

Dynamic Response of a Grid Connected Wind Farm with Different Types of Generators

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Article Info

Article history:

Received Nov 10th, 2011

Revised Feb 20th, 2012

Accepted Mar 2nd, 2012

Keyword:

Induction generator
Synchronous generator
Transient analysis
Wind farm

ABSTRACT

For a wide areas wind farm, which composed of different zones of different wind turbines and different generators, this paper aims to simulate a wind farm model that includes a wind turbine and three different types of generators, which are three phase synchronous generator, three phase squirrel-cage induction generator and three phase doubly-fed induction generator, these generators are the main machines that generally used in the field of wind energy generation. All generators are connected in parallel at the point of common coupling (PCC) and connected to the utility grid. This model is a simple representation of the actual model of zafarana wind farm, which is the biggest wind farm in Egypt and further to use it in different kinds of simulations, and display the difference in response among all generators, where all generators are 500 kw power rating, and subjected to the same operating conditions. After modeling the system, the transient response of the system will be studied and analyzed at different operating cases as: case.1 constant wind speed operation; case.2 variable wind speed operation; case.3 sudden change in turbine mechanical power; and case.4 sudden change in wind speed. So this paper introduces a survey on the dynamic response of a large wind farm of different generators at different operating conditions

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1. INTRODUCTION

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern wind turbines, can be used to generate electricity.

In many countries of the world wind power expands, and covers a steadily increasing part of these countries' power demand. From an environmental point of view this is a favorable development, but there are some technical problems that need to be addressed. Growing wind power has impacts on the power systems into which the wind turbines feed their power. Increasing wind power penetration in a power system means, that wind turbines substitute the conventional power plants that traditionally control and stabilize the power system.

The installation of a wind power plant has significantly increased since several years due to the recent necessity of creating renewable, sustainable and clean energy sources. Before the accomplishment of a wind power project many pre-studies are required in order to verify the possibility of integrating a wind power plant in the electrical network. The creation of models in different software and their simulation can bring the insurance of a secure operation that meets the numerous requirements imposed by the electrical system.

2. WIND FARM MODEL

As shown in Figure.1 the wind farm model represents the wind turbine, and three types of generators (three phase synchronous generator, three phase squirrel-cage induction generator and doubly-fed induction generator), all generators are connected in parallel at the point of common coupling (pcc), and connected to the utility grid. All generators are 500 kW in power rating.

The model is created in MATLAB software that enables the dynamic and static simulations of electromagnetic and electromechanical systems where all generators are standard models in MATLAB library. A detailed description of the system dynamics, parameters and analysis can be found in [5]. Since the wind speed is varied, pitch control is used to control the turbine mechanical power and disconnect the turbine at high wind speeds to protect it from damage. Many breakers are added in the system to disconnect any unit at any time, and at any abnormal operation or faults.

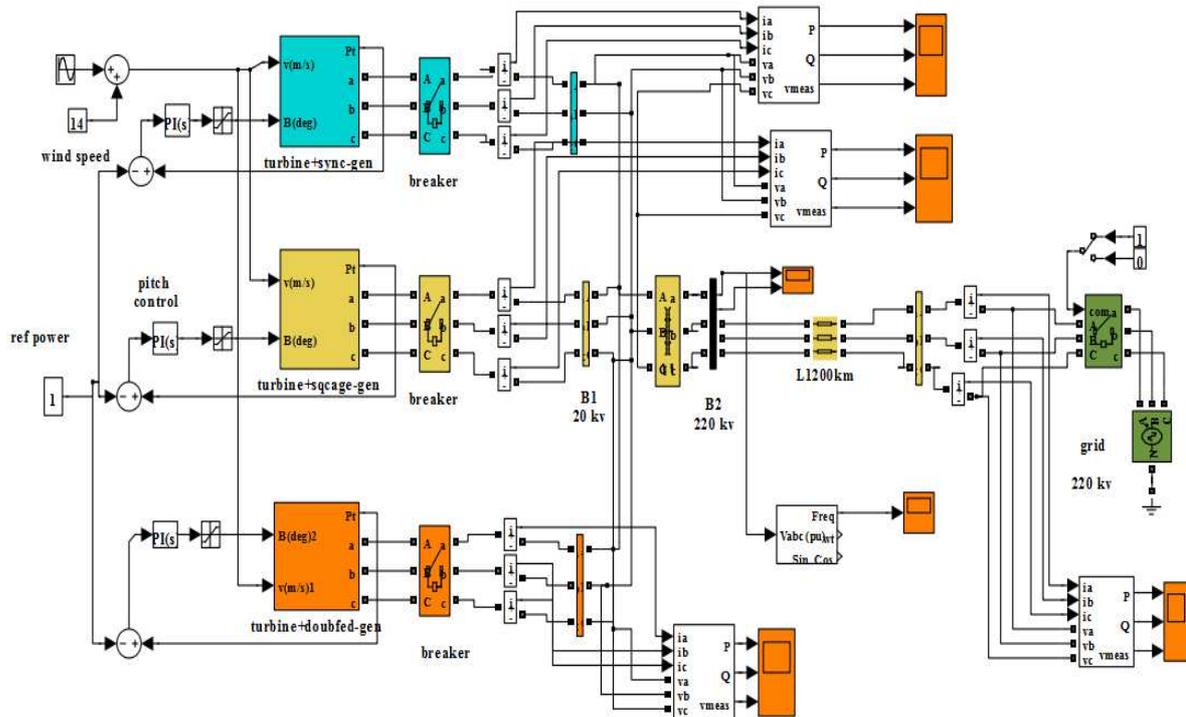


Fig.1 the wind farm simulation diagram

3. NORMAL OPERATION AT CONSTANT WIND SPEED

In case.1 the dynamic response of the wind farm will be simulated at a constant wind speed, this ideal case will aid in studying the response of the wind turbine and the different generators without any disturbance or abnormality.

Figure.2 shows the wind speed, which is assumed to be constant at 13 m/s this value is selected from the wind turbine characteristics [5] to cover the generators rated power. Figures 3, figure 4, and figure 5 show the active and reactive power in pu of the synchronous generator, squirrel-cage induction generator, and doubly-fed induction generator respectively. The wind turbine pitch angle is controlled by a PI controller for each generator to achieve rated power of the wind turbine for each generator.

