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# 6-MW floating offshore wind farm to Sabratha Naval Platform

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# مزرعة رياح بحرية عائمة بقدرة 6 ميجاوات لتشغيل منصة صبراتة البحرية

**Abstract**

Recent developments in the electric utility industry are encouraging the entry of power generation and energy storage . This led to increase interest in the local renewable energy generation at the generation level. basing on this, this paper presents a floating offshore wind turbine model. The system consists of stand alone wind turbine model located in Sabratha Naval Platform. The model will provide a 6Mw as a case study to supply full load at the platform . The system is comprised of Four wind turbine modules each rated at 1.5 Mw to obtain a total peak power of 6 MW. In addition, AC DC AC converter of the system.

The paper presents the mathematical modeling of the wind turbine and a computer simulation for its operation using Matlab/Simulink , then the analysis of the input/output characteristics at steady state is presented.

**Keywords**— Renewable energy**,** floating offshore, wind turbine, AC DC AC converter.

الخلاصة

**التطورات الحديثة في صناعة المرافق الكهربائية تشجع على بدء توليد الطاقة وتخزين الطاقة. أدى ذلك إلى زيادة الاهتمام بتوليد الطاقة المتجددة المحلية على مستوى التوليد. بناءً على ذلك ، تقدم هذه الورقة نموذجًا لتوربينات الرياح البحرية العائمة. يتكون النظام من نموذج توربينات الرياح المستقلة في منصة صبراته البحرية. سيوفر النموذج 6 ميجا واط كدراسة حالة لتوفير حمولة كاملة في المنصة. يتألف النظام من أربعة توربينات رياح تم تصنيف كل واحدة منها بقدرة 1.5 ميجاوات للحصول على طاقة قصوى إجمالية قدرها 6 ميجاوات. بالإضافة إلى ذلك ، AC DC ACمحول النظام.**

**تعرض الورقة النمذجة الرياضية لتوربينات الرياح ومحاكاة كمبيوتر لتشغيلها باستخدام ماتلاب / سيمولينك ، ثم تحليل الإدخال / الإخراج و يتم تقديم الخصائص في الحالة مستقرة.**

## 1- Introduction

Offshore renewable energy resources have great potential to contribute to the global energy supply chain; however the offshore power is still higher as compared to conventional power generation. With a growing interest in offshore resources and considering the capacity of offshore renewable resources, they are anticipated to contribute a larger share of electric power in the next decade[1,2] . Offshore wind turbines offer many benefits over land-based turbines, but also have greater challenges. Offshore wind turbines are located far from property and buildings, so noise and collapse are insignificant concerns from a human factor standpoint. Wind speeds are often far greater offshore, as there are no land masses to alter the flow of the air, allowing for greater efficiency and more power produced. Offshore farms are also more costly to construct, due to the required floating structure and power distribution lines which must connect the turbines to land [2,3].

Locating wind turbines far offshore, twenty miles or more, has many benefits, can be closer to load centers, reducing the required length of transmission lines ;as in offshore oil platforms Simulation of the system is realized using MATLAB/Simulink. This study was validated at the Sabratha Naval Platform, a semi-submersible platform, located 110 km off the Libyan coast in the Bahr al-Salam field, off Tripoli. It is one of the largest oil and gas facilities in Libya at a depth of 190 meters. The platform consists of three gas generating units with a capacity of 6 MW, two basic units and a backup unit. The total consumption is about 4.5 MW. The production is divided into two generating units that provide all the necessary facilities for separation and initial processing of the produced gas, as well as maintenance equipment (FMWR) and residential and living areas. The average annual wind speed in this region is between 20 to 30 knots, or about 10.8 to 15 meters per second, which is suitable for wind power generating units with a total capacity of 6 megawatts feeding the entire platform loads.[4]

