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Performance of On-Grid Wind Turbine with East Libyan Wind Speed Data

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Abstract

One of the most important issues in distribution networks in Libya is the voltage drop, that is due to the huge demand of electrical power. Therefore, integrating renewable energy sources connected to the distribution networks as a distributed generator such as wind turbines would certainly improve the voltage profile and will overcomes the power demand deficit in Libya. In addition,as technologies will play a major role in decreasing greenhouse gases, as well as air and soil pollution, however, connecting such sources to the distribution networks will present other issues related to the voltage profile such as stability of the network. This paper searches and studies the behavior of a distribution networks in Libya(11/0.4) kVwhich is connected to a renewable energy sourcevia a power transformer, represented by a wind turbine1.5 MVAusing the matlab software, and tries to solve the issues related to the voltage regulation profile and stability of the network, by means of controlling the performance of the wind turbine accordingly to the changes in load demand and wind speeddata was recorded in Al-fattaih-Derna east of Libya.

Keywords—Wind speed, pitch angle, voltage level, frequency value, reactive power compensator, pitch angle controller**.**

الملخص

من أهم المعوقات والصعوبات التي تجابه شبكات التوزيع في ليبيا هو هبوط الجهد وخصوصا في ظل الطلب الهائل للطاقة الكهربائية، ومن هنا فإن توصيل مصادر للطاقات المتجددة كمولد توزيع DGمن أجل تحسين الجهد وكذلك لتغطية جزء من الطلب عن الطاقة الكهربائية، بالإضافة إلى أن هذه التقنيات لها دور أساسي في تقليل من غازات الاحتباس الحراري، ومن جهة أخرى فإن توصيلها بشبكات التوزيع تؤثر على استقرارية الجهد. في هذه الورقة دراسة لأداء شبكات التوزيع في ليبياkV (11/0.4)المتصلة مع مصادر الطاقة المتجددةعن طريق محول المتمثلة في تربينة رياح1.5 MVA عن طريق برنامج matlab software، وحل للمشاكل المتعلقة بالاستقرارية وتنظيم الجهد بواسطة عملية التحكم في أداء التربينه بناء على التغير في الحمل وسرعة الرياح بناء على البيانات لمنطقة الفتيح في الشرق الليبي.

الكلمات الرئيسية: سرعة الرياح، زاوية الملعب، مستوى الجهد، قيمة التردد، معوض القدرة التفاعلية، وحدة التحكم في زاوية الملعب.

1. introduction

There are so many types of wind turbines which are used in the world, but according to the architectures, there are two main principles: horizontal axis wind turbines (HAWT), and vertical axis wind turbines (VAWT), both types are used according to the needs, nevertheless (HAWT) is the most common used in producing electricity, that is due to the ability to place the turbine rotor above a very high tower, in order to capture more steady and faster wind speed. Standard modern wind turbines have two basic operations modes, a constant or variable speed wind turbines [1]. The major earlier installations in developing countries are based on the constant speed wind turbine technology, because of its economy, durability, and simplicity in design [2]. The main element in wind energy is the wind generator, which rotates the shaft of the rotor in order to convert the kinetic energy to mechanical energy. The coupling can be direct or through a gearbox, the generator will receive the mechanical energy and converts it to an electrical energy, as shown in Figure 1 [3].