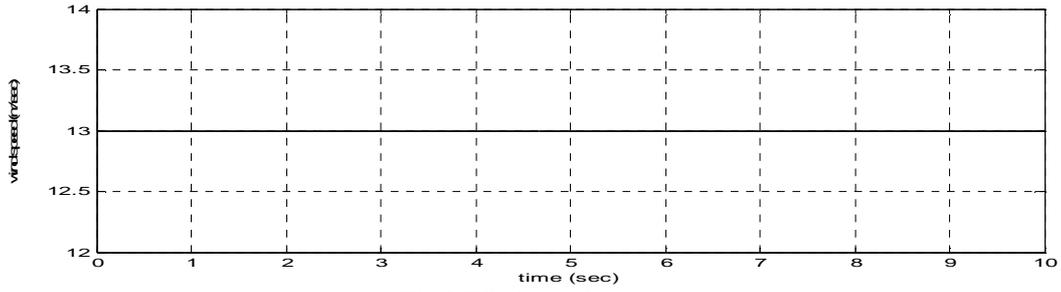


Fig.2 Wind speed (m/s)

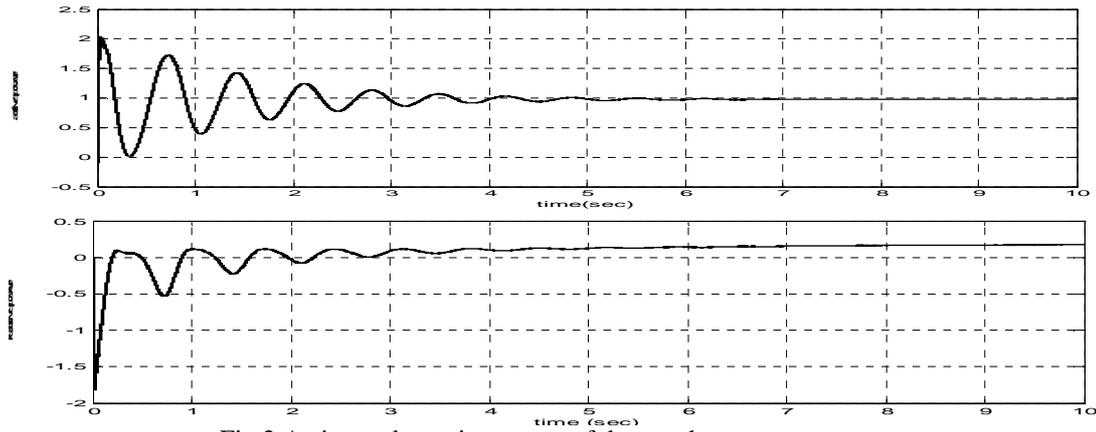


Fig.3 Active and reactive power of the synchronous generator

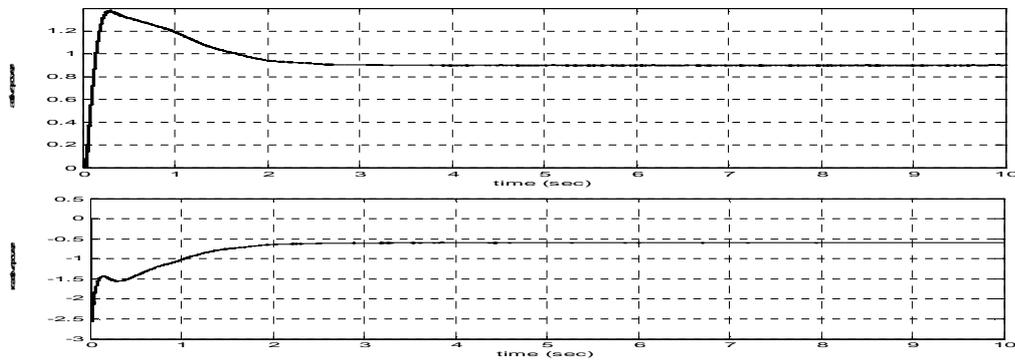


Fig.4 Active and reactive power of the squirrel-cage generator

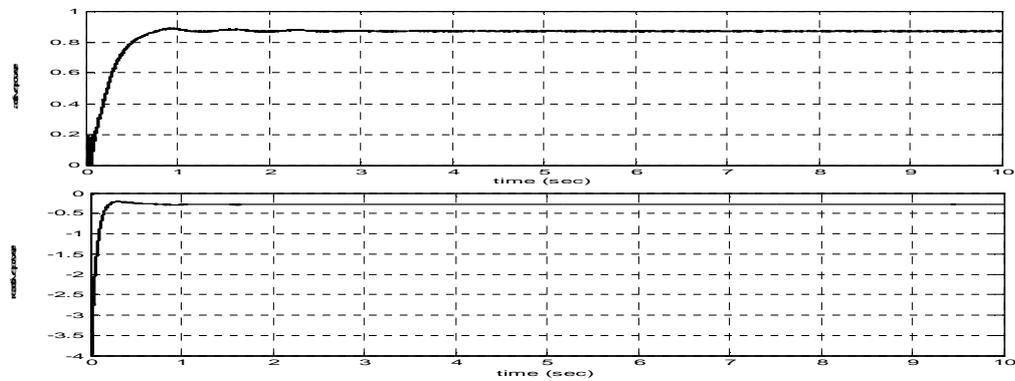
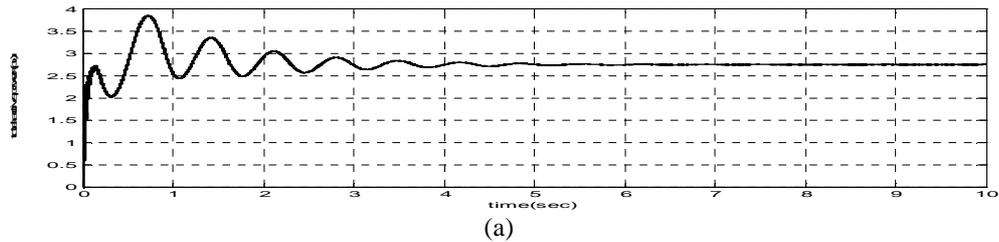
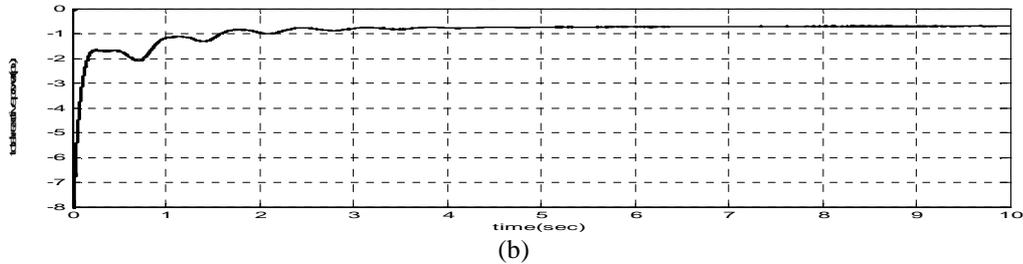


Fig.5 Active and reactive power of the doubly-fed generator

Figure 6.a and figure 6.b show the total active and reactive power of the overall wind farm; these powers are simply the sum of the powers of all generators.



(a)
Fig.6.a total active power of the wind farm



(b)
Fig.6.b total reactive power of the wind farm

Figure.7 and figure.8 show the grid frequency and root mean square voltage at the point of common coupling, the frequency and voltage values are satisfying the grid code requirement [1].

