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Wind Energy Potential in Nigeria

Agbetuyi A. Felix, Akinbulire T.O, Abdulkareem A, Awosope C.O.A

Abstract— Wind energy is one of the fastest growing technologies in energy generation industry nowadays. The erratic and epileptic state of power in this country and the concern about global warming should be a great concern for all and should drive us into strong demand for wind generation. The main advantages of electricity generation from wind are the absence of harmful emissions, very clean and the almost infinite availability of the wind that is converted into electricity. In Nigeria, where the wind power prospect is estimated to be high or moderate has not connected this renewable resources to the grid. It is not just enough to say that the wind turbines should be connected to the grid because there are sufficient wind speeds to drive the wind turbine. Mostly, the stability and reliability studies must be carried out whenever wind power is to be connected to power system to predict severe consequences on the power system to which the wind generators will be connected.

This paper therefore describes the wind energy potential in Nigeria and specifies the conditions to be met before the wind generator can be connected to the existing grid and how it can be connected. The paper also shows that short-circuit power at Point of Common Coupling (PCC) is the crucial value for the permissible installed power ratings of the turbine.

***Index Terms*— Grid, Power System, Reliability, Stability, Wind farm, Wind power integration.**

I. Introduction

Energy has a major impact on every aspect of our socio-economic life. It plays a vital role in the economic, social and political development of our nation [1]. Despite the abundance of energy resources in Nigeria, the country is still in short supply of electrical power. Only about 40% of the nation's over 140 million has access to grid electricity [2]. Even the electricity supply to the consumers that are connected to the grid is erratic. There is therefore the need to harness renewable energy potential (such as wind, solar e.t.c) for reliable power supply in this country. Also the concern about global warming and continued apprehensions about nuclear power around the world should drive us into strong demand for wind generation.

Wind turbine converts wind energy into electrical energy, which is fed into electricity supply system.

The main advantages of electricity generation from renewable energy sources, such as wind, are the absence of harmful emissions, very clean and almost infinite availability of wind that is converted into electricity [3].

Wind generation has been described to be one of the mature and cost effective resources among different renewable energy technologies [4].Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth's surface [5]. Wind is a classical example of a stochastic variable; due to this stochastic nature, wind energy cannot be controlled, but can be managed. This is because wind power is available only when the wind speed is above a certain threshold [6].

This paper therefore describes the wind energy potential in Nigeria and the conditions to be met before the wind generator can be connected to the existing grid and how it can be connected. The effect the new generation source might have on the existing power network will also be discussed.

A.F Agbetuyi is with Covenant University, Canaanland, Ota, Ogun State, Nigeria.
E-mail: ayo.agbetuyi@covenantuniversity.edu.ng
T.O Akinbulire is with University of Lagos, Nigeria.
A. Abdulkareem is with Covenant University, Canaanland, Ota, Nigeria. E-mail: adekaree@gmail.com
C.O.A Awosope is with Covenant University, Canaanland, Ota, Nigeria.E-mail: coaawosope@yahoo.co.uk

II. POWER IN THE WIND

The theoretical power in the wind is given by [7]-[14]

$$P_{ae} = \frac{1}{2}\rho\pi R^2 V_{eq}^3 C_p(\theta_{pitch}, \lambda) \quad (1)$$

where P_{ae} is the aerodynamic power extracted from the airflow [Watt],

ρ is the air density [typically 1.225Kg/m^3]

C_p is the power coefficient which is the fraction of power in the wind captured by a wind turbine, which depends on the pitch angle θ_{pitch} [degree] and on the tip speed ratio, is given by

$$\lambda = \omega_{rot}.R/V_{eq} \quad (2)$$

i.e it is the ratio between the blade tip speed ω_{rot}*R and the equivalent wind speed V_{eq} [m/s^2],

R is the rotor radius; ω_{rot} *is the rotor speed.*

C_p is equal to 0.59 which means, the 59% of wind power is the maximum power that a wind turbine can utilize.

Equation (1) shows that the power which a particular wind turbine can extract from wind is a cubic function of the wind speed.

Once the aerodynamic power is determined, the aerodynamic torque can be calculated directly according to

$$T_{ae} = \frac{P_{ae}}{\omega_{rot}} = \frac{1}{2\lambda}\rho\pi R^3 V_{eq}^2 C_p(\theta_{pitch}, \lambda) \quad (3)$$

The mechanical input can be chosen as either the mechanical power or the mechanical torque, and then the other quantity can be calculated using equation 3 [15].

