

The mean wind speed is one of the most important site parameters considered in the wind profile at any given site. The mean wind speed (MWS) is used to gauge the wind potential at a known site for small-scale to the large-scale energy project. The wind speed at height of 10m was used. However, for this research study, other height values were extrapolated for 30m and 60m hub respectively. The mean wind speeds at wind sites were obtained using the equation (1) below:

$$V = \frac{1}{N}\sum_{i}^{N} V_i \qquad (1)$$

where V_i is the wind speed sampling at t^{th} time, and N is the number of wind speed data points.

2.1 Air Density Variation with Height(s)

The air density is another important site parameter considered when assessing the wind potentials at a potential site. The air density at a site has a significant effect on the operation and performance of the WECS. The wind power generation of the WECS is proportional to the air density at height (h), as a function of the atmospheric pressure and air temperature. As the air temperature of 15 °C above the ground level, the density of dry air has a constantly approximated value of 1.225 kg/m3 [13]. Some of the mathematical models available for modeling of the prevailing air temperature and atmospheric pressure are discussed below:

(i) For a known air temperature and atmospheric pressure readings at a hub height h, the air density at the site can be obtained using the equation 2:

$$\rho = \frac{P}{RT} \tag{2}$$

where ρ is the time varying air density at the site, P is the atmospheric pressure, T is the air temperature and R is the molar gas constant.

(ii) When information about the atmosphere pressure and the air temperature readings of the wind site are unavailable, the air density can be determined using the experiential formula proposed in [14]. The mathematical relationship that exists between the air densities for a reference height h is given as [15]:

$$\rho(h) = 1.225e^{-0.001h} \tag{3}$$

where $\rho(h)$ is the varied air density at the considered hub height h. Thus, the determination of the wind profiles at a new height h_2 is crucial because it influences the turbine performance at that height, as well as reducing the life span of the turbine rotor blades due to fatigue [16]. The hub height is related to the wind speed by the mathematical relationship below [15]:

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{4}$$

where v_1 is the reference wind speed at a 10 m hub height h_1; v_2 is the new wind speed at any hub heights h_2; and α is the exponent which depends on the site surface roughness. The characteristic of the selected sites were considered, it varies from open flat terrain, low crop vegetation, no obstacles, occasional large obstacles, and isolated obstacles.

2.2 Weibull Distribution Function

The Weibull distribution is the most widely used statistical distribution which has found various applications in life data analysis; reliability engineering; partial discharge analysis and insulation aging; wind energy study as well as in the modeling stochastic deterioration. [17], [18]. In the wind energy study, the Weibull model is the standard statistical function used among several statistical distribution functions for modeling of the wind speed at a given site [19].

In the modeling of site wind speed using the Weibull distribution function, the wind speed variations are described by using its shape and scale parameters.

The Weibull cumulative distribution function (CDF) is given by [15]:

$$F_w(k,c) = 1 - exp\left[-\left(\frac{v}{c}\right)\right]^k \tag{5}$$

where F_w is the Weibull cumulative distribution function which is used to define the fraction of the time at which an observed wind speed is within a particular speed interval; k is the Weibull shape parameter, and c is the Weibull scale parameter.

The cumulative distribution function (CDF) is given by [15]:

$$f_w(k,c) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{6}$$

where f_w is the Weibull density function (pdf) and is defined as the probability at which the wind speed v prevails at a given site.

2.3 Estimation of the Wind Power Density

The available wind power moving across the rotor blade surface per unit swept area is defined by as [15]:

$$p(v) = \frac{1}{2}\rho(h)V^3 \tag{7}$$

where V is the observed wind speed, $\rho(h)$ is the time varying air density sweeping the rotor blades, and $p(v)$ is the wind power density.