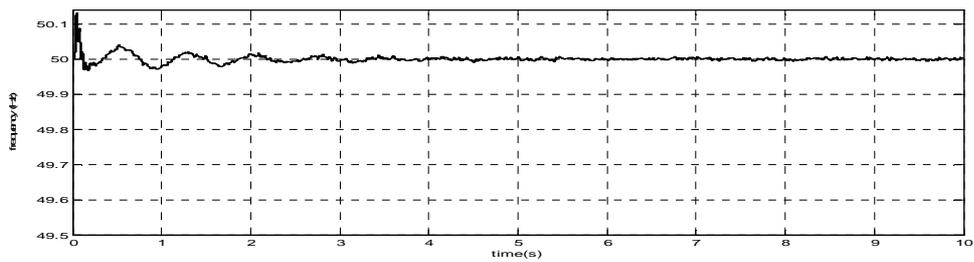


Fig.7 grid frequency at the point of common coupling

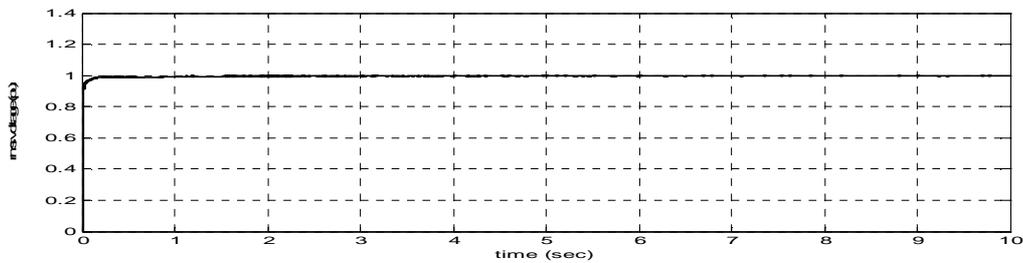


Fig.8 grid rms_voltage at the point of common coupling

4. NORMAL OPERATION AT THE NATURAL WIND SPEED VARIATIONS

In case.2 the dynamic response of the wind farm will be studied at the natural wind speed variations, figure 9.a shows the reference power and the actual wind turbine power, where the reference power is taken 0.7 pu. Figure 9.b and figure 9.c show the wind speed and the pitch angle.

Figures 10, figure 11, and figure 12 show the active and reactive power of the synchronous, squirrel-cage, and doubly-fed generators respectively. The wind turbine pitch angle is controlled by a PI controller to achieve the reference power of the wind turbine and generators.

Figure 13 shows the total active and reactive power of the wind farm, these powers are simply the sum of the powers of all generators.

Figure 14 and figure 15 show the grid frequency and the grid root mean square voltage at the point of common coupling. The frequency and voltage values are satisfying the grid code requirement [1].

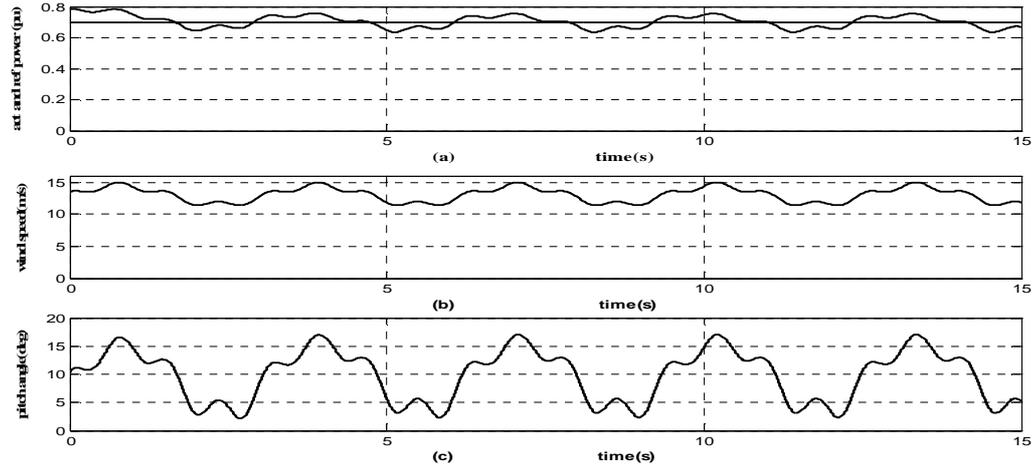


Fig.9 (a) reference and actual power (pu), (b) wind speed (m/s), (c) pitch angle (deg)

