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UTILIZING A PERMANENT-MAGNET ALTERNATOR WITH THE FULL CONVERTER IN WIND TURBINE INCREASES THE EFFICIENCY OF SUPPLYING AN ACTIVE AND REACTIVE POWER TO THE ELECTRICAL NETWORK

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Abstract: *The alternator depends entirely on the conversion of kinetic energy into electrical energy by the presence of a magnetic factor. Wind energy is defined as the process of converting wind energy into another form of energy that is easy to use. In this paper, a permanent-magnet-alternator (PMA) with full-converter (FC) was used in the wind turbine (WT) generator instead of the excitation coil of the magnetic field. This method was used to save lost energy in the induction coil. A complete wind turbine model with a (FC) was connected to a generator with a fixed magnetic field and an electric grid was fed. This simulation system was completed by PSIM simulation program. In this work, the IP control system was used to operate the simulation system. In this study, a greater stable amount of real and reactive power was obtained from the wind turbine.*

Keywords: Wind Energy, Wind Turbine (WT), Permanent-Magnet Alternator (PMA) and Full-Converter (FC).

INTRODUCTION

Today, the most important characteristics of the electric power system are being composed of AC three-phase systems run at a constant voltage, synchronous machines (generators) operate at constant frequency and power transmits for long distances. In addition, all electric power systems with a variety of AC and DC systems are predicted to be integrated into all three stages: ***generation, transmission*** and the ***distribution***. These power systems should also be able to handle all types of synchronous and asynchronous generators, centralized and decentralized resources (distributed) [1]. These networks still need various sources of energy in order to support them due to the incredible demand for power. Therefore, the main goal of power

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generation engineers is to find more abundant, cheap and environmentally friendly sources. According to the Energy Law, this stipulates that the energy is not depleted and is not created, but turns from one form to another. There are many forms of energy such as ***kinetic energy, thermal energy, mechanical energy, nuclear energy, chemical energy*** and others [1], [2]. This energy can be converted from one form to another by using different devices such as electricity which is the mainstay of life. Electricity is obtained from converting several energy sources like fossil ***fuels-petroleum***, which is created by the pressuring and heating of the living organisms. In fact, these sources are harmful to the environment because they produce toxic gases when burned, and are not available in all regions of the world. Currently, in most countries, wind power is increasing in demand for electric power production and is rapidly being planned for interconnection. It is expected to continue in this direction (i.e. the use of wind energy to produce electricity) for several reasons; including increasing concerns about the pollution of the environment and the warming of the globe, keep energy production safe, and provide jobs. There are a large number of advanced technologies to manufacture different types of wind turbines, which in turn compete for a larger share in the market for this booming industry [3].

As is generally known, the basic principle of the energy that is generated in the generator by spinning the rotor inside the stator where the ***electric magnetic field*** is there. The magnetic field for excitation is created by a low current (about 4 Amps).This means; there is a dissipated energy (around 30 watts) in the coil due to this current [2].

The basic idea of this research is to solve this issue by using a permanent magnet instead of the coils in the alternator of the “full-converter” wind turbine. The energized coils were replaced by a permanent magnet to produce constant magnetic and a special design uses for the stator in order to be able to increase the voltage when the rotation of the turbine is low (in case of the slow wind). The generated voltage of the wind driven, self – excited induction generator (SEIG) is mainly depending on the wind velocity fluctuations and load variations. By choosing, the proper value of the self-excitation capacitor banks achieves the reactive power requirements [3]. A combination of series and parallel capacitors are used to excite the induction generator while operating at variable speeds [4].

The (PM) has a ***flux*** that measures in "kWB for turns" [1]. Each per-unit of a magnetic-strength produces a voltage at the terminal within the ***rated-range***. This will happen during the rotating of the machine at normal speed and under "no-load" condition. In addition, this type of alternator is very appropriate to use in hydro power plants (high-speed turbines) [5], [6]. In other words, in order to maintain the amount of output power at maximum and not allow any amount of power to be dissipated. The advantages of this technology are actually as follow:

- To improve the power quality of the network
- To separate the generator from the network when a fault occurs and
- To allow the wind turbines to work with a vast range of wind speeds.