III. WIND ENERGY POTENTIALS IN NIGERIA

The technologies for harnessing wind energy have, over the years, been tried in the northern parts of the country, mainly for water pumping from open wells in many secondary schools of old Sokoto and Kano States as well as in Katsina, Bauchi and Plateau States.

Other areas of “potential application” of wind energy conversion systems in Nigeria are in Green electricity (which is the type of electricity produced from renewable source that is environmentally friendly and non-polluting) production for the rural community and for integration into the national grid system.

In 1998, a 5-kW wind electricity conversion system for village electrification has been installed at Sayyan Gidan Gada, in Sokoto State [16].

According to the report of Lahmeyer (International) Consultants [17], wind energy reserve in Nigeria at 10m (or 40m) height based on data analyzed for ten wind stations cutting across North West, North East, North Central, South East and South West geopolitical zones shows that some sites have wind regime between 1.0 and5.1m/s (1.0 and 6.3m/s) depending on the particular stations, and still confirms that Nigeria falls into the moderate wind regime.

Table I shows data of wind energy resources mapping for ten (10) sites in Nigeria including Sokoto collected from on ground measurement carried out between May 2004 and May 2005 also by Lahmeyer International. It can be seen from the table that the sites are potential wind farm areas. This is because most wind turbines start generating electricity at wind speeds of around 3-4 meters per second (m/s) [18].

The bar chart of Table I is also shown in figure 1

It was reported that offshore areas from Lagos State through Ondo, Delta, Rivers, Bayelsa to AkwaIbom states also have potentials for harvesting strong wind energy throughout the year.

Detailed wind speed measurements and data carried out in Nigeria in some hilly and coastal areas have shown an excellent wind potential for implementation of wind farms in those areas.

Table II below shows the wind energy density estimate at 25m height. It can also be seen from the table that Sokoto and Jos have the annual wind energy from wind turbine (kWh) of 97,035.94 and 94,559.98 respectively [19]. These figures are also in agreement with Ojosu and Salawu survey of wind energy potentials in Nigeria [20].

A number of authors [19] - [23] recommended base on the wind speeds that these potential wind farm areas should be connected to the grid (at Distribution level).

The Director General of Energy commission of Nigeria in a Paper presented at International Association for Energy Economics Third quarter 2009 [21] still lamented that these renewable Energy resources most especially wind have not been integrated to the Nigeria grid.

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Table I. showing ranking of the wind speed at various measurement stations [17].

Site ID	Site Name	Measured mean wind speed at 30m Height (m/s)
Sok 01	**Sokoto/Badaga**	**5.4**
Jos 01	**Jos Airport/ Kassa**	**5.2**
Gem 01	**Gembu/Mambila plateau**	**5.0**
Pan 01	**South part of Jos plateau/Pankshin Hotel**	**5.0**
Kan 01	**Kano/ Funtua**	**4.9**
Mai 01	**Maiduguri/mainok**	**4.7**
Lag 01	**Lagos/ Lekki Beach**	**4.7**
Enu 01	**Enugu/Nineth mile corner**	**4.6**
Gum 01	**Gumel/ Garki**	**4.1**
Ibi 01	**Ibi metrological station**	**3.6**

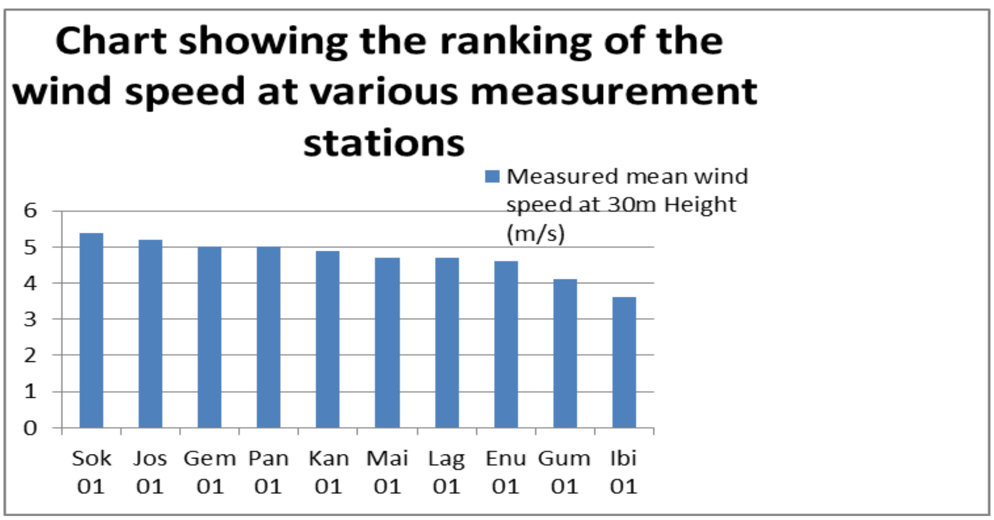

Figure 1: Chart showing ranking of the wind speed at various measurement stations