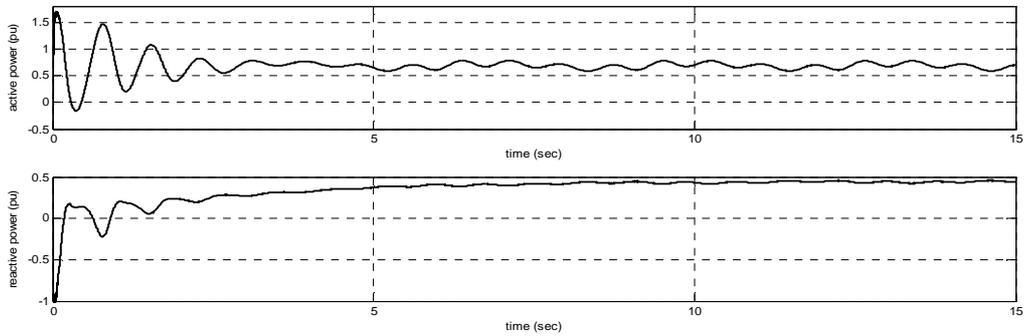


Fig.10 active and reactive power of the synchronous generator

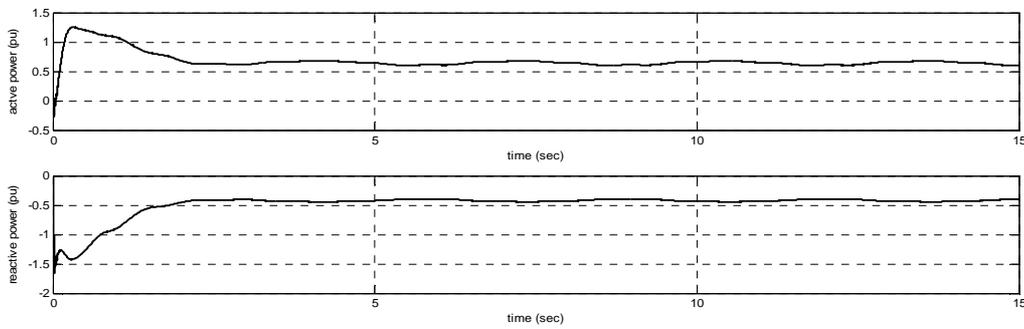


Fig.11 active and reactive power of the squirrel-cage induction generator

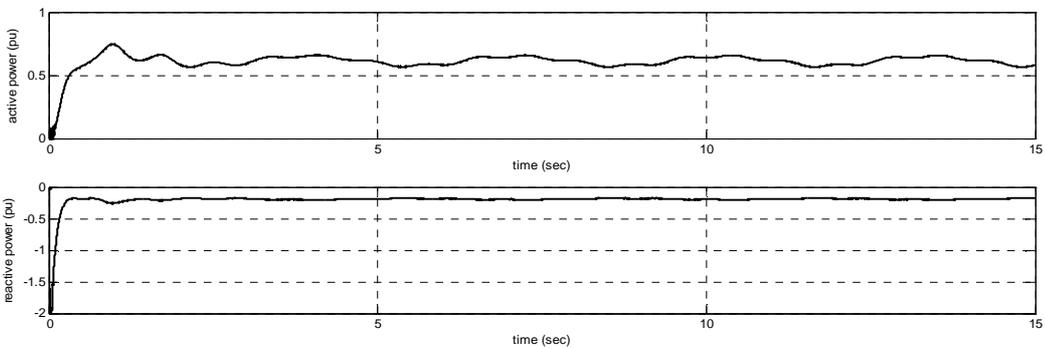


Fig.12 active and reactive power of the doubly-fed induction generator

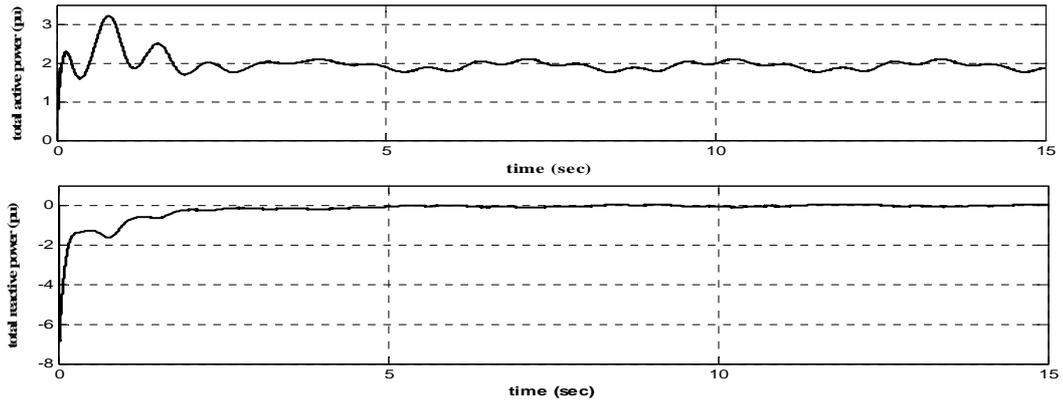


Fig.13 total active and reactive power of the wind farm

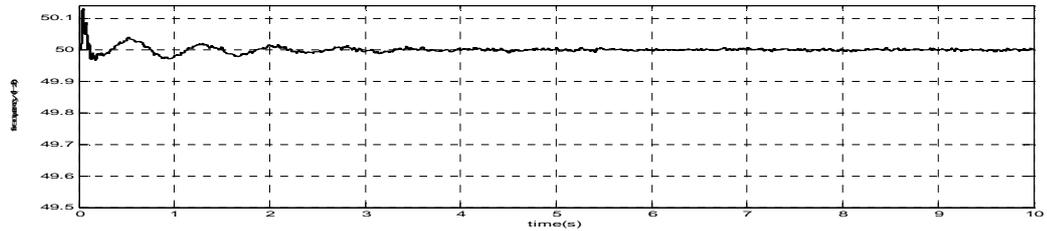


Fig.14 grid frequency at the point of common coupling

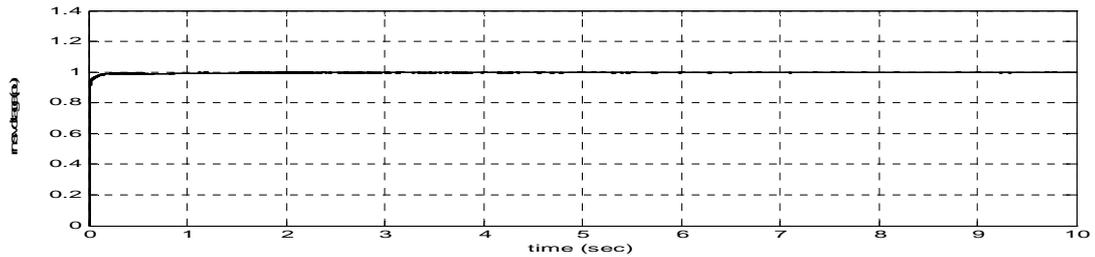


Fig.15 grid rms_voltage at the point of common coupling

5. STEP CHANGE IN TURBINE MECHANICAL POWER

In case.3 the dynamic response of the wind farm will be studied at a step change in reference power and at the natural wind speed variations, figure 16.a shows the reference power wind turbine power, where the reference power changes from 0.5 pu to 1pu and come back to 0.5 pu again. Figure 16.b and figure 16.c show the wind speed and the pitch angle.

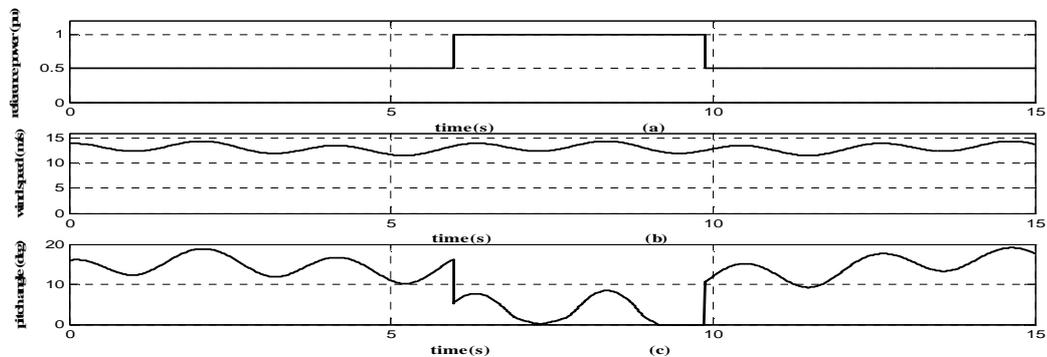


Fig.16 (a) reference power, (b) wind speed, (c) pitch angle

Figure 17 shows the synchronous generator rotor speed, and the stator current during the tracking process, the speed is almost constant, but the stator current increases with increasing the reference power.

Figure 18 shows the active and reactive power of the synchronous generator during tracking the reference power.