The mechanical power of the WECS is defined by:

$$P_m(v) = C_p \frac{1}{2}\rho(h)AV^3 \tag{8}$$

C_p is the rotor power coefficient and A is the swept area. For accurate wind assessment, the electrical outputs can then be estimated as:

$$P_s(v) = C_p * \eta \frac{1}{2}\rho(h)A\int_0^{\infty} V^3 f(v)dv \tag{9}$$

where P_s (v) is the electrical power outputs of the WECS; $\rho(h)$ is the time varying air density, and $f(v)$ is the Rayleigh and Weibull wind distributions. A is the swept area

III. DATA COLLECTION

There are two major seasons (rain and dry) that influence the wind characteristic in the country. The dry season is heralded by a heap of dust, air mass from the Sahara desert known as the tropical continental air mass, while the rainy season comes as a result of the air mass originating from the far South Atlantic Ocean generally known as the tropical maritime air mass. This seasonal variations are caused primarily as a result of the changes in the wind speed that heavily influence the season. This causes a change in the availability of the wind at a different season in a year, thereby affecting the wind forecasting and prediction for the generation of electricity.

A 30 year (1980-2010) monthly wind data were obtained from the Meteorological Agency of Nigeria for the selected sites as follows: Kaduna (Latitude-10.1590°N, Longitude-8.1339°E, Altitude- 626m), Bauchi (Latitude-10.637°N, Longitude-10.0807°E, Altitude- 616m), Katsina (Latitude-12.5139°N, Longitude7.6114°E, Altitude- 519m), Kano (Latitude-12.0022°N, Longitude-8.5920°E, Altitude- 484m), Maiduguri (Latitude-11.8311°N, Longitude-13.1510°E, Altitude- 325m) and Jos (Latitude-9.8965°N, Longitude8.8583°E, Altitude- 1290m). The cup-generator anemometer located at each site was used to capture the wind-speed data on the height of 10m for the different locations considered.

IV. SIMULATION RESULTS AND CONCLUSIONS

The annual mean wind speeds at height 10m of each locations is shown in Fig.1. The minimum annual mean wind is obtained in Maiduguri with a value of 2.7m/s and maximum value of annual mean speed is computed as 8.05m/s for Jos.

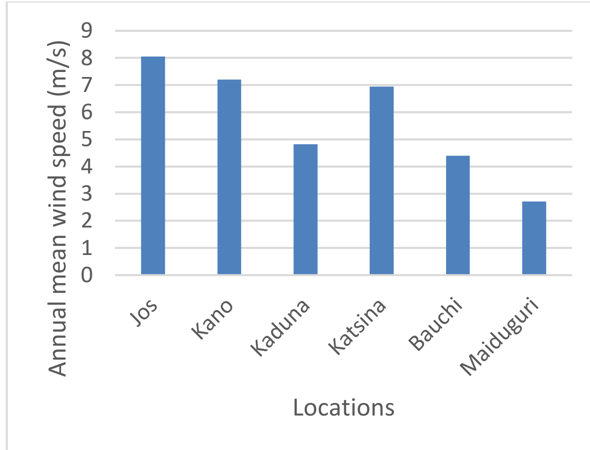


Fig.1 Annual mean wind speed

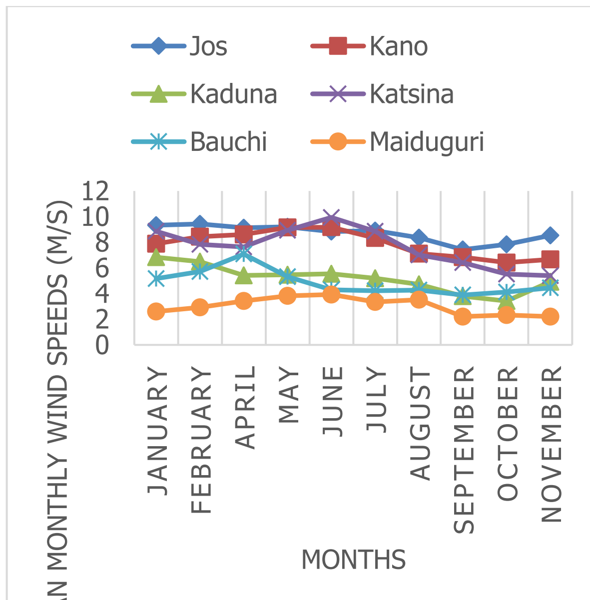


Fig.2. Monthly variation of mean wind speeds for the selected locations

The monthly mean wind speed of the location is as shown Fig.2. The monthly mean wind speed varies for the locations depending on the time of the year.

