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Simulation of the Different Transmission Line Faults for a Grid Connected Wind Farm with Different Types of Generators

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Abstract:
This paper aims to simulate a wind farm model that includes 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, 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 with the same power rating (500 kW) and subjected to the same operating conditions and faults. This paper describes the simulation of the different faults that occur along the transmission line of the power system such as single-line fault, line to line fault, double lines to ground fault, and finally three line faults. The response of the wind turbine and the different generators will be analyzed and discussed to compare the transient response of all generators at the different types of faults, where the fault period is selected to be 300 ms. The model is created in MATLAB software that enables the dynamic and static simulations of electric, electromagnetic and electromechanical systems. The machines are standard blocks in the software library.

***Keywords**: transient faults, wind farm, simulation model.*

1. Introduction

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. In many countries all over the world wind power is expanding and covers a steadily increasing part of these countries' power demand. However, if wind turbines are to substitute for conventional power plants they have to take over many of the control tasks that keep the power system stable [1]. One of these control tasks is to ride through transient faults in power systems. This means that generation must not be lost due to voltage excursions caused by transient faults. As wind power penetration increases, the respective power system operators are concerned about the stability and reliability of their networks. This is why many power system operators issue grid connection requirements that specifically address wind turbines and demand them to ride through transient faults.

So this paper introduces a survey on the different possible line faults that may be occur in the power system and discuss the severity of each one and the effect of each fault on the grid voltage and frequency. The response of each machine pre- and after each type of fault case will be discussed.

2. Wind Farm Model

As shown in Fig.1 the wind farm model represents the wind turbine which takes its natural wind speed variation , and three types of generators (three-phase synchronous generator , three-phase squirrel-cage induction generator and three-phase 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 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.

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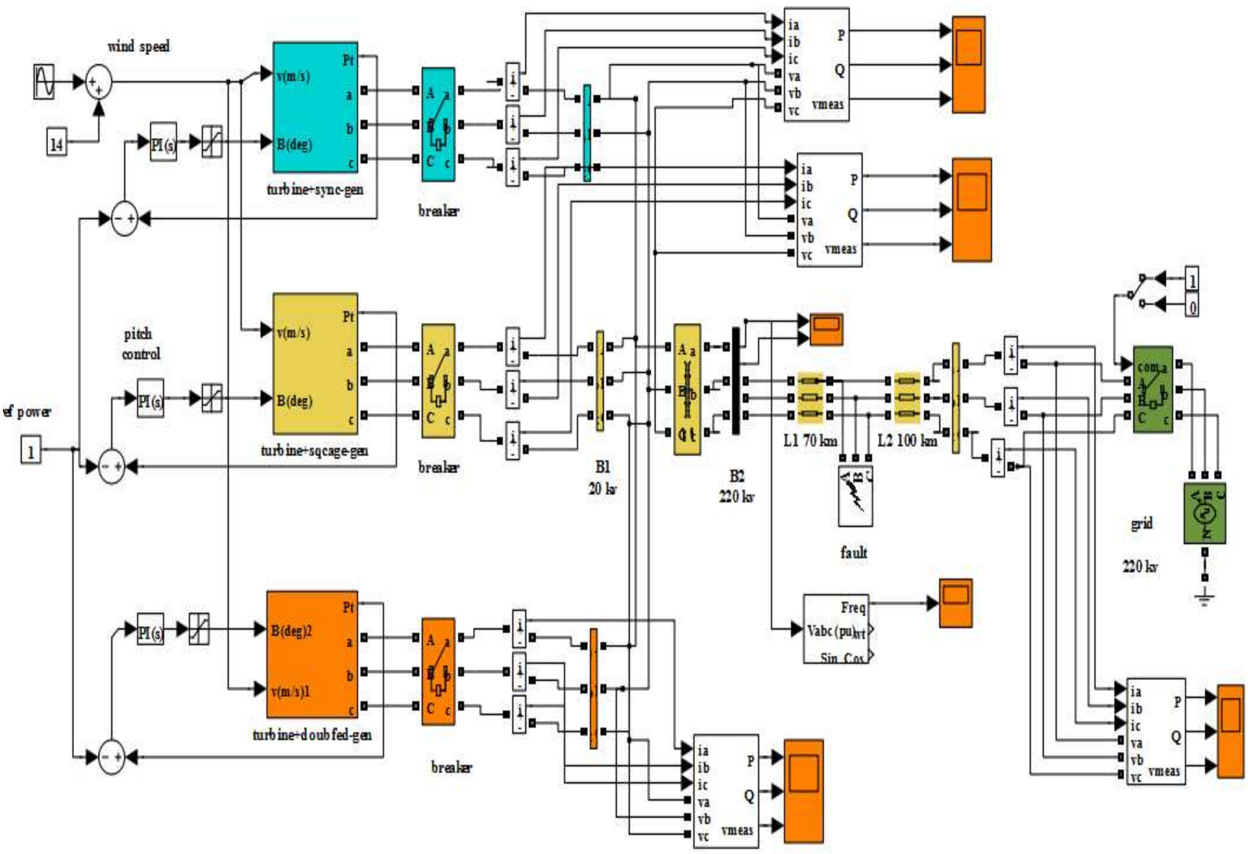