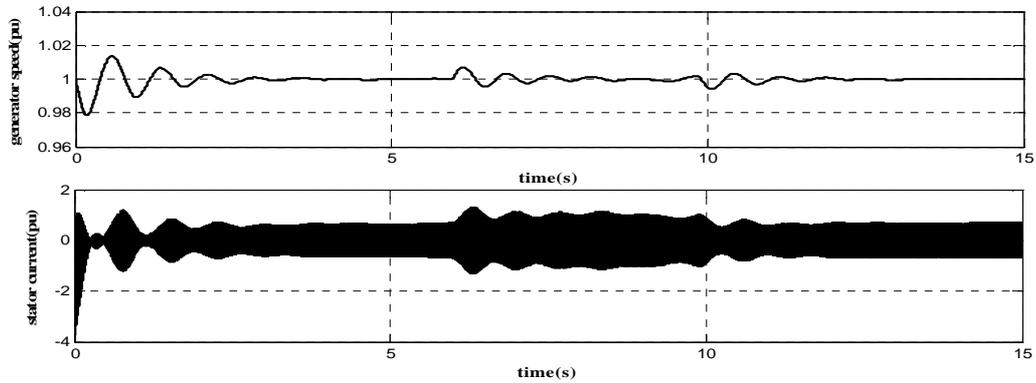


Fig.17 the synchronous generator rotor speed, stator current during the tracking process

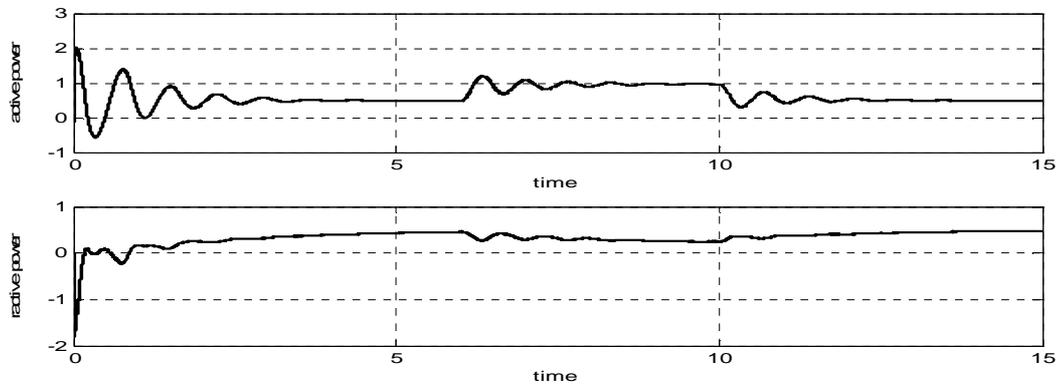


Fig.18 active and reactive power of the synchronous generator during tracking process

Figure 19 shows the squirrel-cage induction generator rotor speed, and the stator current during the tracking process, the speed has a small variation with load, but the stator current increases with increasing the reference power. Figure 20 shows the active and reactive power of the synchronous generator during tracking the reference power. Figure 21 shows the doubly-fed induction generator rotor speed, the stator, and rotor currents during the tracking process, the speed has a small variation during the tracking process, but the stator and rotor currents increase with increasing the reference power. Figure 22 shows the active and reactive power of the doubly-fed induction generator during tracking the reference power.

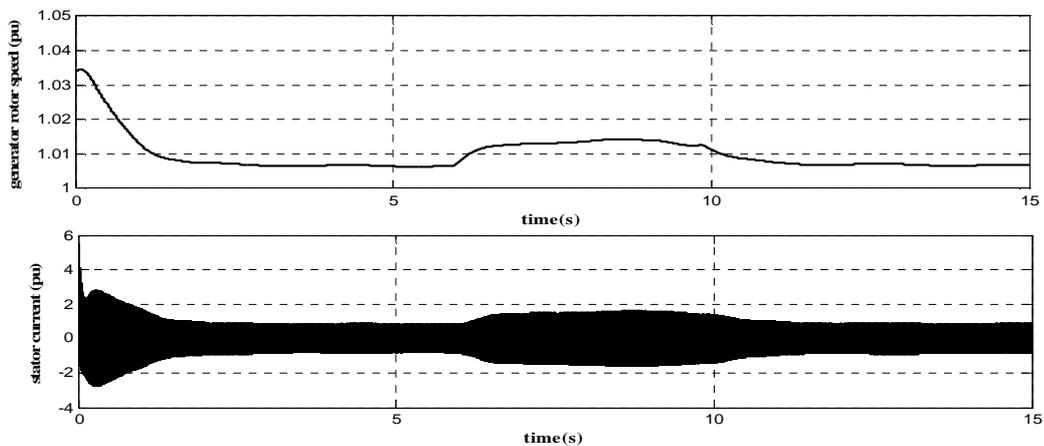


Fig.19 squirrel-cage induction generator rotor speed, stator current during tracking process

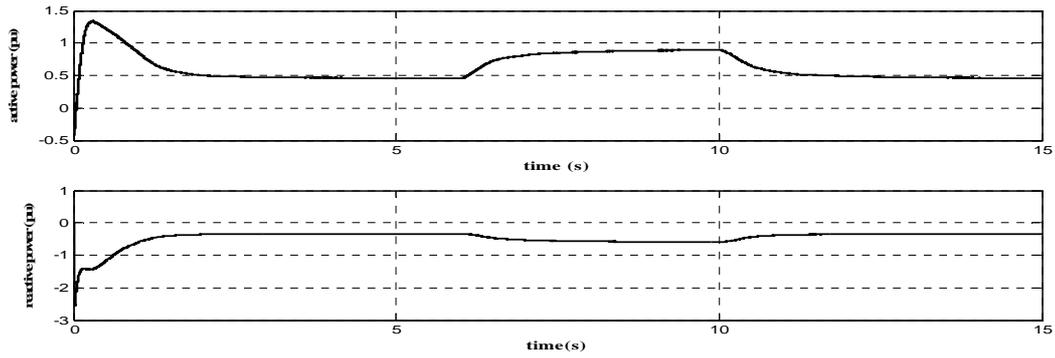


Fig.20 active and reactive power of the squirrel-cage induction generator during tracking process

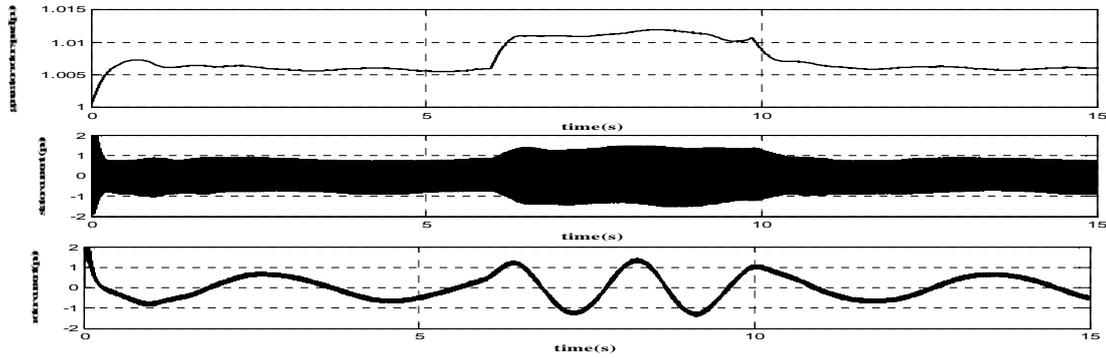


Fig.21 doubly-fed induction generator rotor speed, stator current, and rotor current during tracking process