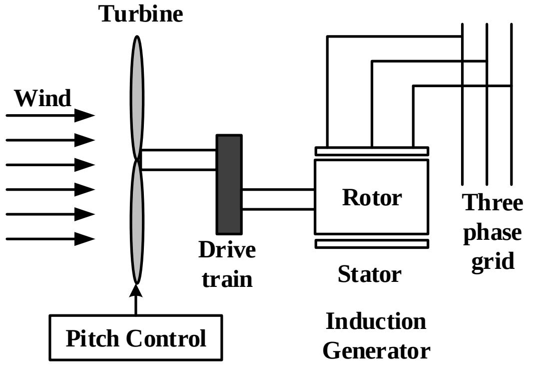

Figure1. System block diagram

For the type of constant speed wind turbine, the rotor speed is must be constant (have a small varying), in this type the wind speed changes do not have much effect on the rotor speed of the generator, because it is determined with the mains frequency by the number of generator poles, or by a multiple stage gearbox. Thus, constant speed wind turbines usually produce less power at low wind speeds [1], to solve this issue an adaptive control must be taken into consideration to maintain the rotor speed constant following the changes in wind speed and load as well, to make null and void the role of multiple stage gearbox. This paper used a close loop controller which reads the speed of generator following the changes of load and wind speed continuously, in order to maintain the generator speed by changing the turbine aerodynamic loading by changing the blades angle of attack to optimize the generator torque which proportional with wind speed and load demand. This paper shows that the wind turbine technologies can be used in a wide range in Libya as a distributed generator to overcome the power demand issues during the peak demand.

2. VOLTAGEDROPMATTER

One of the burning issues in wind turbine technologies is their generators. There are three main types which are used in wind turbines:

- DC generators.
- Synchronous generators.
- Asynchronous generators.

Most modern wind turbines are used asynchronous generators, because they are simple, reliable and inexpensive, in addition, they have got a very high degree of damping the fluctuations, nevertheless, induction generators draw reactive power from the grid proportion with the output active power. In this paper a capacitor banks compensator has been used to compensate the reactive power being drawn by the induction generator to maintain the voltage level at $1pu$[4].

3. CONTROL THEORY

Today's controllers integrate the signals from dozens of sensors to control rotor speed, blade pitch angle, generator torque, and power conversion voltage. The controller is also responsible for critical safety decisions, such as shutting down the turbine when extreme conditions are realized as it is shown in Figure (2).

Nowadays, most turbines operate at constant-speed, the control system regulates the rotor speed to obtain peak efficiency in fluctuating winds by continuously updating the rotor speed and generator loading to maximize power and reduce drive train transient torque loads. Operating at constant speed does not requires the use of power converters to make the generated power match the grid frequency [5].

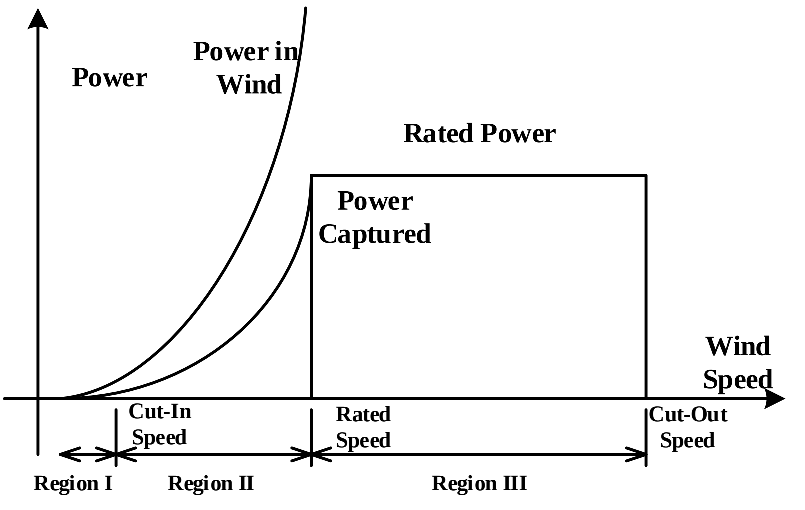

Figure 2. A typical power output versus wind speed curve.

case study

Due to the length of transmission lines of the electrical distribution networks in Libya (11/0.4) kV, furthermore, increasing demand for electric power (exceeding the capacity design in some stations) [6], which has led to an unreliable network represented clearly in frequency value and voltage level. The case study in this paper is the pitch angle controller and reactive power compensator for a fixed speed wind turbine using Matlab SimPower software. The rated power of the turbine is1.5 MVA, rated wind speed $12m/s$, it consists of a Squirrel Cage Induction Generator (SQIG), connected to a distribution network (11/0.4) kV via a power transformer with a rated power 1.5MVA. The wind speed data was recorded in Al-fattaih-Derna east of Libya. It has the highest spread of wind speed because of its altitude173 m and almost consider no obstacles directly on the sea. This data was collected at a height of $50m$from the ground level, and the average wind speed calculations has been done monthly by the method mean wind speed [7]. The highest wind speed was in February $9.26m/s$, whereas the lowest was in November $6.72m/s$, location's annual average wind speed was $8.21m/s$, as shown in Figure 3.

