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The Wind Powered Generator

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Abstract: *The inability of Nigeria's electricity power company (PHCN) to meet the demands of Nigerian consumers necessitates an aggressive search for alternative energy supply. There are many wind catchment sites at various locations in this country. In this paper the possibility of using wind power to feed isolated loads and/or being synchronized with the public supply is discussed. Before that, the principle of operation of wind powered generator is discussed. At the end, possible sites, within Nigeria, where the wind powered generator can be installed, to achieve optimum result, are highlighted.*
Keywords*: Wind powered generation, CSCF machine, wind catchment area, VSCF machine,*

I. Introduction

The wind mill was used in agriculture, in olden days, to pump water in farms and to drive mechanical loads. Today the wind mill is staging a come back in a big way since modern technology has transformed it into a more useful machine.

The wind turbine is simply a device for converting the power in the wind to mechanical energy, at the first stage. At the second stage, the mechanical energy is converted to electrical energy. At the first stage, mechanical loads such as water pumps, grinders, etc, can be coupled to the rotating shaft of the machine. At the second stage, electricity generated can be used to drive electrical loads. More than one machine can be used to drive large loads when they are connected in a special way (paralleling)

II. Principles Of Operation

The power in the wind, $Pw=mK_E$
$=mv^2/2kc$ (1)
Where K_E is the kinetic energy of the wind stream,
m is the mass flow rate (kg/s)
v= velocity of the wind (m/s) and
k_c= conversion factor
The mass flow rate, $m = \partial AV$ (2)
Where;
∂=density of the wind
A= cross sectional area of the wind stream.
Substituting value of m in eqn(1),
$Pw=\partial aV^3/2Kc$ (3)
If maximum power, $Pmax=8\partial AV^2/27Kc$
Then maximum theoretical efficiency, $\eta_{max}=Pmax/Pw=8x2Kc/27Kc= 16/27=59.3\%$ (4)
The real efficiency, η =Actual output power, Pa/input power, Pw
Or $Pa=\eta Pw=\eta\partial AV^3/2Kc$ (5)
And η varies between 30% and 40%.

III. Forces On The Blades

There are two forces acting on the propeller type blade: the axial force acting in the direction of the wind stream and the circumferential forces acting in the direction of rotation of the turbine wheel. The circumferential force, Fc , is responsible of producing the rotational torque.

The circumferential torque, $T_c = {P_a}/{\pi \mathrm{DN}}$ (6)
Where P_a= actual power output
D= diameter of the rotor shaft=$\sqrt{4\mathrm{A}/\pi}$
N=speed (m/s) and
A= cross sectional area of the shaft.
For the machine of eqn(5), circumferential torque, $T_c = \pi DV^3/8kc$ (7)
The axial thrust, $F_a = \partial \mathrm{A}\left(\mathrm{V}^2 - \mathrm{V_0}^2\right)/2\mathrm{k_c}$ (8)
Where:

V=input velocity
V_0= exit velocity

IV. Mean Wind Energy

The mean wind energy can be calculated from the mean wind speed measured at different intervals.

Mean wind speed, $V_{av} = (\sum_1^n V^3/n)^{1/3}$ (9)

Where **n** is the number of observations

Mean wind energy, $E_m = p_m t = \partial at V_{av}^3 / 2k_c$

$$= \partial at \left((\sum_1^n V^3/n)^{1/3} \right)^3 / 2k_c \quad (10)$$

Where t=consumption interval,
P_m= mean power.

The wind energy conversion system consists of ;
1.The aerodynamic system which receives the wind power, Pw and converts it to mechanical power, Pm,
2.Mechanical transmission system where mechanical power is converted to electrical power, Pg and
3.The electrical system where the generated power is processed to suit electrical load.
Fig1 shows the components of the wind conversion system where K_1, K_2 and K_3 are conversion factors.

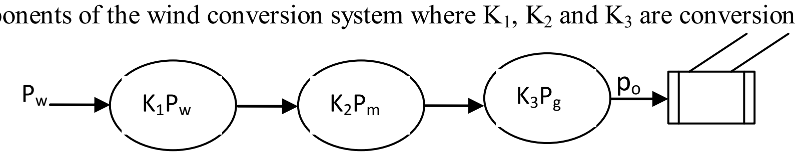

Fig 1: The wind energy conversion system

The power in the wind, Pw is converted to mechanical power, P_m by the aerodynamic system. K1 is a factor which determines the efficiency of conversion and depends on the type, shape and nature of the aerodynamic system

So $P_m=K_1P_w$. Similarly, K_2 and K_3 are factors which determine the efficiency of conversion from mechanical to electrical and from generated electrical power to processed power output respectively; $k_2P_m=P_g$ and $P_o=k_3P_g$.

So total power output from the wind turbine, $P_o = (k_1P_w)(k_2P_m)(k_3P_g) = k_1k_2k_3P_w$ *watts* (11)

There are two basic techniques:

(i) To keep both the turbine speed and frequency constant by manipulating the generator characteristics or adjusting the turbine blade pitch. This system is referred to as constant speed, constant frequency system (CSCF).