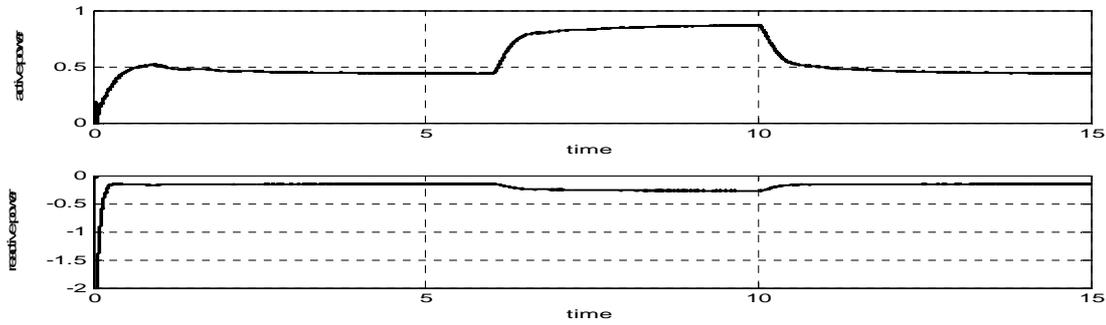


Fig.22 active and reactive power of the doubly-fed induction generator during tracking process.

Figure 23 shows the total active and reactive power of the wind farm, these powers are simply the sum of the powers of all generators

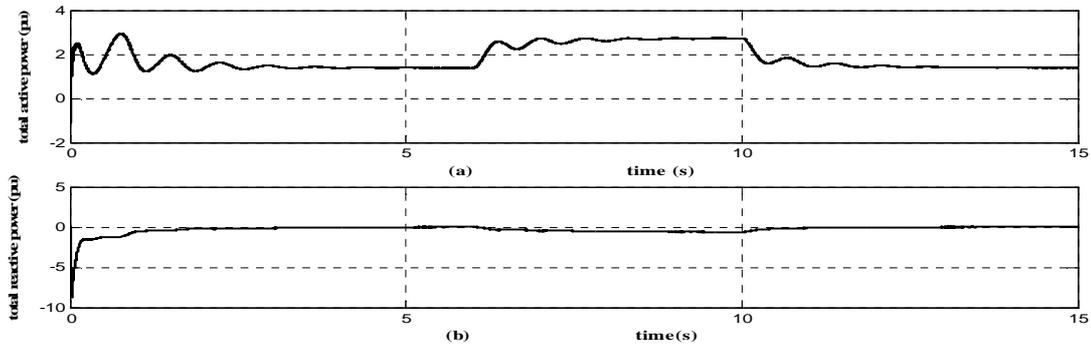


Figure 23 (a) total active power (b) total reactive power

Figure 24 and figure 25 show the grid frequency and root mean square voltage at the point of common coupling. The frequency and voltage values are satisfying the grid code requirement [1], and they have a unnoticeable oscillations during the tracking operation.

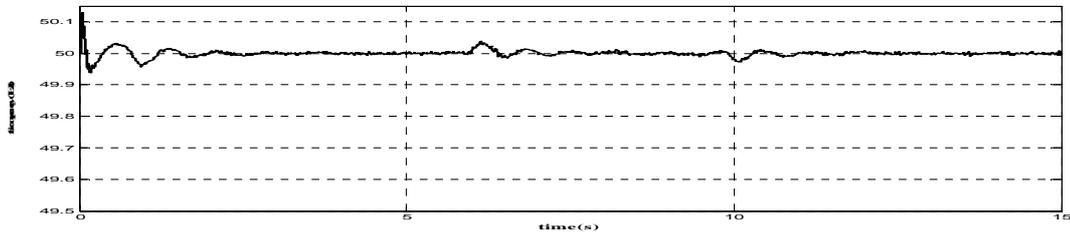


Figure 24 the grid frequency

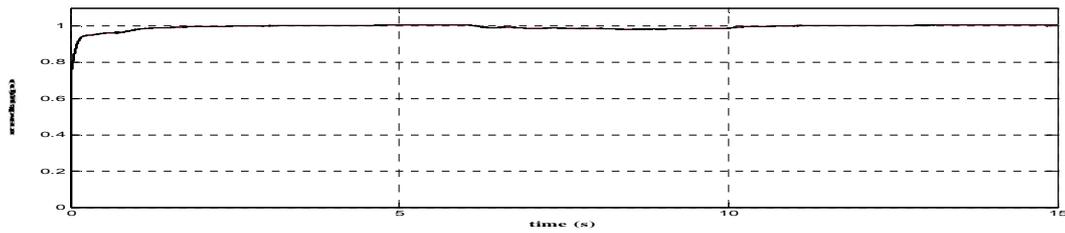


Fig. 25 the grid root mean square voltage at the point of common coupling.

6. SEP CHANGE IN WIND SPEED

In case.4 the dynamic response of the wind farm will be studied at a step change in wind speed with the natural variations in speed. No pitch control is assumed in this case, and the turbine mechanical power depends on the wind speed and the tip speed ratio. Figure 26 shows the wind speed which is varied steeply after 10 seconds.

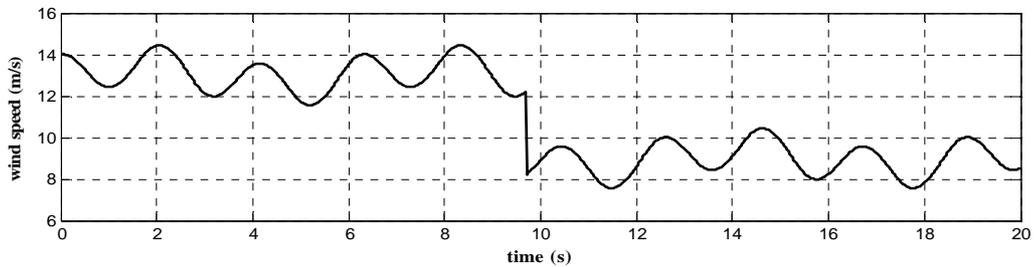


Fig.26 variable wind speed (m/s)

Figure 27 and figure 28 show the grid frequency, and voltage at the point of common coupling during a step change in the wind speed, the frequency is not affected by this change in wind speed, but the grid voltage at the point of common coupling has alight increase with decreasing the wind speed.