Table 1 shows the monthly variation of the Weibull parameters of shape (k) and scale (c) for the six selected locations at 10m height. The power densities and average mean power were computed as shown in Table 2 with Jos having the highest power density (PD) of 602.79W/m^2 and mean average energy (AVE) of 447.62kWh/m^2 in January while Maiduguri has the lowest power density of 62.58W/m^2 and average mean energy of 45.26kWh/m^2 in September. According to the international wind power classification, it can be concluded that wind resource in Jos, Kano, Katsina, and Kaduna fall into class 7 ($400< P_D < 1000$) while Bauchi and Maiduguri fall into class 3 ($150< P_D < 200$). Modern wind turbines have cut-in-wind speed in the range of 3m/s and 5m/s for electricity generation to be achieved [20]. Considering the individual categories based on the wind power classification earlier shows that, Jos, Kaduna, Katsina and Kano are thus suitable for the wind energy development, while Bauchi and Maiduguri can be considered as marginal for the development of wind power. Tables 3 and 4 results are the extrapolated variations of the of the Weibull parameters of the selected locations at the other heights.

Table 1. Monthly variation of Weibull parameters (k and c) at 10m height of the selected locations

	Jos		Kano		Kaduna		Bauchi		Katsina		Maiduguri	
	k	c	k	c	k	c	k	c	k	c	k	c
January	4.24	9.85	2.09	8.6	5.89	7.26	2.86	5.69	4.14	9.73	7.88	2.74
February	3.91	9.68	2.97	8.95	4.29	6.97	2.49	6.23	2.89	8.36	4.47	3.26
March	4.51	8.31	3.12	8.6	3.87	6.2	2.14	6.15	3.47	7.12	6.11	3.57
April	6.22	9.35	5.17	9.03	6.52	5.72	2.84	7.72	5.13	8.22	10.46	3.49
May	6.72	10.6	5.1	9.76	6.3	5.73	2.95	5.81	5.72	9.42	7.03	3.96
June	5.33	9.67	3.87	9.86	8.54	2.76	2.47	4.67	5.12	10.48	7.47	4.04
July	5.42	9.73	4.12	9.37	8.22	5.35	2.49	4.52	4.31	9.66	7.34	3.49
August	6.04	8.48	3.76	7.5	6.02	5.06	2.38	4.75	4.72	6.59	1.12	3.68
September	5.16	7.91	4.27	7.2	6.04	4.12	2.32	4.45	2.43	6.52	3.13	2.32
October	4.68	7.16	4.64	6.4	5.31	3.59	2.11	4.52	3.64	6.25	2.12	2.54
November	5.31	6.16	3.42	7.11	5.13	5.29	2.06	4.86	4.47	5.62	5.39	2.32
December	7.43	5.84	3.92	7.89	6.09	6.38	1.91	4.82	3.47	7.64	4.27	2.43

Table 2. Monthly variations of average power densities and average energies for the six locations