(ii) To keep the frequency constant while the speed varies (with power output). This model is called the variable speed, constant frequency system (VSCF).see fig2 for the power- duration curves.

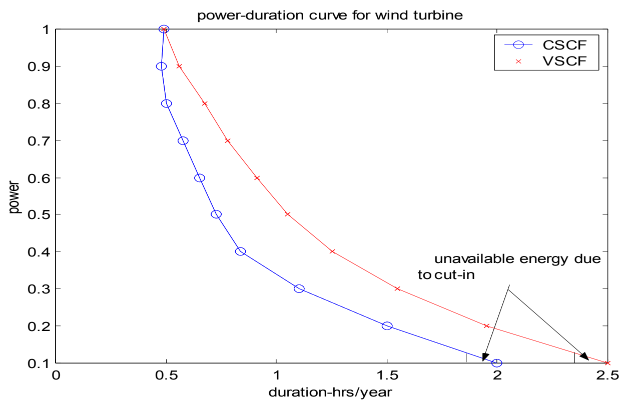

Fig2: Power-Duration curve for wind turbine

IV. The Constant Speed Constant FREQUENCY (CSCF) SYSTEM

The wind strikes the aerodynamic system, and since the wind speed varies, the turbine rotor speed varies also, resulting in variable output. The pitch of the turbine blade can be adjusted to maintained constant

speed irrespective of the wind speed. The frequency of the machine may vary as the wind speed because the machine is connected to a d.c exited alternator but when the machine is synchronized to the grid, the grid frequency toes it's varying frequency. Therefore the wind turbine must be made to run at synchronous speed, Ns=f/p. where; f=output frequency and P=number of pairs of poles.
Induction machines are usually used as wind turbine generators. They maintain fairly constant speed at lower slip. When operated above synchronous speed (negative slip) the induction machine becomes a generator and when connected to the grid, it runs at grid frequency.

V. Variable Speed Constant Frequency (Vscf)

In this technique, the ratio, turbine rotor speed (N_r) /wind speed (N_w), determines the conversion factor,K_1. The machine's rotor is allowed to run at the wind speed. That is, N_r is proportional to N_w. When K_1 is maximum, there is maximum efficiency of conversion from wind energy to mechanical energy. Since constant frequency is required, the output of the machine is rectified and fed to an inverter tuned to produce constant frequency. VSCF machine is more reliable but more expensive due to additional electronics circuitry (for rectification and inversion) than the CSCF machine

Another version of VSCF machine is an alternating voltage excited generator which produces amplitude modulated output. The rotor speed, $Nr=LN_w$. Where L=loss factor. So the modulated output power is made up of fr+fs and fr-fs components. Where fr=rotor frequency and fs=system frequency used for excitation. The power-duration curve of the systems is shown in fig2.

VI. Materials And Methods

Induction machines used for electric power generation can be either dc excited or ac excited. In dc excited system, at normal excitation, the reactive component is small, but when over excited, the reactive power increases at the expense of the active power. With ac excitation, the power output is a modulated wave with frequencies fr+fs and fr- fs as mentioned earlier. To maintain constant frequency, the power output is rectified and fed to an inverter which is tuned to produce constant output frequency. Another approach is to use a dc generator whose output is regulated and fed into an inverter tuned at grid frequency. The latest development is the introduction of double induction generator (DOIG) where the slip rings supply the slip frequency. The line cumulated inverter produces one output while the other output is derived from the stator.

VII The Aerodynamic System

There are two basic types of aerodynamic system; the vertical axis machines and the horizontal axis machines. See figs. A 1 and 2 in appendix.
In horizontal axis machines, the starting force, $F_s = kF_{wm} + F_g$ (12)
Where: k= factor, F_{wm}= Maximum force produced by the wind and F_g= gravitational force (9.81N). Horizontal machines using propeller blades do not have starting problems when they are properly oriented. They start at minimum wind speed. The vertical axis machines do not need to be oriented to the wind direction before their vanes can freely rotate. The effect of gravity is negligible on them unlike the horizontal axis machines.

VIII Possible Sites For Wind Powered Generator In Nigeria

Nigeria has only few meteorological centers and unfortunately records seen so far about wind energy and speed are not very comprehensive.

For the three meteorological centers considered here, PortHarcourt, Bauchi and Akure; PortHarcourt and Bauchi readings are based on Beaufort scale and wind speeds were not checked on hourly bases. This could give room for inaccuracies more so when conversion is to be made from the beaufort scale to the actual values. At Bauchi center, readings were taken for thirteen years while at PortHarcourt center; readings were taken for fourteen years. At Akure center, readings were taken in actual values but for only two years and again, readings were not taken on hourly bases. Unfortunately, as at the time of investigation, no meteorological center is located in any of our beaches; PortHarcourt, Lagos, Calabar, etc which are good wind catchment sites.
In actual fact, there is no part of Nigeria where the wind turbine cannot work but there are some sites that can be used as medium or large wind farms: An example of areas for large scale wind farms are all the beaches in the country, some areas in Bauchi and Sokoto where the mean wind speed are high (2.32-5.2m/s). Some of the high lands in various parts of the country and some part of the riverrine areas can serve as medium scale wind farms.