However, the real wind speed during the whole year varies from $1m/s$ up to $23m/s$, table 1 shows how many hours that wind speed will be between the cut-in speed and the cut-out speed of most commercial turbines [7].

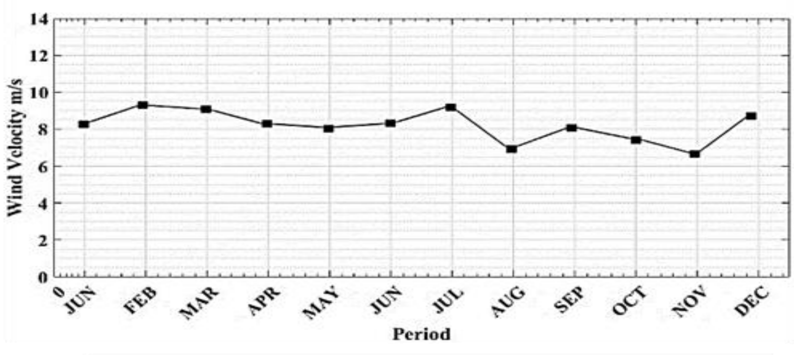

Figure3. Annual average wind velocity

Table 1. Annual Wind Velocity

Wind velocity	Hours per year	Wind velocity	Hours per year	Wind velocity	Hours per year
0-1	42	8-9	1105	16-17	25
1-2	209	9-10	739	17-18	22
2-3	408	10-11	521	18-19	10
3-4	702	11-12	386	19-20	2
4-5	959	12-13	202	20-21	5
5-6	1082	13-14	125	21-22	1
6-7	1051	14-15	79	22-23	1
7-8	1140	15-16	44	23-24	0

Network load changes from 2.23MVA to 2.9MVA. The pitch angle controller is to optimize the proper attack angle of the turbine blades, in order to correct the turbine output torque proportional to the electrical load, as well as wind speed to maintain the generator speed, maintainfrequencyvalue. Since the (SQIG) draws reactive power from the grid, a reactive power compensator must be used to maintain the voltage at grid level ($1pu$). In this paper, the capacitor bank has been used to compensate the reactive power which has been drown by the induction generator.

MODELING OF THE SYSTEM

To maintain the generator rotor speed constant, generally the system can be minimized into two main components. The plant which represents the turbine with its accessories (The target being controlled), and the controller which will control the operating mode of the target. A close loop controller uses the output of the target as an input to achieve the wanted action. The aim is to get the desired output power from the generator throughout the presence wind speed & load demand. The inputs of the wind turbine model are the blade pitch angle, generator speed (feedback signal) and wind speed; on the other hand the output will be the generator rotor speed Figure 4 shows the block diagram of the whole system according to the system parameters as shown in table 2..

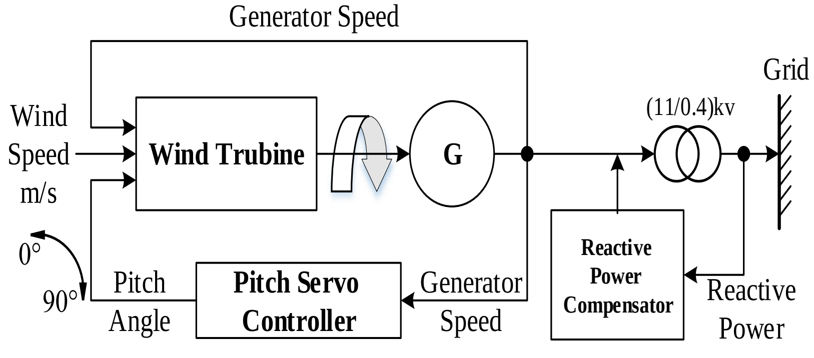

Figure 4. Block diagram of the system

Table 2. System Modelling Parameter

Working mode	Network connection
Nominal mechanical output power	1.5 MW
Base power of the electrical generator	1.5 MVA
Blade number	3
Cut in wind speed	5 m/s
Cut off wind speed	1 m/s
Base wind speed (m/s)	12 m/s
Cut out wind speed	25 m/s
Frequency	60 Hz
Generator used	Asynchronous squirrel cage
Generator number	1
Generator voltage	400V
Rotor speed range	10-30 rpm
Nominal rotor speed	30 rpm
Generator nominal cycle	1500 rpm
Transformer	(Yg/Yn) (0.4/11)Kv