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In addition, this topology needs a convertor, which is capable of carrying the entire output of the generator [7]. As a final output, wind energy extraction will be improved. This type is very expensive, but it provides a high amount of ***active-power*** and ***reactive-power*** to the network. In this research, a system of integrated wind turbine containing a control circuit, a magnetic generator and a (FC) to connect the turbine to the grid was simulated. This application was achieved by PSIM program. All results and curves were measured and plotted respectively by using the same simulation program.

1. TECHNOLOGY'S CLASSIFICATIONS FOR WIND TURBINE

Wind turbine technologies are amazingly developed and used in large numbers today. As well as most of the wind, power plants made up of large numbers of turbines are usually located in groups called wind farm, often using the same technology.

To summarize these different technologies, consideration must be given to the cost, complexity of manufacturing, the type of equipment used for this process and, most importantly, the efficiency of extracting a large amount of energy from the wind. Modern wind turbines often consist of a rotary part and blades connected to it to extract kinetic energy from the wind, the gearbox is used to increase the speed transferred from the rotor to the generator to be sufficient to rotate at its specified speed, and a generator to generate electricity. As a result, changing the speed of the wind continuously needs the generators that are inherently synchronous. Thus, ***synchronous-induction generators*** are used in the most typical wind turbines. Also, electronic converters are used in order to control the both parts of the power output (real and reactive) of the wind turbine [8]. In general, Wind turbine technologies can be categorized into four main types:

a) (WTs) with ***Fixed-speed*** (FS)
b) (WTs) with ***Variable-slip*** (VS)
c) (WTs) with ***Doubly-fed induction generator*** (DFIG)
d) (WTs) with (FC).

Figure 1 shows all the above types of (WT) technologies.

The most use for (WTs) are the fixed speed type Figure 1-a. They work with a little bit change in the speed of their rotor and they use the ***squirrel-cage*** type of the ***induction machines*** which are usually directly connected to the network. Most of these turbines are not capable to control the pitching of the blades. Despite being fairly strong and reliable, this technology has a huge disadvantage, vis that the extraction of energy from the wind is below the required level and therefore it needs the compensation for the reactive-power. Variable speed wind turbines are designed in figure 1-b to operate the rotary with an extensive range of speed. Usually these turbines use blades-monument in their work. For this reason, these turbines capture more wind energy than fixed-speed turbines. The resistance of the dynamic of the rotor or the variability of the slipping in the turbine is to control and to increase the range of the speed of operation and that can

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cause a dissipated power in the rotor. The losing power in the slipping could be repaired by employing the (DFIG) **Fig. 1-c** and the ***back-to-back (AC/DC/AC)*** converter to the rotor circuit of the turbines [8]. The rotor current is controlled by the "flux vector" that can allow to decouple the output of the real power and reactive power. In addition, this can increase the extraction amount of energy from the wind and can reduce the stresses on the mechanical parts. As a result, the converter cannot operate at full capacity because the converter manages the power just in the rotary circuit. Commonly, the flow of the power in turbines with full converter figure 1-d, a ***back-to-back (AC/DC/AC)*** converter, is one path to the grid. In addition, it is impossible to connect these turbine types directly to the network. In addition, they use either synchronous or inductive type of generators to offer an independent control to the real power and reactive-power. In this paper, another synchronous generator replaced the synchronous generator in the last type (Full-Converter) of the turbine, but it contains a permanent magnet for the “excitation field” instead of coils [8].