IX . Viability In Nigeria

Nigeria generates her electricity power from two major sources-hydro and gas. There are three hydro stations at Kainji, Jebba and Shiroro with total installed capacity of 1,936 Mw. The rest are predominantly thermal/gas stations located at Afam, Sapele, Ogorode (delta), Egbin, etc with total installed capacity of about 8264Mw. The generated power in this country is grossly inadequate. To worsen the situation, there are lots of other limitations in both transmission and distribution sectors, like transformers, cable sizes and others. They make it difficult for the consumers to enjoy steady electricity supply. Although some of the power stations are now being renovated and upgraded, the maximum demand is far not met. See fig4

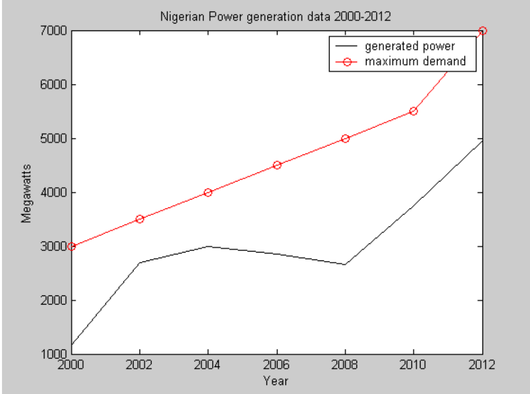

Fig4: Power supply in Nigeria from 2000 to 2012

The wind power generator will succeed in Nigeria because the lack luster performance of the public electricity supply company, the PHCN, is disturbing the electricity consumers; as such, those leaving in good wind catchment areas will not hesitate to ask for the machines.

Wind powered generators can be installed in remote areas where erection of power lines pose some problems due to the nature of the area. For example, the islands or areas located in swamps, such as those in Niger Delta area of the south-south and also in small isolated towns and villages located in rocky highlands.

The total cost of the wind turbine system, C_t, can be expressed as $C_t = C_c(C_a + C_m)TP_fA_mL_f$ (13)

Where;

C_c=Capital cost for the machine.

C_a=Annual charge rate

C_m= Maintenance and operational costs

T= total operational hours per year

P_f= the load factor and

L_f= factor for losses

Let the total installed power for n machines, $P_t = \sum_{i=1}^{n} P_i$ $watts$

If the total load, L_t, connected to the system. $L_t = \sum_{j=1}^{n} L_j$ $watts$. To meet the maximum demand, $P_t \geq L_t$

That is, $\sum_{i=1}^{n} P_i \geq \sum_{j=1}^{n} L_j$ (14)

For longevity, it is recommended that machines should not be operated beyond 80% of their rated capacity if they are to be in continuous operation.

So for utilization factor of 0.8 and diversity factor, d, the system loss, $L_l = \sum_{i=1,j=1}^{n}(0.8P_i - dL_j)$ (15)

The probability that the system will be stable after T years, $P_s = \frac{\sum_{i=1}^{T} t_{si}}{T8760}$ (16)

Where;

T=Number of years the system is under operation.

t_s= No of times the system is stable in a year.

X. Conclusion

The wind powered generator is in two basic forms: The constant speed, constant frequency (CSCF) and the variable speed, constant frequency (VSCF) types. The VSCF system is more reliable but more expensive than the CSCF system but the double induction machine seems to be more advantageous than both of them.

The wind powered generator will prosper in Nigeria, more especially at the beaches and various highlands at various locations in the country. Smaller machines can be paralleled to feed large loads.

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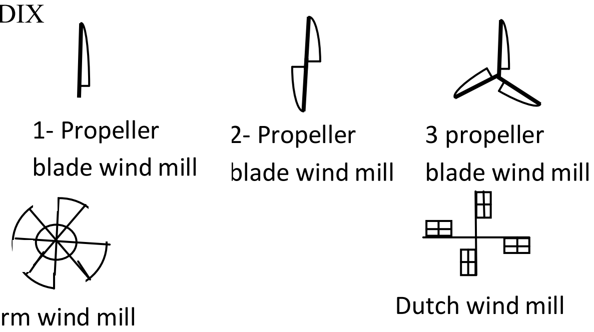
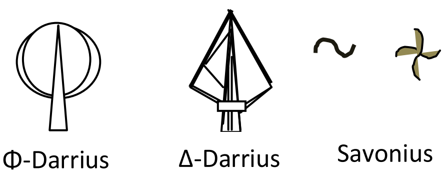
APPENDIX



FigA1: Some horizontal axis machines



FigA2: some vertical axis machines

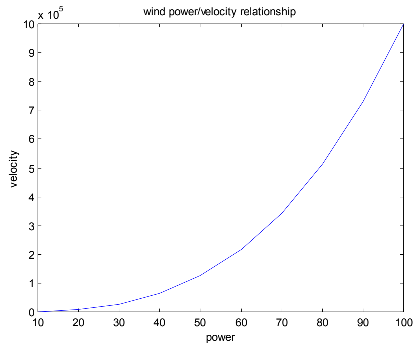


Fig A3: The velocity-power curve for the wind.