ANALYZING THE ROTOR SPEED

The model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The output power of the turbine is given by the following equation [8]:

$$P_m = C_p(\lambda,\beta)\frac{\rho A}{2}V_{wind}^3 \quad (1)$$

Where:

P_m: Mechanical output power of the turbine.

C_p: Performance coefficient of the turbine.

ρ: Air density (Kg/m^3).

A: Turbine swept area (m^2).

V: Wind speed (m/s).

λ: Tip speed ratio of the rotor blade tip speed to wind speed.

β: Blade pitch angle (deg).

The mechanical power P_m as a function of generator speed, for different wind speeds and for blade pitch angle $\beta = 0$ degrees. The figure 5 is obtained with the default parameters (base wind speed = $12m/s$). The performance coefficient C_p of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle. C_p reaches its maximum value at zero β[9].

$$C_p = \frac{P_{out}}{P_{wind}} = \frac{\frac{1}{2}\rho A V^3 C_{p(\lambda,\beta)}}{\frac{1}{2}\rho A V^3}; \leq \frac{16}{27} \tag{2}$$

$$\lambda = \frac{V_{tipblade}}{V_{wind}} \tag{3}$$

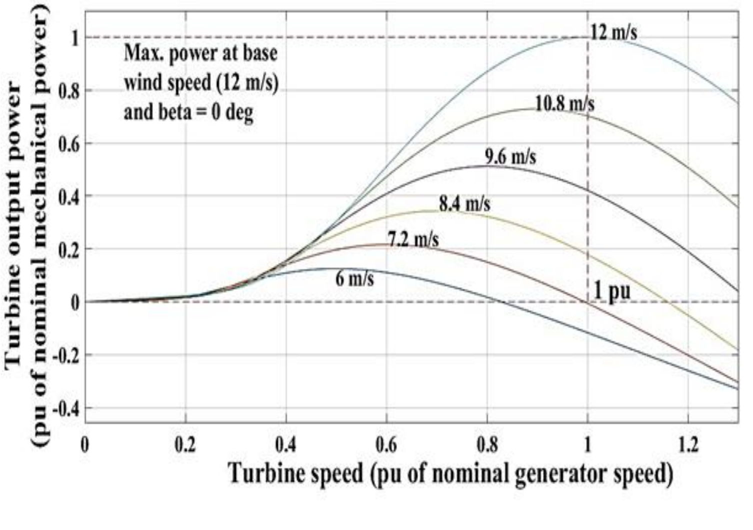

Figure 5.Turbine Power Characteristics (Pitch angleβ=0°)

The pitch angle controller controls the attack angle of the turbine blades β from 0°up to 90°, calculated from the vertical axis, as shown in Figure 6. This leads to change the power coefficient value C_p, thus, turbine mechanical output power will be changed. So this will keep the rotor speed constant regardless to wind speed and load demand [9]. In the meanwhile, λdepends entirely on the value of the pitch angle β. The largest area of the turbine blades which faces the wind is at $\beta = 0°$, and it decreases by increasing the value of β, as shown in Figure.6. To make the generator speed constant, a closed-loop controller was used in this paper, to optimize the proper value of the pitch angle which fits the desired load as well as the wind speed at that moment.