Fig(1): platform wind energy

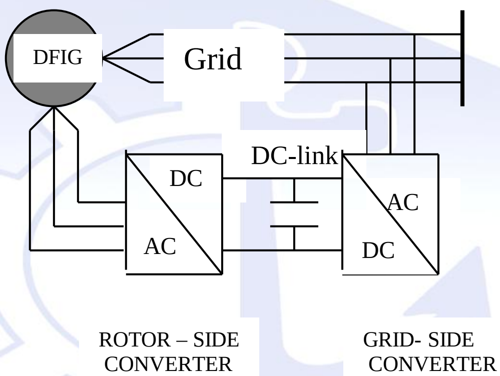

**Fig(2) sabratha platform**

**2- Wind turbine**

With the use of power of the wind, wind turbines produce electricity to drive an electrical generator. Usually wind passes over the blades, generating lift and exerting a turning force. Inside the nacelle the rotating blades turn a shaft then goes into a gearbox. The gearbox helps in increasing the rotational speed for the operation of the generator and utilizes magnetic fields to convert the rotational energy into electrical energy. Then the output electrical power goes to a transformer, which converts the electricity to the appropriate voltage for the power collection system. A wind turbine extracts kinetic energy from the swept area of the blades. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time.[1,2,5,6,7]

## 3- Model of wind generator

Simplified model of DFIG is shown in Fig.3. The rotor of induction machine is connected to the grid with a back-to-back voltage source converter which controls the excitation system. This most significant feature enables sub synchronous and super synchronous operation speeds in generator mode and adjustable reactive power generation[9,10] .



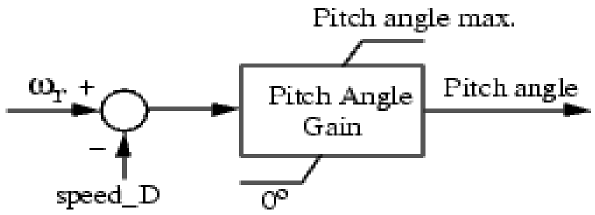

**fig(3) DFIG detailed model**

## 4- DC-link voltage

the DC link voltage capacitor connected on DC side acts as a DC voltage source. It is steady state value for mid-level output power can be modeled as in figure(3) . It is believed that a better tuned controller, would result in improved results. More complex controllers could also be added to improve the response[11-13].

## 5- Pitch angle control system

The pitch angle is kept constant at zero degree until the speed reaches point D speed of the tracking characteristic[3,6]. Beyond point D the pitch angle is proportional to the speed deviation from point D speed. For electromagnetic transients in power systems the pitch angle control is of less interest. The wind speed should be selected such that the rotational speed is less than the speed at point D. If wind speed is below the rated value the rotational speed is adjusted so that power coefficient remains max when the pitch angle is zero. Mean while, if wind speed increases above the rated value pitch angle control is activated to increase the pitch angle to limit the mechanical power.




**Fig(4): Conventional pitch angle control system[23].**

**6- Mathematical Model**

Under constant acceleration, the kinetic energy of an object having mass m and velocity v is equal to the work done, W in displacing that object from rest to a distances under a force F , i.e.:

$$E = W = Fs$$

According to Newton's Law, we have:

$$F = ma$$

Hence,

$$E = ma \times s \qquad (1)$$

Using the third equation of motion:

$$\upsilon^2 = u^2 + 2as$$

we get:

$$a = \frac{(\upsilon^2 - u^2)}{2s}$$

Since the initial velocity of the object is zero, i.e.

u = 0 , we get:

$$a = \frac{\upsilon^2}{2s}$$

Substituting it in equation (1), we get that the kinetic energy of a mass in motions is:

$E = \frac{1}{2} m\upsilon^2$ (2)

The power in the wind is given by the rate of change of energy:

$P = \frac{dE}{dt} = \frac{1}{2}\upsilon^2 \frac{dm}{dt}$ (3)

As mass flow rate is given by:

$\frac{dm}{dt} = \rho A \frac{dX}{dt}$ (4)

and the rate of change of distance is given by:

$$\frac{dX}{dt} = \upsilon$$

we get:

$$\frac{dm}{dt} = \rho A\upsilon$$

Hence, from equation (3), the power can be defined as:

$P = \frac{1}{2}\rho A\upsilon^3$ (5)

If the rotor diameter is d, the area of the disc subtended by the rotor is :

$$A = \frac{\pi d^2}{4}$$

Thus the power available from the wind is :

$P = \frac{1}{2}\rho \frac{\pi d^2}{4} v^3 = \frac{\pi}{8}\rho d^2 v^3$ (6)

From eqns. (5) and (6), keeping everything constant except for the wind speed, we can for the power ratio:

$\frac{P(v)}{P_0(v)} = \left(\frac{v}{v_0}\right)^3$ (7)

Thus doubling the wind speed leads to an increase in the wind power by a factor of $2^8$.

## 7. Simulation and Results :

### 7.1 Wind stand alone Simulations

The three-phase stand alone wind system was simulated using MATLAB/ Simulink ; this was done to evaluate the performance of the proposed wind system and to check the performance and robustness of the proposed model. stand alone wind system was evaluated with regard to performance indicator: the system response under normal operation.

The model of complete grid-connected wind system was implemented in MATLAB/Simulink. Based on this test conditions were simulated in steady-state operation .The wind system has a maximum power rating of about 6 Mw. The model of a DFIG wind farm shown in figure (5).

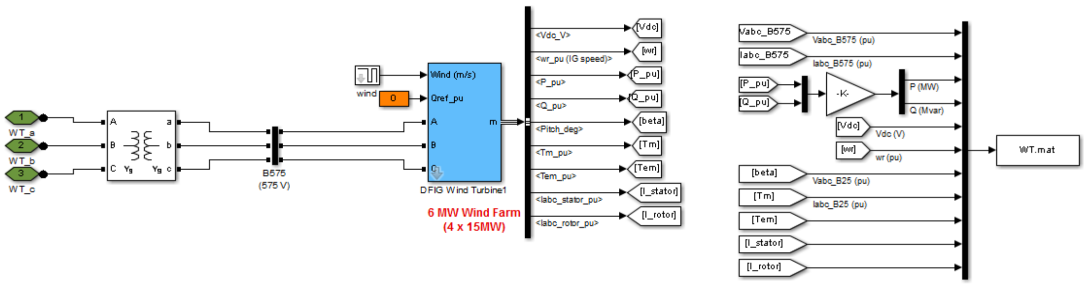



**Fig (5): Model of DFIG wind farm with a rating of about 6 MW.**

The simulation results of the total output voltage produced by the designed wind system are illustrated in figure (6) .