Fig..1 System model diagram

3. Single-line to ground fault

The frequency in an AC power system is stable when the electrical demand plus the electrical losses equal the electrical generation in the system. An imbalance between generation and demand leads to rising grid frequency if the generation exceeds demand, and to dropping grid frequency if the demand exceeds the generation. The grid frequency finds a new equilibrium if there is either sufficient frequency sensitive load in the system, or if the generators are equipped with governors that adjust the prime mover power so the generators pull the frequency back to its rated value. Governor controllers, which control the mechanical power of the prime mover, are used to control the steady state frequency of the system in all modern power systems.

If a change in load or in generation happens gradually, the frequency will deviate gradually. If a step change happens, the frequency will experience transient oscillations before it settles to its new equilibrium. In case 1 a single-line to ground fault where phase A is selected to be shorted with the ground from the time 8 sec to 8.3 sec for 300 ms period and 70 km distance from the point of common coupling, the simulation shows the effect of this fault on the grid frequency , voltage , and the wind system. Fig. 2 and Fig. 3 show the grid frequency and voltage at the point of common coupling pre- and after the fault clearance, during the fault period the frequency has a light oscillations and the voltage become 13% of its rated value, and after fault clearance the frequency and voltage come back to their rated values within the grid code requirements [2].

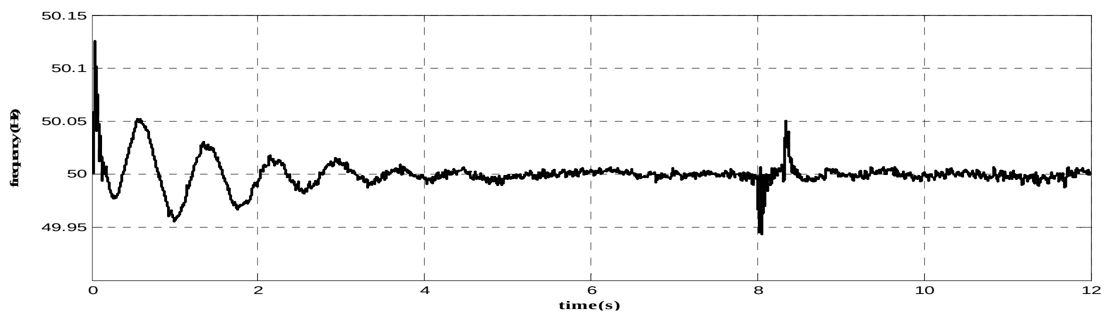

Fig. 2 Frequency of the power system at the point of common coupling pre- and after fault clearance