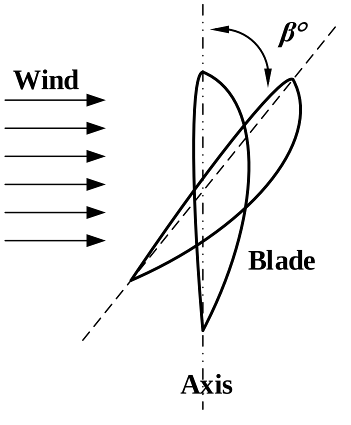

Figure 6. Pitch angle β

RESULTS AND DISCUSSION OF SIMULATION

The wind speed varies during the months mentioned from $1m/s$ up to $23m/s$ as shown in table 1, according to the wind turbine characteristics, the wind turbine will be out of synchronization (cut off condition) at the wind speed $1m/s$ to $5m/s$. However, without pitch angle controller $\beta = 0°$, the wind turbine output torque will change according to wind speed, not to load demand, this will lead to a variable generator rotor speed (frequency) and variable voltage level as shown in table 3.Figure 7 shows the variation of rotor speed with specific pitch angles.

Table 3. Rotor Speed and Stator Voltage without Controller$\beta = 0°$

Wind speed	Fix Pitch angle β(deg)	Rotor Speed	Stator Voltage
Minimum (1 m/s)	0°	Cut-off	Cut-off
Maximum (23 m/s)	0°	$3.16\ pu$	$0.8\ pu$

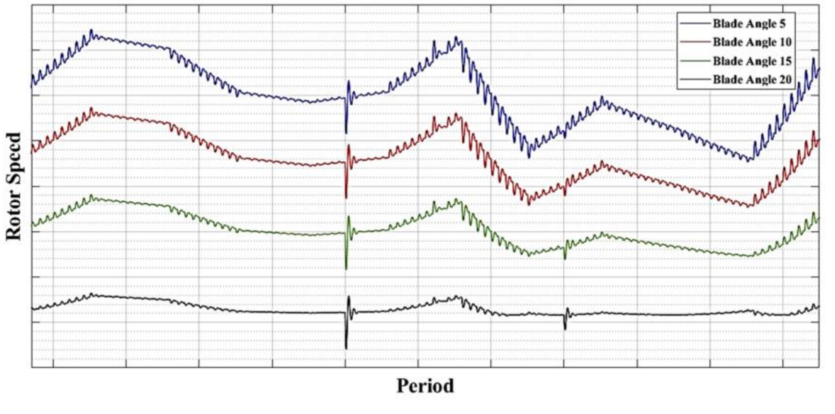

Figure 7. Variation of rotor speed with specific pitch angles

The wind turbine without controlling the angle of its blades, variable wind speed and the load demand will face so many issues, such as variable rotor speed (frequency), as shown in Figure 8.

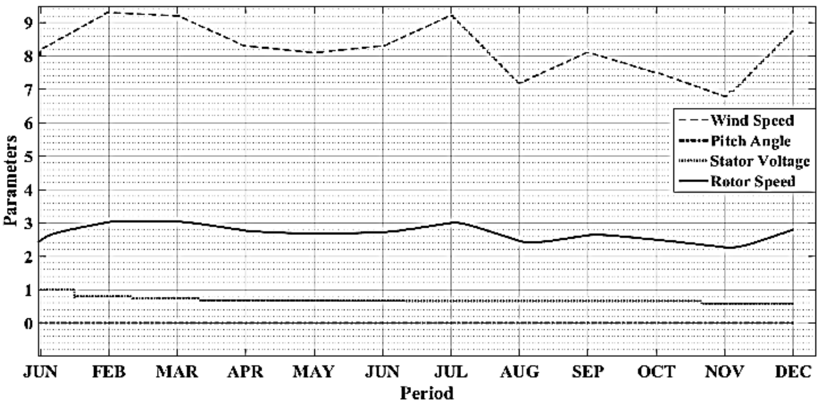

Figure 8. Annual Parameters without controller

To address these fluctuations in generator rotor speed (frequency) and voltage level, by other words to make the wind turbine output torque follows the power demand according to wind speed. A pitch angle controller should be used. It controls the β angle according to wind speed as shown in Figure 9, to optimize the desired mechanical output torque for the load demand and wind speed as well.