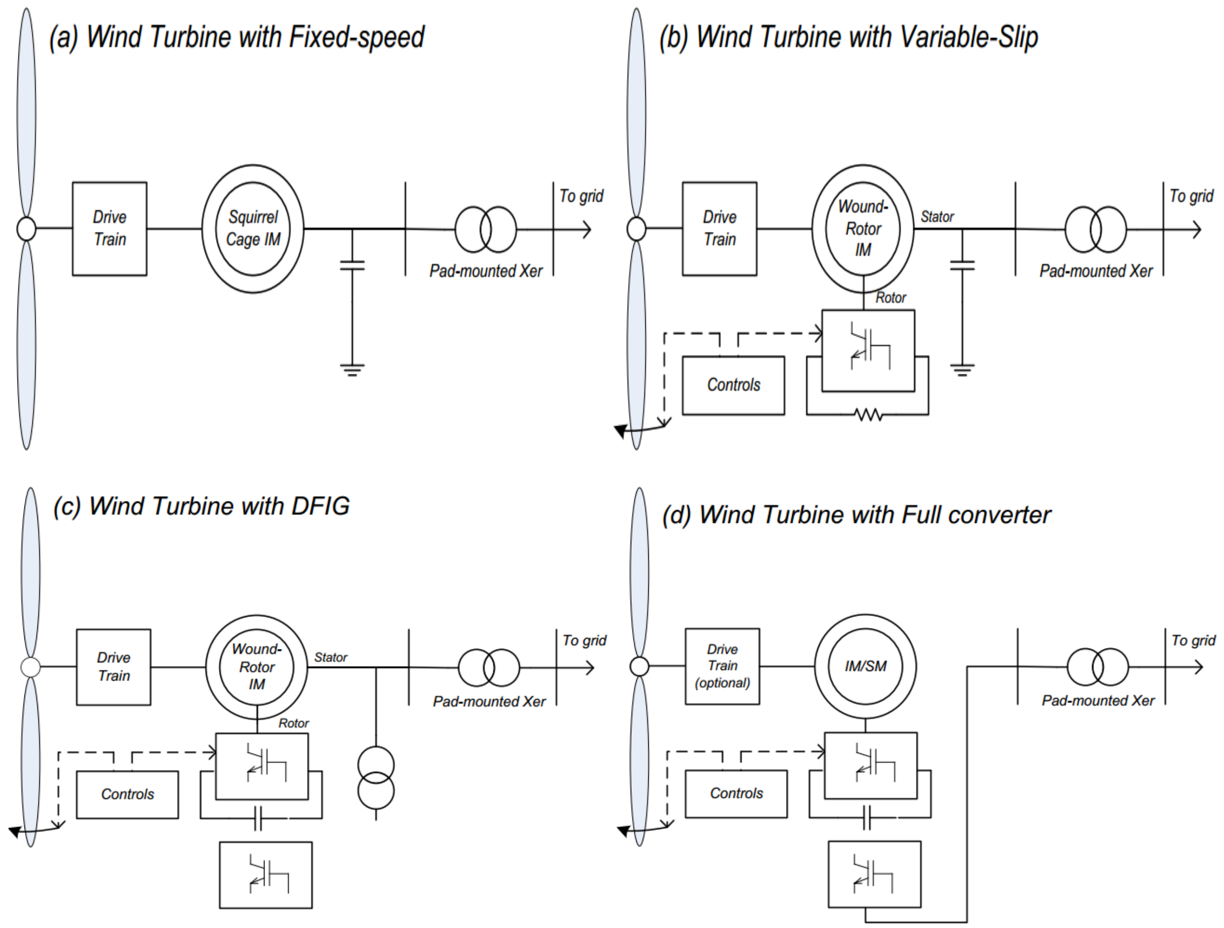

Figure1. Wind Turbine Technologies [6]

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2.THE IMPLEMENTED MODEL IN PSIM

Figure 2 shows the full model of the (WT) that simulated by "PSIM" program, without the diversified control blocks, after each individual sub-system were compiled. Based on that, In order to simplify the simulations in this work, the systems of conversion and control will be explained separately from the rest of the system. Therefore, the full- convertor Permanent Magnet Alternator (PMA) wind turbine consists of the following sub-systems:

Tables below (1, 2 and 3) show the characteristics of both the turbine and the alternator in (PSIM) program that used in this simulation.