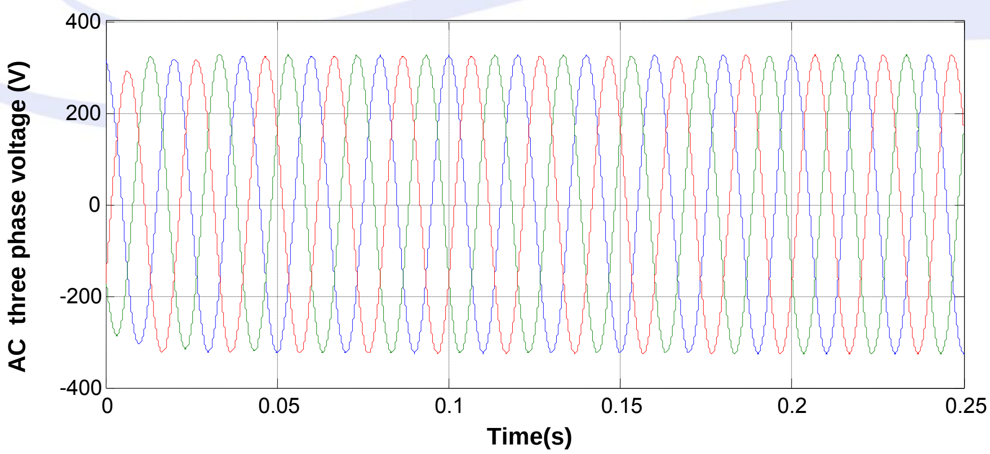


**Fig (6): Total output wind system AC three phase voltage(V).**

**7.2 Case Steady State Operation.**

At steady state, the generation unit is operating at it is nominal point, and supply power to the loads.

Figure (7) shows voltage simulation result at DC Link when the system operates at average normal wind speed by magnitude of 15 m/s at time between 0s to 5s at the beginning of the operating condition the voltage is unstable which n known transient situation after that the voltage is stable at 1000 volt DC.

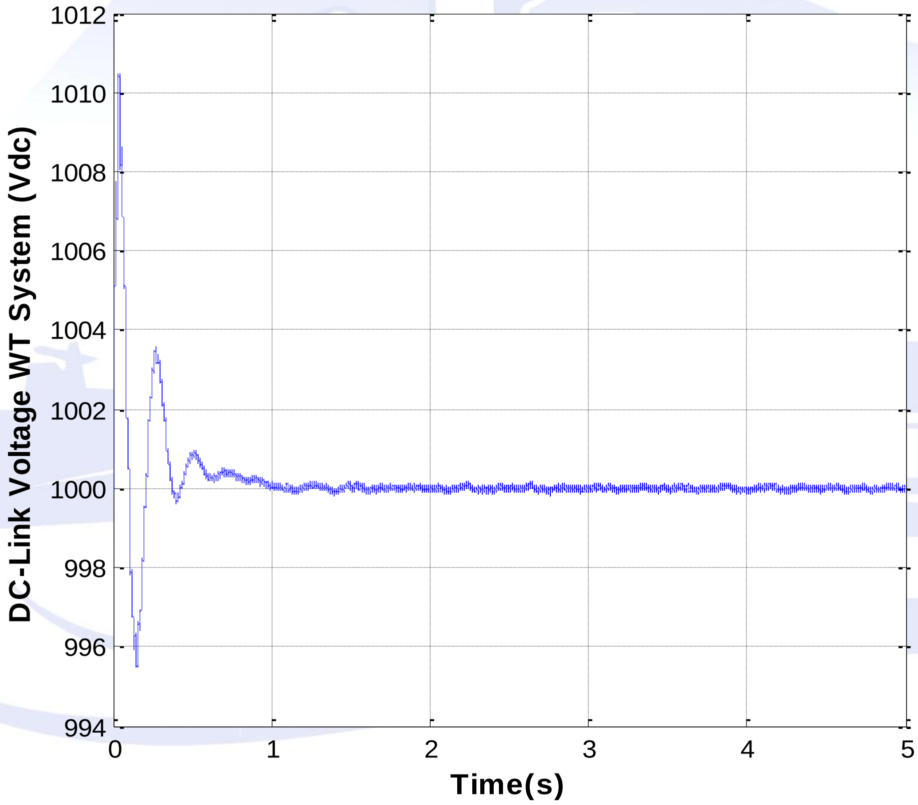
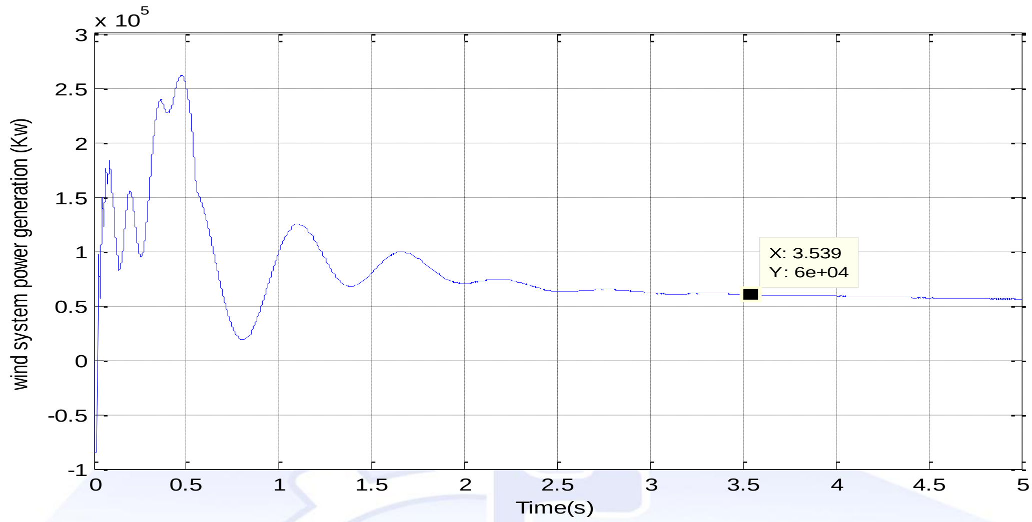