S/N	Station	Mean wind speed at 25m Level (m/s)	Monthly mean Wind Energy (kWh)	Annual Wind Energy (kWh)	Annual Wind Energy from a Wind Energy Turbine (kWh)	
					10m Blade Diameter	25m Blade Diameter
1	Benin City	2.135	2.32	27.86	2,187.81	13,673.78
2	Calabar	1.702	1.12	13.42	1,053.69	6,587.53
3	Enugu	3.372	7.83	93.91	7,375.75	46,097.96
4	Ibadan	2.620	4.15	49.78	3,.909.79	24,436.19
5	Ilorin	2.078	1.23	14.73	1,157.06	7,230.57
6	Jos	4.430	16.05	192.64	15,129.60	94,559.98
7	Kaduna	3.605	9.91	188.88	9,36.81	58,355.08
8	Kano	3.516	8.57	102.86	8,078.61	50,491.28
9	Lagos(Ikeja)	2.671	4.36	52.32	4,099.78	25,682.52
10	Lokoja	2.235	2.60	31.21	4,451.23	15,320.17
11	Maiduguri	3.486	8.42	101.01	7,933.61	49,583.17
12	Minna	1.589	1.05	12.60	989.60	6,185.01
13	Makurdi	2.689	4.44	53.27	4,183.51	26,148.85
14	Nguru	4.259	14.48	173.74	13,645.19	85,284.42
15	Oshogbo	1.625	1.07	12.81	1,006.60	6,288.09
16	P.H.	2.640	4.17	49.98	3,925.48	24,533.88
17	Potiskum	3.636	9.44	113.25	8,894.35	55,591.46
18	Sokoto	4.476	16.47	197.68	15,525.75	97,035.94
19	Warri	2.027	2.02	24.20	1,.900.66	11,879.15
20	Yelwa	3.360	7.76	93.13	7,314.88	45,714.59
21	Yola	1.824	1.45	17.34	1,361.88	8,511.75
22	Zaria	2.891	5.32	63.88	5,017.26	31,357.02
	Total		**134.23**	**1,680.5**	**120,078.9**	**790,548.39**

Table II showing Wind Energy Density Estimates at 25m Height [19].

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IV. INTEGRATING WIND ENERGY GENERATORS TO THE GRID

The first issue in integrating any level of wind generation into power system is siting suitable locations for new wind farms. It is important to state that the ability of a site to sufficiently accommodate wind generation not only depends on wind speeds (as shown in the tables above) but also on its ability to interconnect to the existing grid [24].

A number of literature works argue that the connection of wind turbines into the electric grid may influence or affect power quality and /or stability of the system due to the [25] - [28]

- random nature of the wind
- characteristics of the generators technology used.

For the reasons stated above, it is important to predict the impact of the wind turbines on the electric grid before the turbines are installed or connected at distribution level. It is not just enough to say that the wind turbines should be connected to the grid because there are sufficient wind speeds to drive the wind turbine. Mostly, the stability and reliability studies are carried out whenever wind power is to be connected to power system to predict severe consequences on the power system to which the wind generators will be connected [29].

When the aim of any research is to investigate grid integration of wind turbines, there are three main interests [10, 16]. These are

- Steady-state voltage level influence.
- Flickers which are commonly due to rapid changes in the load or the switching operations in the system.
- Response to grid disturbances/faults (Stability).

As a piece of advice, the Energy Commission of Nigeria (ECN) should sponsor research on the three points listed above as a follow up to the existing energy policy. The results that will be obtained from the research will make us to emphatically say that some wind farm sites should be connected to the existing distribution grid.

A. One-line diagram of wind farm connection to a grid.

Figure 2 illustrates an example of one-line diagram of wind farm connected to a grid. Wind farm is connected to the network with equivalent short-circuit impedance, Z_k. The network voltage at the assumed infinite busbar and the voltage at the PCC (Point of Common Coupling) are U_s and U_g, respectively. The output power and reactive power of the wind farm are respectively Pg and Qg. The corresponding current is Ig.