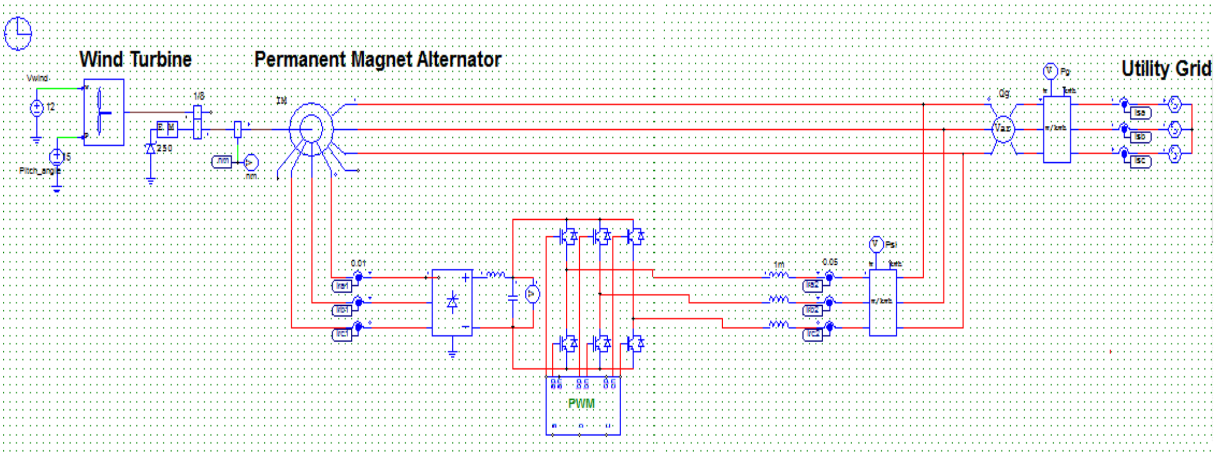

Figure 2 The simulated Model without the control circuits

Table 1: Characteristics of the Turbine

Made of the Turbine	**Enircen E84 3MW**
Diameter of the rotor	80 m
Height of the Hub	76 m
Number of the Blades	(3)
(Cut-in) speed of the wind	(5 m/s)
(Cut-out) speed of the wind	(27 m/s)
Speed Rate of the wind	(6 m/s) - (17 m/s under used)
Speed of the Rotor	(4/20 rpm)

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Table 2: Rates of the PMA

MVA Ratio	(3 MVA)
Ratio of the Voltage	(4.6 kV L-L)
Ratio of the frequency	(50 Hz)

Table 3: Parameters of the PMA

R-Winding of the Stator	0.018 pu
X- Leakage of the Stator	0.058 pu
Unsaturation of the X for the (d-axis)	0.49 pu
Unsaturation of the R for the (q-axis)	1.09 pu
R-of the d-axis of the damper winding	0.63 pu
X- of the d-axis of the damper winding	0.179 pu
R- of the q-axis of the damper winding	1.09 pu
X- of the q-axis of the damper winding	1.182 pu
Intensity of the Magnetic	4.9 pu

Converter: The duties of the rectifier and buck/boost converter in the models are to convert the AC output of the PMA to a constant DC voltage. A three-phase diode-bridge uses to convert the output of the PMA to a changeable DC-voltage. The maintaining of the DC-voltage level to be constant at 3.6 kV is the duty of buck-boost converter. There is a link of a DC capacitor, a ground between two identical capacitors, due to the issues grounding of the reference of the PSIM, which are indicated in Figure 3.

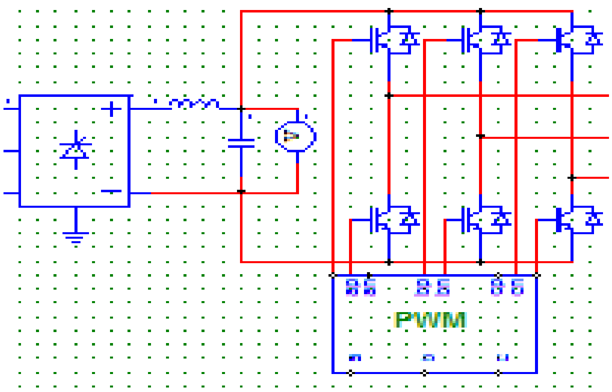

Figure 3: Converter-Circuit of **Rectifier and Buck/Boost**.

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A proportional–integral (PI) control: The main idea of the controller depends on PI-control. This means that the output of the controller is directly proportional to the error of the signal. For this work, the duty-signal that runs the PI produces when there is an error between the required voltage, which sets at (3.6 kV), and the real voltage which drives the PI-controller. Then, duty-signal compares with a square wave signal in order to send signals of firing to switch the Insulated Gate Bipolar Transistor (IGBT) in the buck/boost converter ON or OFF as cleared in Figure 4.