**Fig (7) DC link voltage wind turbine system (Vdc steady state = 1000 volts)**

Figure (8) shows the simulation result of AC power produced by the designed system when the wind speed set at 15 m/s.




**Fig( 8): Wind system power generation (Kw).**

In figures (9), (110), after short period of time in the beginning of the operation, the pitch angle controller was stable, as a result, the pitch angle set at 10.35 deg, therefore the rotor speed was stable at 1.48 pu and limit output power to 6MW.

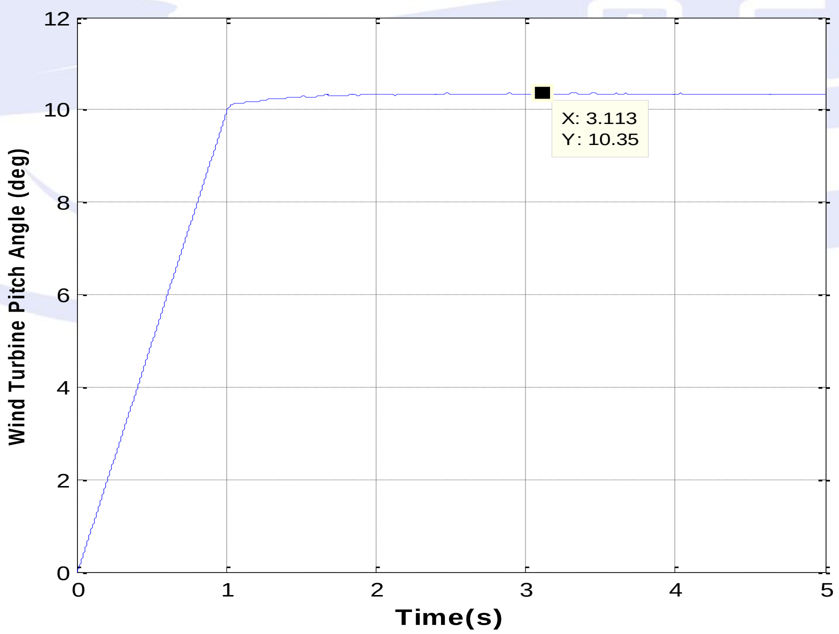


Fig (9) Wind Turbine Pitch Angle (deg).