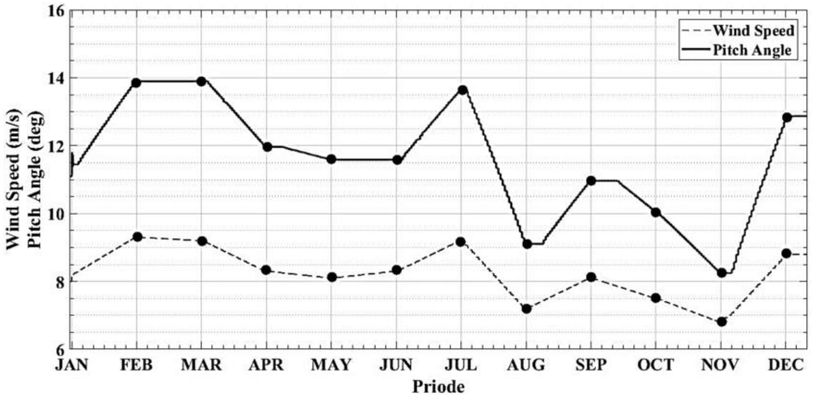

Figure 9.Annual wind speed & pitch angle

And then to maintain the generator rotor speed to $1pu$. In order to maintain the voltage to the grid voltage level $1pu$, a capacitor banks must be used on the induction generator terminals, as shown in figure 10to compensate the reactive power which has been drown by the induction generator. The figure 11 shows the final result for the controlling processor by the bitch angle and power reactive switches to keep the speed rotor and voltage at 1 pu.

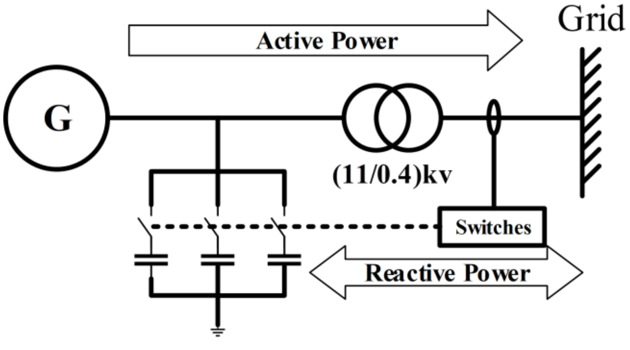

Figure 10. Reactive power controller

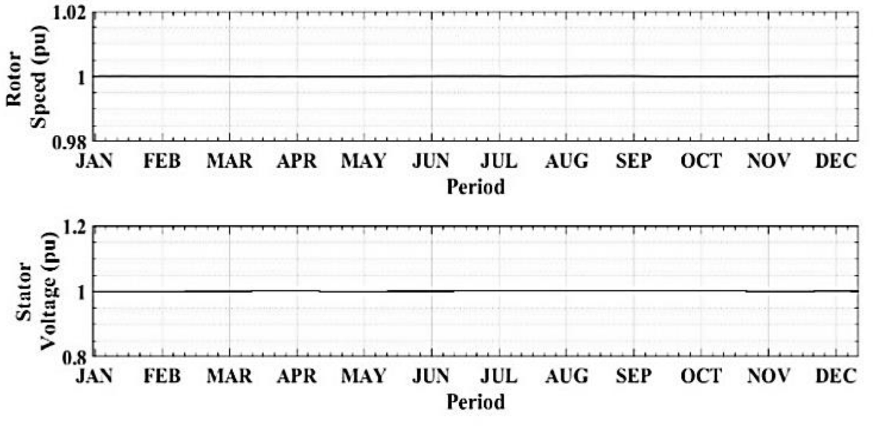

Figure11. Annual rotor speed & stator voltage

CONCLUSION

Wind speed data was evaluated by the mean wind speed during one year in Al-fattaih- Derna east of Libya, in order to study the performance of wind turbine connected to an electrical distribution network. From the results, it was clearly observed that the pitch angle controller and the reactive power compensator banks acted probably together in maintaining generator rotor speed ($1pu$) and the voltage level ($1pu$) respectively. Clearly, noticed that the bitch angle β was 13.9° at maximum mean wind speed 9.26 m/s and load demand 2.3MVA with a compensating reactive power2.2 MVAR. Where β was 8.25° at minimum mean wind speed 6.72 m/s and load demand 2.92 MVA with a compensating reactive power 2.9 MVAR. In summary, these results show that the wind turbine technologies can be solve the issues related to the voltage regulation profile and stability of the network, by means of controlling the performance of the wind turbine accordingly to the changes in load demand and wind speed.

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