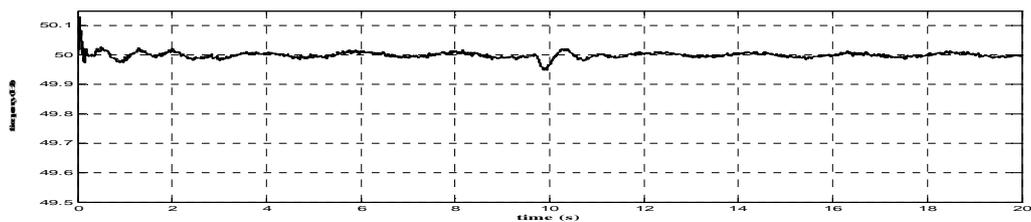


Fig. 27 the grid frequency during step change in wind speed

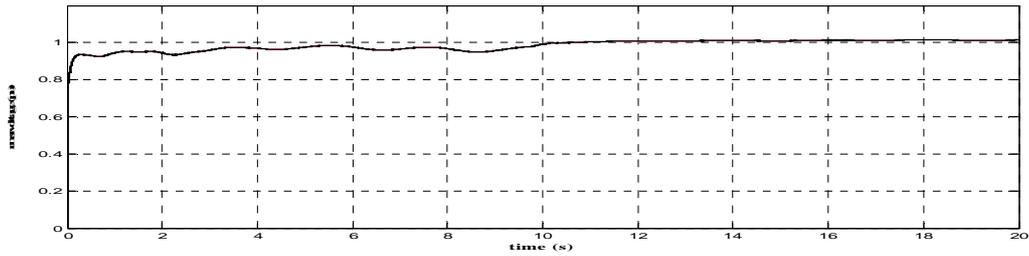


Fig. 28 the grid root mean square voltage at the point of common coupling, during step change in wind speed

Figure 29 shows the synchronous generator rotor speed, and the stator current during the tracking process, the speed is almost constant, but the stator current increases with increasing the reference power. Figure 30 shows the active and reactive power of the synchronous generator during tracking the reference power.

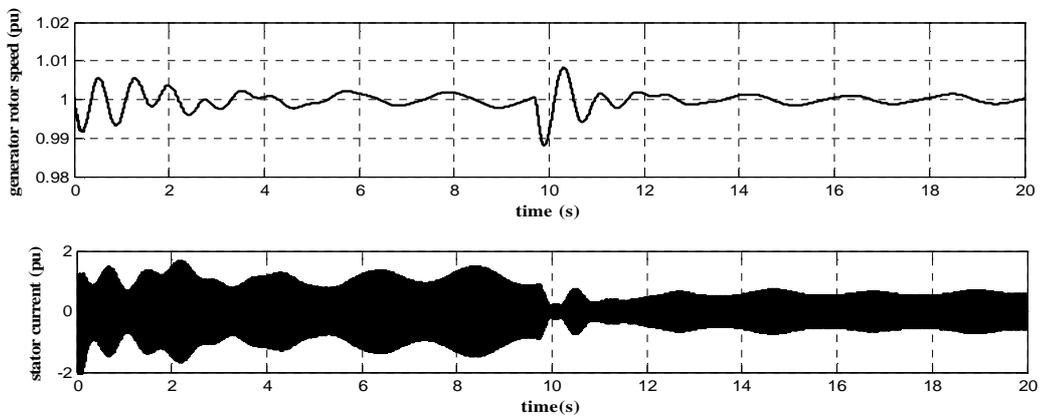


Fig.29 the synchronous generator rotor speed and stator current during step change in wind speed

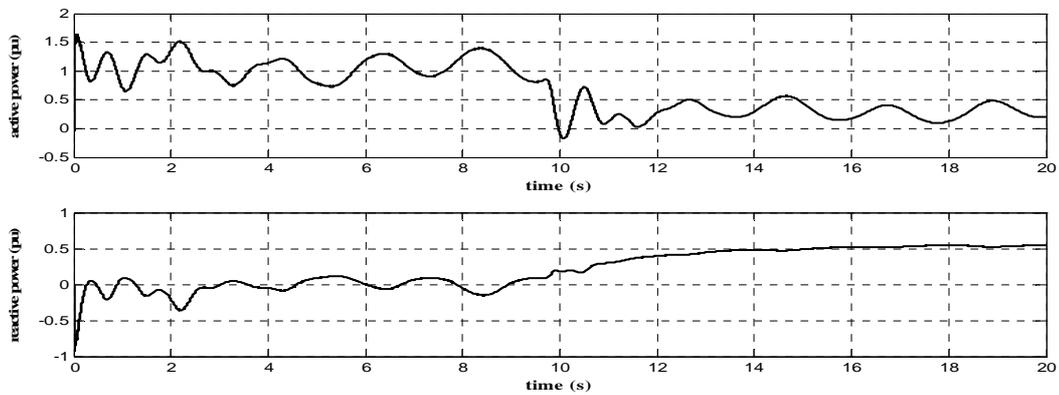


Fig. 30 active and reactive power of the synchronous generator during step change in wind speed

Figure 31 shows the squirrel-cage induction generator rotor speed, and the stator current during the tracking process, the speed has a small variation with load, but the stator current increases with increasing the reference power. Figure 32 shows the active and reactive power of the synchronous generator during tracking the reference power.

Figure 33 shows the doubly-fed induction generator rotor speed, the stator, and rotor currents during the tracking process, the speed has a small variation during the tracking process, but the stator and rotor currents increase with increasing the reference power. Figure 34 shows the active and reactive power of the doubly-fed induction generator during tracking the reference power.

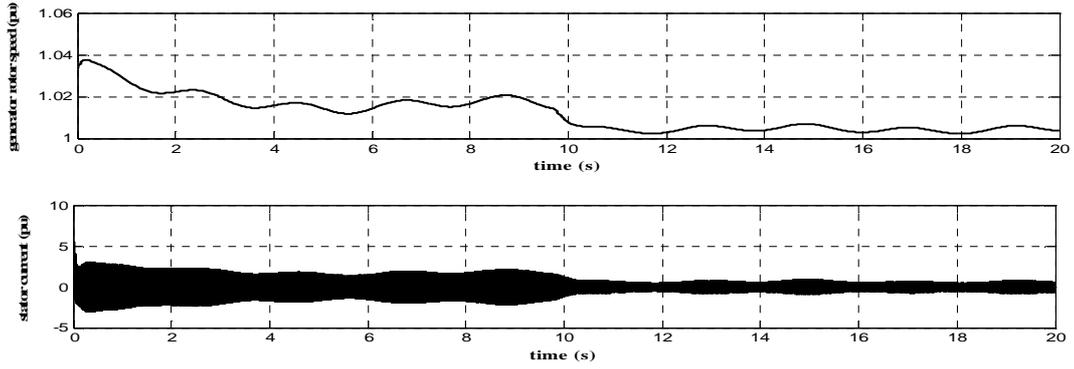


Fig.31 squirrel-cage induction generator rotor speed and the stator current during step change in wind speed