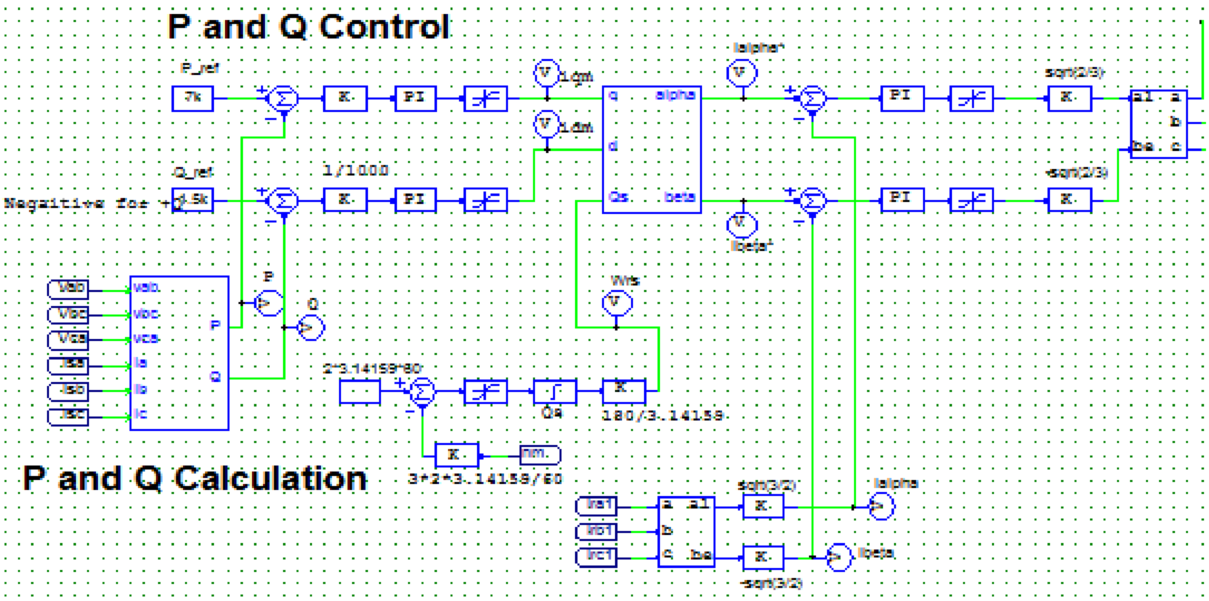

Figure 4: The PI controller.

Inverter: Figure 5 shows an implemented current controlled of the voltage-source inverter (VSI). This inverter should be able to separate the control of the real and reactive power, since the design of the controller for the inverter depends on the theory of the flux-vector. Two controllers are independent PI, for comparing the "reference-signals" of the values of real, and the error, as indicated in the Figure 5. The error of the real power drives the (Iq) signal, whereas the error of the reactive-power drives the (Id) signal. The domain values of dq0 are transformed to the reference (I_{abc} values) as cleared in Figure 5 (take into consideration the angle-signal this is calculated from the voltage-phasor.

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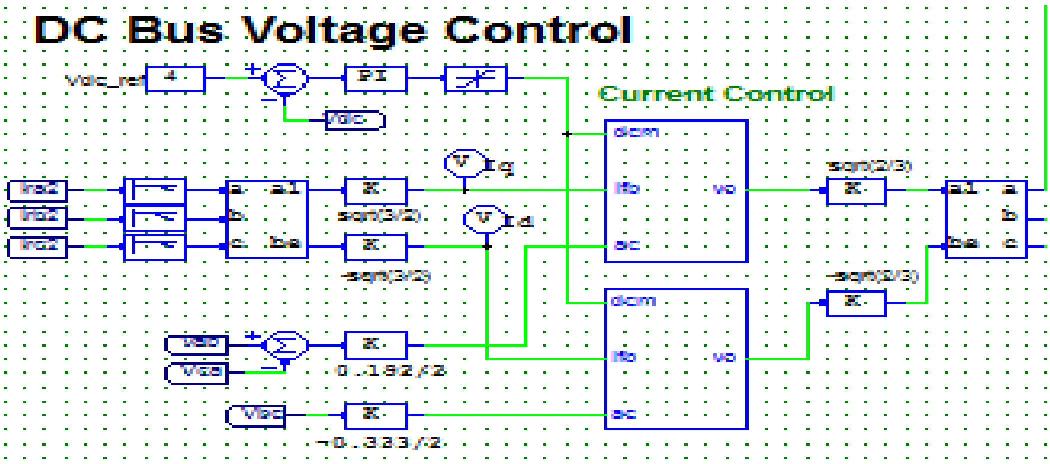