PCC is the point of connection of wind turbine with the existing system.

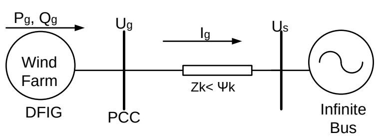

Figure 2 One-line diagram of wind farm connected to a grid [16]

From the one-line diagram,

$$I_g = \frac{U_g - U_s}{Z_k} = \frac{P_g - JQ_g}{U_g} \quad (4)$$

$$U_g - U_s = \Delta U = Z_k I_g \quad (5)$$

where ΔU is the voltage difference between the infinite bus and PCC.

But

$$Z_k = R_k + jX_k \quad (6)$$

Then

$$\Delta U = \frac{R_k P_g + X_k Q_g}{U_g} + \frac{j(P_g X_k - Q_g R_k)}{U_g}$$
$$= \Delta U_p + j\Delta U_q \quad (7)$$

Refer to equation (7), the short-circuit impedance, the real and reactive power outputs of the wind farm determines the voltage difference, i.e. the variations of the generated power will result in the variation of the voltage at PCC.

B. What makes a grid strong or weak?

In the literature regarding integration of wind turbines into the power system, the existing grid is often classified as weak or strong [30].

When the impedance Z_k , in figure 2 above, is small, then the grid can be said to strong and when Z_k is large, then the grid can be said to be weak. Since the terms “strong” and “weak” are relative concepts, then for a given electrical wind power capacity P, the ratio [16], [30],

$$R_{sc} = \frac{S_{sc}}{P} = \frac{U_s^2}{Z_k P} \quad (8)$$

where R_{sc} is the short-circuit ratio and S_{sc} is the short-circuit power.

Refer to (8), **the short-circuit power at PCC is the crucial value for the permissible installed power ratings of the turbine.**

The grid may be considered as strong with respect to the wind farm installation if Rsc is above 20 and weak if Rsc is below 20. It is obvious from equation 8 that short-circuit ratio is directly proportional to the voltage at assumed infinite bus and inversely proportional to the impedance between source and load.

If the impedance is larger, then fault level (S_{sc}) will be less, so will be the short-circuit ratio and the grid will be considered weaker [30].

This according to [30], [31] will restrict the possible connection/installation of the wind turbines to the distribution system due to two factors: **operating voltage levels and voltage flickers.**

Also for large wind farm-grid connections, the PCC voltage level has to be as high as possible to limit voltage variation [16].

C. How then are wind generators connected to the grid?

There are two ways according to [32] in which a wind generator can be connected to the grid:

a) Parallel interconnection
b) Roll-over

- In parallel interconnection, the wind generator and the grid are always connected to the load and to each other. If the wind generator supplying fails, the grid instantaneously takes over and therefore avoiding interruption of power flow to the load due to unexpected failure. This procedure applies equally when the grid source fails. **But in order to parallel wind energy system to the grid, a main requirement is the limitation of voltage deviation caused by the wind systems at the PCC, for which ±2% of the nominal voltage is a commonly established limit.**
- In roll-over mode, only one of the two sources is connected to the load at a time. This operates in such a way that if one fails then a human being (slower) or an automatic sensor operates the switch so that it changes or connects the load to the other supply which is not faulty. This implies that if wind does not blow, then back-up supply from other power stations must supply the load.

V.Conclusion

The efficient integration of wind generators into electrical interconnected power system is very necessary in order to enjoy green electricity (which is the electricity produced from renewable sources that are environmentally friendly and non-polluting) production.
This paper in particular is drawing our attention to the fact that the ability of a site to sufficiently accommodate wind generation not only depends on wind speeds but its ability to interconnect to the existing grid. If integration of wind power into the existing grid will bring new challenges because of the fluctuating nature of the wind and comparatively new types of its generators, then research work on the impact of this new generation (wind) on the existing grid should not also be neglected. If the wind generator is to be connected to the grid, the voltage and the frequency limits of the consumers must not be compromised. The overall purpose of the power system operation, independent of wind power generation level, is to supply an acceptable voltage to consumers and continuously to balance production and consumption.
Sponsored research on the stability and reliability studies need to carried out whenever wind power will be connected to power system to predict severe consequences on the power system to which is to be connected.

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