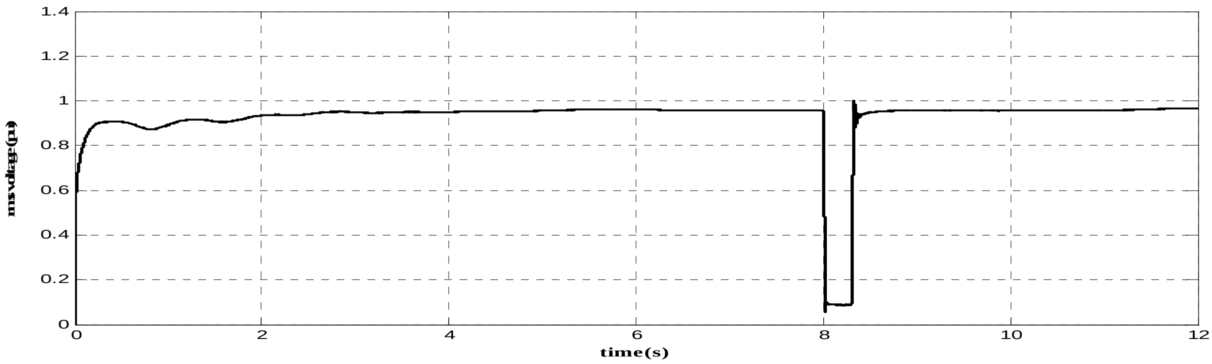

Fig.3 Rms_voltage of the grid at the point of common coupling pre- and after fault clearance

Fig. 4 to Fig. 6 show the active and reactive power of each generator before and after the fault occurrence, during the fault period the machine active power is reduced and the reactive power is increased to compensate the grid voltage. After the fault clearance all powers come back to the pre- fault value, and the system is stable and has a good performance.

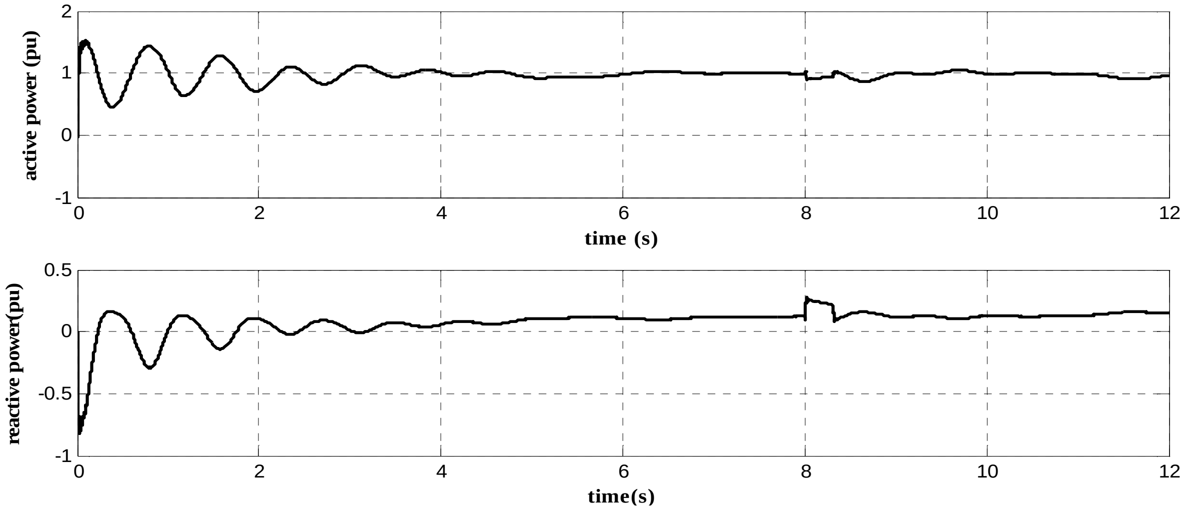

Fig.4 active and reactive power of the synchronous generator pre- and after fault clearance