Figure 5: Real-power and reactive-power errors drive q and d controllers of current respectively

For the control system, the switching of the IGBTs happened by the comparison between (***I_{bec}***) currents of the reference and with both of the real currents. Figure 6 shows the final stage of the controller of the real power and reactive power of the model due to the switching of the IGBTs of the inverter ON.

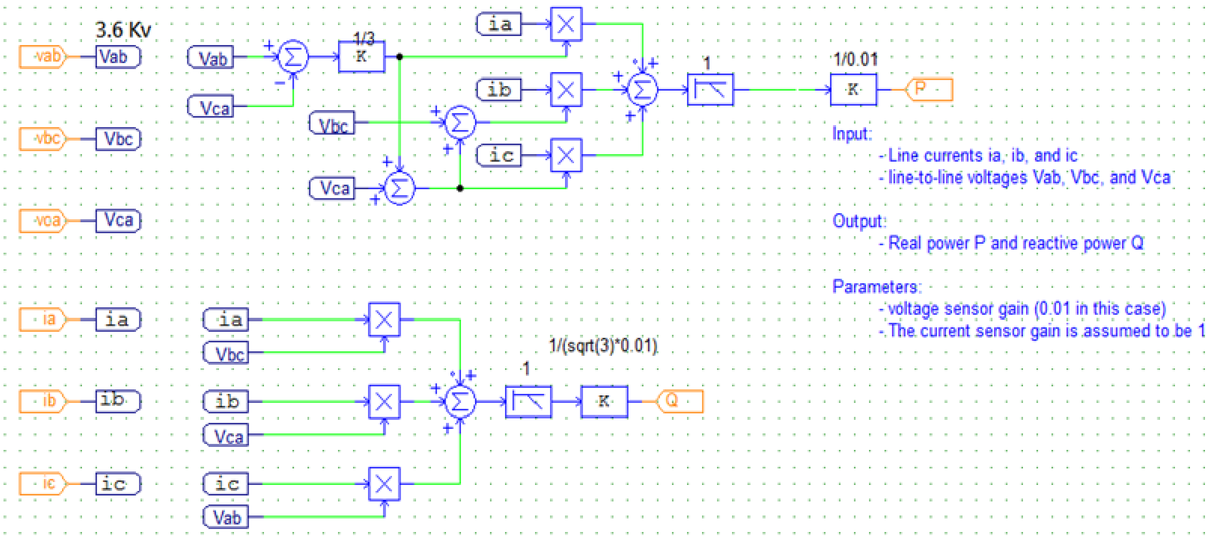

Figure 6: Switching-IGBTs controls P and Q

3. RESULTS AND DISCUSSION

In order to verify if the independent control of the real power and reactive power is established or no, four tests performed on the simulated model: reduced real-power, reduced reactive-energy, increased real power and increased reactive-power. These models were changed individually a step-by-step, i.e., at a given moment, the change of the step was done by either the speed of the wind or the demand for reactive-energy.

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First test, the simulation was run by reducing the real power. The change to the speed of the wind was from 12 m/s to 10 m/s at t =11s. The demand for reactive-power was fixed at 0.6 MVAR. Figure 7 shows that the real power-output reduces and stabilizes to the new amount. Reactive-power reduces at first, but improves to the main value.