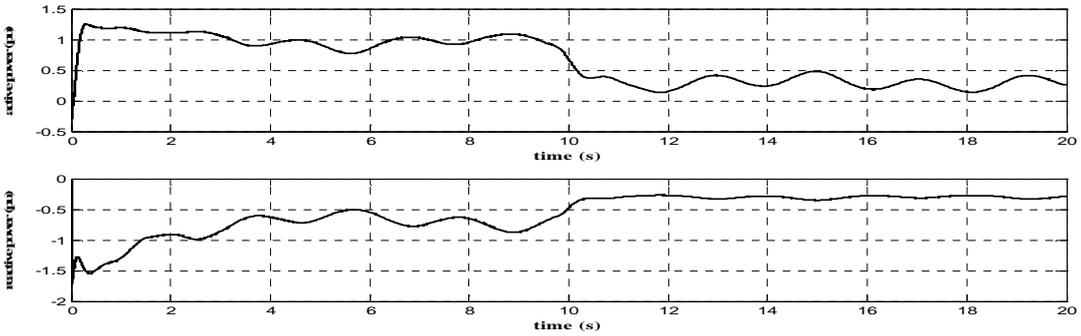


Fig.32 active and reactive power of the squirrel-cage induction generator during tracking process

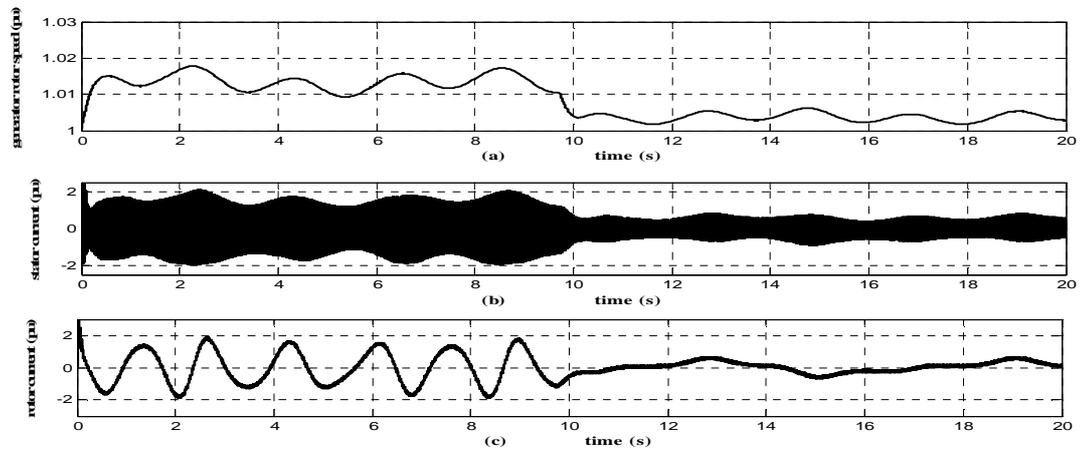


Fig. 33 doubly-fed induction generator (a) rotor speed (b) stator (c) rotor currents during the tracking process, the speed has a small variation during step change in wind speed

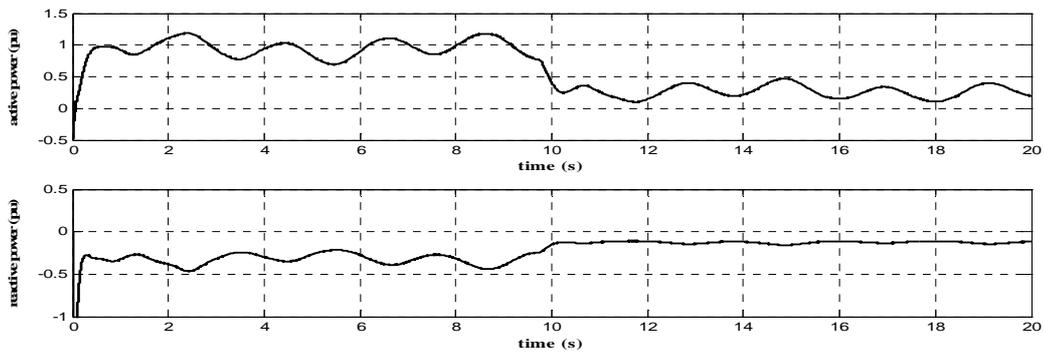


Fig.34 active and reactive power of the doubly-fed induction generator during tracking the reference power.

Figure 35 shows the total active and reactive power of the wind farm, these powers are simply the sum of the powers of all generators

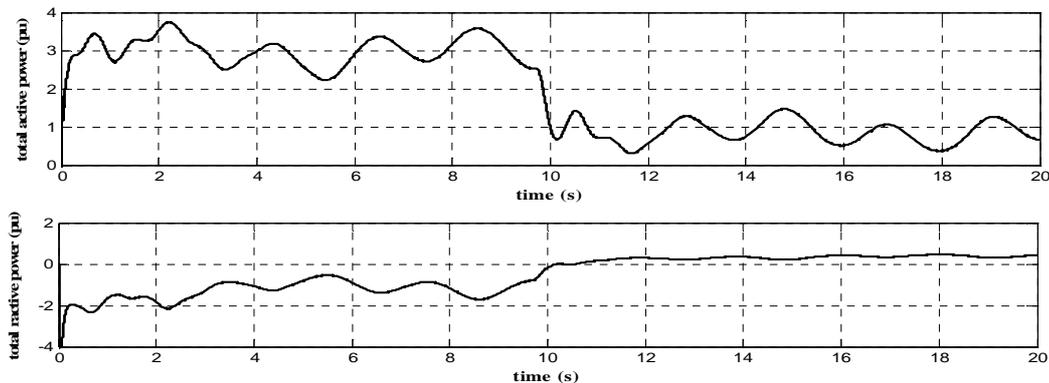


Fig. 35 total active and reactive power of the wind farm

7. CONCLUSION

It is shown in this paper that a fixed speed active-stall wind turbine, which has only its pitch system to control its output power, is capable of contributing to the damping of power system oscillations due to the variation in wind speed, a PI controller used here to control the turbine mechanical output power as the wind speed varied. If the controller is not used the turbine power depends on the wind speed and the tip speed ratio at that speed. It is shown in this paper that the doubly-fed induction generator is more robust and has smoother characteristics than squirrel cage induction generator than synchronous generator respectively but needs a complicated control system. At a variable wind speed the generators power is not the maximum available power in the wind, so a power electronic control system must be used to adjust the generators speed with the variation in wind speed to obtain optimal tip speed ratio and maximum power coefficient. Since the rotor in a SG rotates synchronously with the stator field, the rotor speed is the same as the electrical frequency. Hence, rotor speed oscillations are grid frequency oscillations, which have to be dampened before the whole system becomes unstable. In a conventional power plant, SG equipped with power system stabilizers dampens these oscillations. If future wind farms substitute a considerable amount of conventional power plants, these wind farms have to be involved in the damping of grid frequency and inter-area oscillations

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