	Jos		Kano		Kaduna		Bauchi		Katsina		Maiduguri	
	PD	AVE	PD	AVE	PD	AVE	PD	AVE	PD	AVE	PD	AVE
January	602.79	447.62	410.25	305.43	209.64	156.24	114.23	84.21	561.45	417.35	98.25	75.54
February	542.63	364.8	476.92	322.63	193.47	129.48	158.16	108.54	384.02	256.94	158.36	105.05
March	483.45	362.35	384.63	287.64	142.57	105.64	147.34	128.24	223.78	163.78	169.89	127.47
April	536.47	386.24	406.41	293.78	101.47	73.84	130.34	112.34	305.65	221.39	138.23	103.64
May	473.25	352.73	513.68	381.48	100.73	77.46	89.32	64.12	476.29	360.47	145.87	107.58
June	428.66	309.85	572.62	411.32	101.47	73.49	70.45	50.33	653.2	468.72	171.56	122.21
July	422.12	313.4	415.76	309.48	85.72	63.98	69.58	51.32	500.72	371.86	152.64	111.65
August	370.32	275.94	263.75	198.24	66.4	50.24	71.4	53.25	228.72	169.92	74.56	54.58
September	258.52	187.32	222.18	160.32	38.01	26.87	60.21	45.2	183.14	128.73	62.58	45.26
October	322.24	238.45	178.76	133.63	25.68	20.21	71.51	52.19	166.76	121.03	71.49	53.64
November	461.72	332.39	221.39	160.34	80.42	57.71	114.13	82.87	105.72	76.45	104.58	74.25
December	576.42	431.38	326.12	242.32	140.93	106.45	98.54	74.58	268.15	195.82	80.25	59.54

	Jos		Kano		Kaduna		Bauchi		Katsina		Maiduguri	
	k	c	k	c	k	c	k	c	k	c	k	c
January	4.39	12.31	3.24	12.64	3.62	9.38	3.15	7.38	3.65	11.86	2.92	7.08
February	4.21	11.23	3.32	12.35	5.13	9.12	2.79	8.42	3.42	10.87	2.64	7.32
March	5.48	10.45	3.64	11.89	7.24	8.32	2.47	8.12	5.73	9.45	3.39	7.63

April	4.32	10.13	5.72	12.21	4.12	7.65	3.21	9.87	6.42	10.24	4.67	7.84
May	5.52	11.41	5.75	11.69	8.21	7.61	3.47	7.85	5.83	11.62	3.82	8.15
June	5.74	12.59	4.73	11.39	6.10	7.27	2.63	6.32	4.69	12.34	2.89	7.92
July	4.21	12.32	4.45	11.64	7.33	7.34	2.59	6.04	4.79	11.94	3.16	7.75
August	5.31	10.31	4.38	10.78	7.42	6.75	2.43	6.17	5.34	9.02	3.08	6.67
September	5.32	9.42	4.69	9.72	5.21	5.43	2.12	6.43	4.57	8.85	3.14	5.78
October	4.62	9.89	5.62	10.94	5.13	5.04	2.03	6.04	5.04	7.59	2.34	5.87
November	5.23	9.08	3.64	11.16	5.07	6.92	2.05	6.62	3.72	7.62	2.56	6.21
December	5.12	9.22	4.82	12.32	5.52	8.34	2.58	6.53	3.54	9.72	2.36	5.78

Table 3. Extrapolation of the Weibull distribution parameters k and c at 30m turbine height

Table 4. Extrapolation of the Weibull distribution parameters k and c at 60m turbine height

	Jos		Kano		Kaduna		Bauchi		Katsina		Maiduguri	
	k	c	k	c	k	c	k	c	k	c	k	c
January	5.21	13.11	3.32	13.71	4.12	10.65	3.24	8.71	3.71	12.81	2.81	8.24
February	5.38	12.22	3.24	13.34	5.54	10.34	3.04	9.23	3.35	12.11	2.97	8.72
March	5.84	12.34	3.71	13.56	7.45	9.24	2.62	9.21	4.16	10.65	3.21	8.92
April	4.72	11.89	6.42	13.17	4.62	8.68	3.51	11.12	6.17	11.37	4.12	8.74
May	5.31	11.40	5.78	12.84	8.64	8.29	3.52	8.72	6.82	13.32	3.53	9.24
June	5.76	10.52	4.56	12.32	6.21	8.96	3.03	7.31	6.15	14.54	2.72	9.32
July	5.76	11.42	4.64	12.36	8.48	8.25	2.91	7.22	5.30	13.25	3.42	9.45
August	5..34	12.59	4.79	11.28	7.12	7.32	2.82	7.32	5.62	10.78	3.15	8.72
September	5.28	10.56	5.76	11.71	5.26	6.45	2.13	7.41	5.33	10.23	3.32	7.62
October	4.62	12.36	3.89	11.71	5.31	5.48	2.31	6.72	5.43	9.13	3.06	6.45
November	5.63	10.35	4.12	13.12	4.62	8.62	2.21	7.23	4.03	8.74	2.43	6.72
December	5.71	9.45	4.84	13.69	5.32	9.51	2.36	7.41	4.62	11.32	2.62	7.32