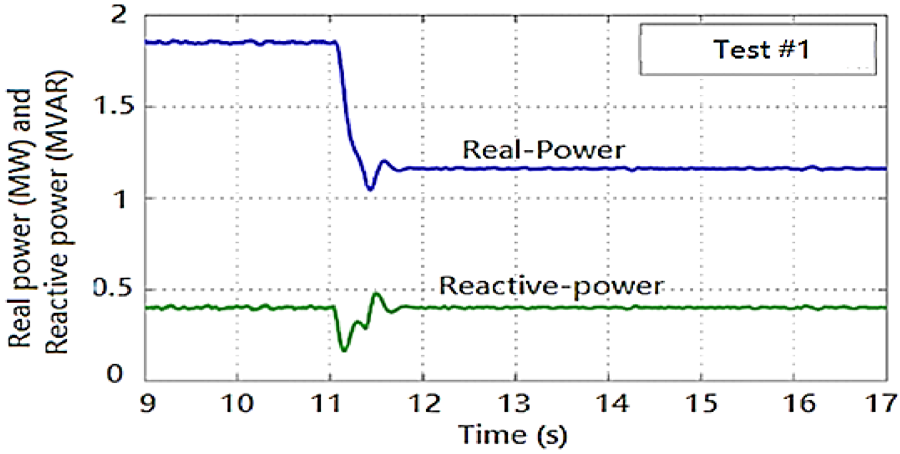

Fig. 7: Real-power-reduced

Second test, the simulation was run by reducing the reactive-power. Figure 8 shows that the speed of the wind stays at 12 m/s during the run, but the demand for reactive-power was varied from (0.5 MVAR to 0.2 MVA R) at t =11s. The reactive-power reduced, as predicted. The output of the real power indicates a little disturbance, but improves to the real value.

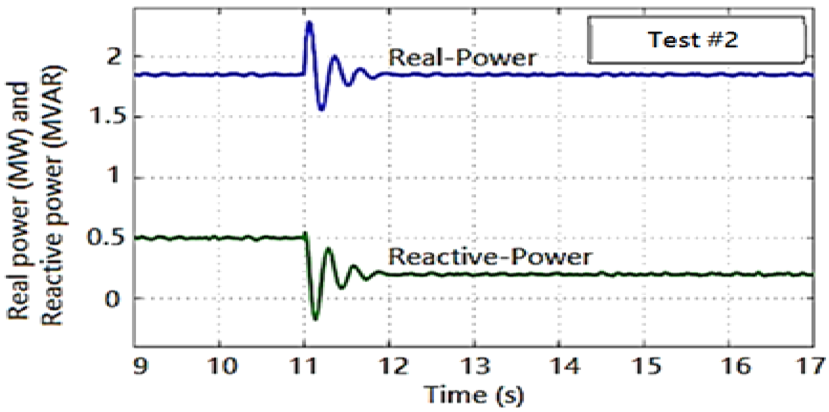

Figure 8: Reactive-power-reduced

Third test, the simulation was run by increasing the real power. The speed of the wind was varied from 10 m/s to 14 m/s at t = 11s. The demand for the reactive-power was fixed at 0.6 MVAR. Figure 9 shows that the output of the real-power increases and stabilizes to the new amount. Reactive-power increases at first and improves to the main value.

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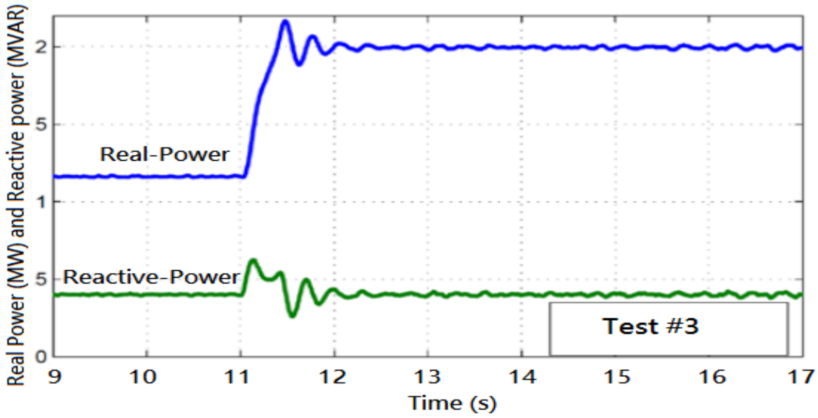

Fig. 9: Real-power-increased

Forth test, the simulation was run by increasing the reactive-power. Figure 10 shows that the speed of the wind stays at 11m/s during the run, but the demand for the reactive- power was varied from (0.5 MVAR to 0.7 MVAR) at t =11s. The reactive-power increases, as predicted. The output of the real power once again shows a little disturbing, but improves to the main value.