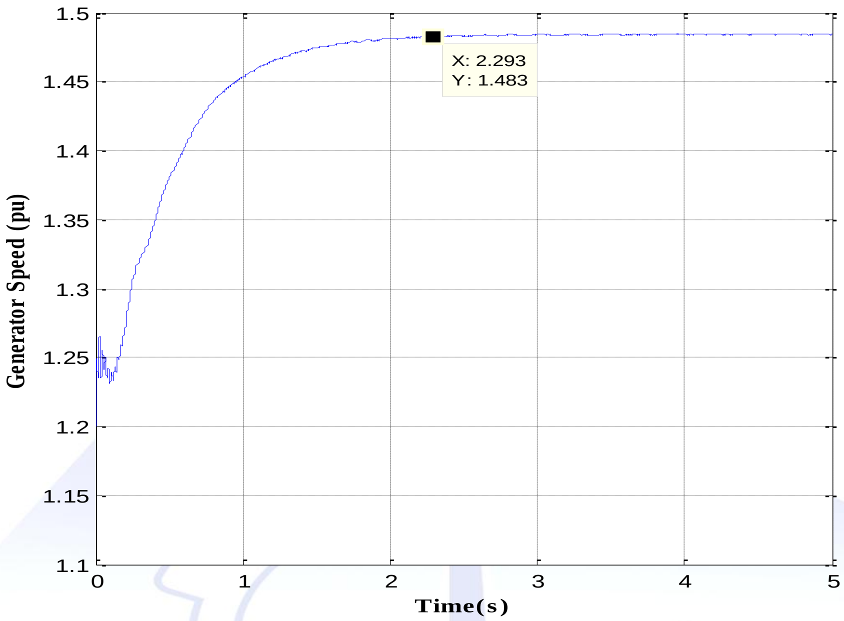



Fig (10) generator speed (pu).

From the figure 11 it is observed that loads of three-phase voltages (Load 2) were nominal value after short period of time (steady state operation) and then remain stable at constant value (322.9v).

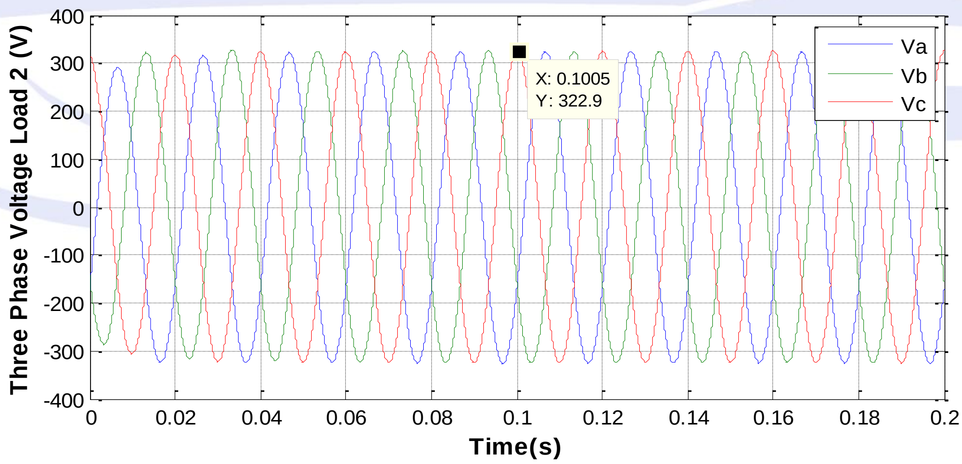



Fig (11) three phase voltage load 2 (V)

## 8- Conclusion

The limited supply of fossil fuels and the desire to reduce the amount of greenhouse gases produced are two of the best arguments for the use of renewable energy sources. Wind energy stands for gains Significantly increase potential energy production by moving the turbine site to one at much higher wind speeds. The Mediterranean is one of the most promising locations in the field of floating wind energy. Turbines are an emerging renewable energy concept that may play an important role in meeting future energy needs. Model of standalone offshore wind turbine has been developed. The model will allow for investigation and provide an understanding the steady state operation at speed of 15m/s . The importance, aims and outcomes of this research are highlighted and summarized. At steady state, the generation units operate stably and provide power for the loads. This paper provides an overview of the nascent offshore wind energy industry including a status of the commercial offshore industry and the technologies that will be needed for full market development.

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