Table 5 shows the seasonal variation of wind characteristics of the selected locations. From the results obtained, Jos has the highest mean wind speed of 8.64m/s during the dry season with an average power density of 585.9W/m^2 in the rainy season. Maiduguri has the lowest mean wind speed of 2.62m/s measured at 10m height. The other locations mean wind speed varies too, according to the season. The duration of each season varies depending on the location. The rainy season starts early in April and ends in September, while the dry season covers nearly the same period of October to March or May depending on the location

Season	Mean-wind speed (10m)	k	c	Average-power density(W/m^2)	Monthly-seasonal (duration range)
Jos					
Rainy	8.64	5.79	9.29	585.9	April- September
Dry	8.98	5.23	7.8	498.21	October-March
Kano					
Rainy	8.12	4.38	8.78	333.01	May- September
Dry	7.5	3.35	7.91	399.06	October- March
Kaduna					

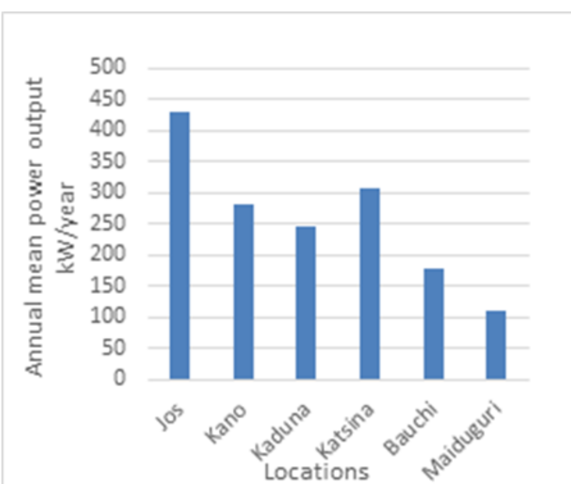
Rainy	4.56	6.94	4.79	82.3	June-September
Dry	5.59	5.09	5.94	132.12	October- May
Katsina					
Rainy	8.14	4.56	8.48	391.29	June-September
Dry	6.87	3.67	7.4	284.18	October- May
Bauchi					
Rainy	4.84	2.58	5.32	107.84	June-September
Dry	4.8	2.26	5.38	94.82	October- May
Maiduguri					
Rainy	2.81	6.09	3.5	124.21	June-September
Dry	2.62	5.04	2.81	113.81	October- May

Table 5. Seasonal variations of wind characteristics of the six sites for the period

Jos has the highest output of 430kW/year compared to other locations. This is closely followed by Katsina and Kano with 307kW/year and 282kW/year respectively. Bauchi and Maiduguri have an estimated energy output of 179kWh/year and 109kWh/year respectively. The total annual power output of the wind turbine in the selected locations is 1.5MW/year.

Table 6. Characteristics of the selected wind turbine

Characteristics	Rating
Hub height (m)	60
Rated Power (kW)	1000
Rotor diameter (m)	56
Number of blades	3
Sweep area (m^2)	2300
Design life (years)	25
Cut-in Speed (m/s)	3
Rated wind speed (m/s)	15
Cut-off wind speed (m/s)	25



CONCLUSION

The analysis of the results obtained in this paper shows that the Northern part of Nigeria has high wind potential and it's geographically well situated for setting up of wind farms in the country. The energy from the wind can be harness for the generation of electricity in the country for the purpose of achieving the renewable energy policy and to equally increase the generation capacity of the country towards meeting the present and future electricity demand. The wind farms power output can also be transmitted over long distance transmission lines and synchronized at a certain voltage level with the other existing traditional mode of electricity generation such as thermal and hydro for integration into the national grid.

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