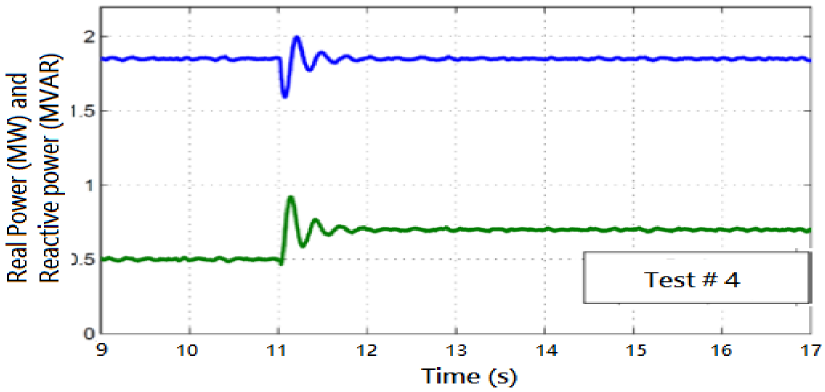

Figure 10: Reactive Power Increased

In fact, the results of this research compared with the results of research No. 6 and 7 were more reasonable and within the applicable limits. Most of the researches on this subject are use capacitors to compensate the dissipated energy as a result of starting the induction generator of the wind turbine to take off.

CONCLUSIONS AND FUTURE WORK

Usually, in wind turbine the number of poles is low in order to increase the speed of the shaft and for this reason the gearbox is used. Thus, any torque applied to the shaft starts to rotate the shaft, which means

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energy transferred go and forth from the turbine to the grid during the change in the load. In other words, an oscillating in a torsional-mode will happen and if there is no way to protect the shaft, it may be damaged.

Finally, the research approved the possibility of using a (**PMA**) with (**FC**) in (**WT**) to raise the amount of energy that transferred from wind turbines to the electrical grid, taking into account the change in wind speed. Also, the results approved that after applying the different quantities of wind speeds in Table 4 to the module, the maximum turbine output at maximum speed can be sustained and stable as cleared from the curve of the power in Figure 11. In addition, we note from the same curve of power that the edge of the curve before the turbine reaches its specified speed is smooth and this is required to produce a stable capacity without creating an operating disturbance.

Table 4: Wind speeds and Power Output for the Simulated Model

Wind speed (m/s)	**Power out (MW)**
4	0.21
5	0.34
6	0.47
7	0.65
8	0.87
9	1.23
10	1.50
11	1.85
12	2.0
13	2.0
14	2.0
15	2.0
16	2.0
17	2.0
18	2.0

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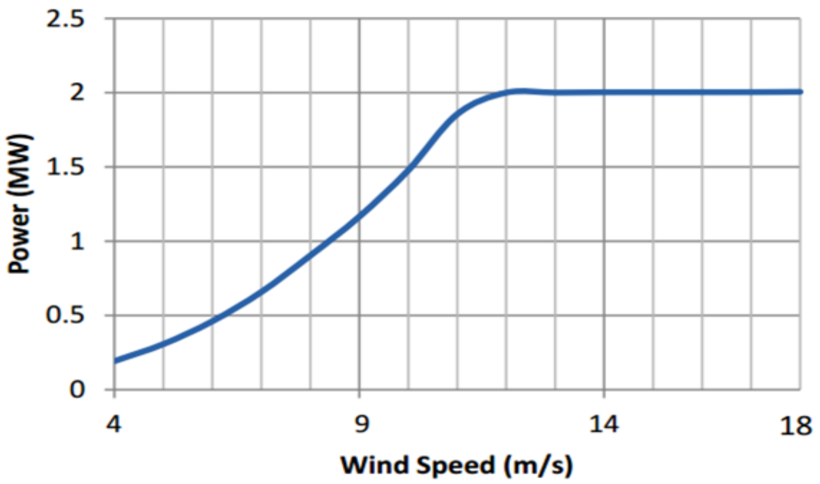

Figure 11: Power Curve for Simulated Model

This research suggests that it is possible to increase the amount of energy produced by wind turbines when considering the design of their electric generator.

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