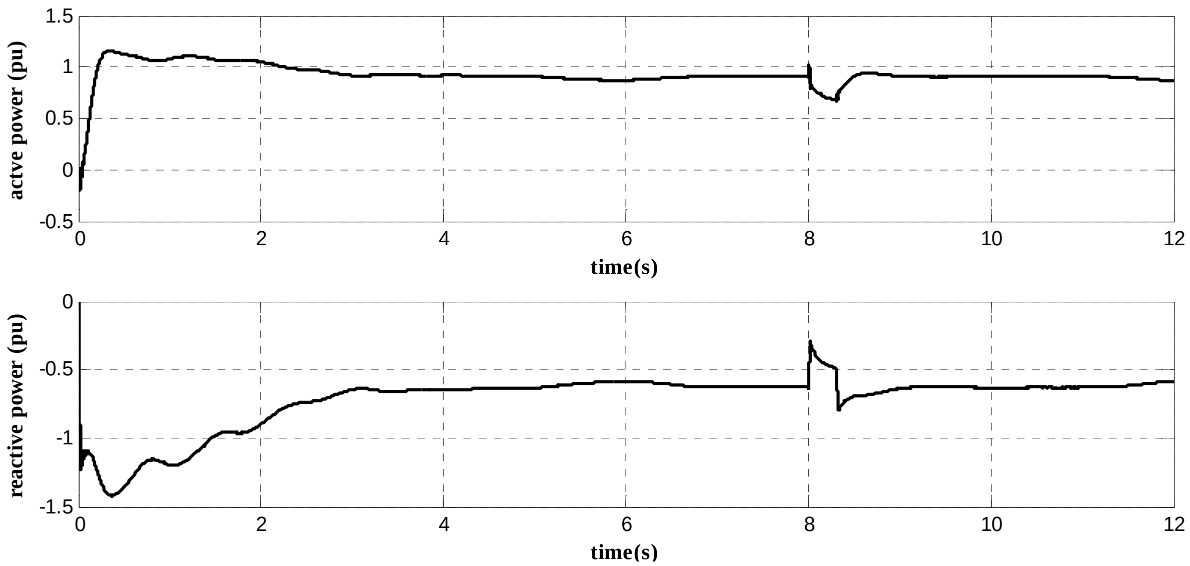

Fig.5 active and reactive power of the squirrel-cage induction generator pre- and after fault clearance

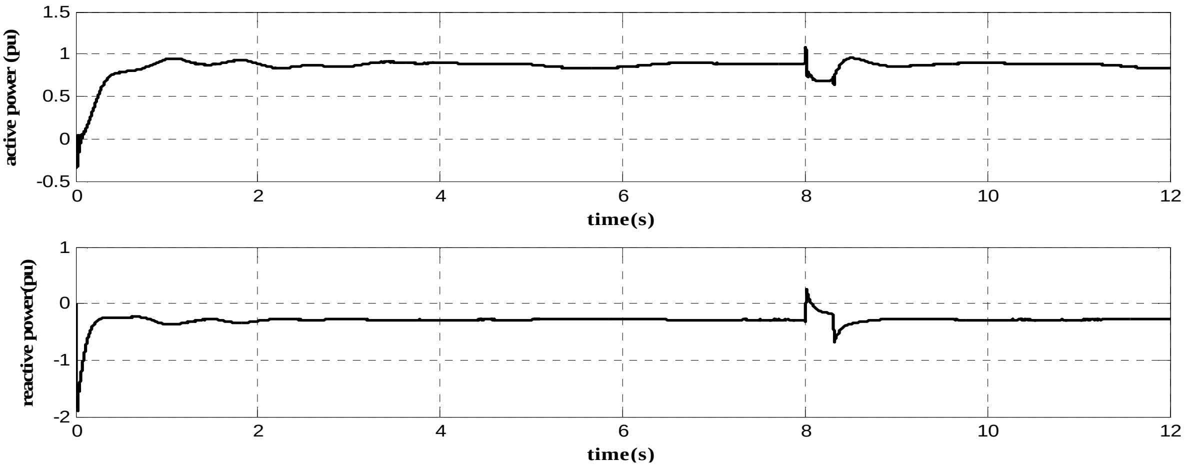

Fig.6 active and reactive power of the doubly-fed induction generator pre- and after fault clearance

4. line to line fault

Case 2 represents a line to line fault, where phase A and B are selected to be shorted from the time 8 sec to 8.3 sec for 300 ms at 70 km distance from the point of common coupling . Fig. 7 and Fig. 8 show the grid frequency and voltage at the point of common coupling pre- and after the fault, during the fault period the frequency has a high oscillations compared to case1, and the voltage become 33% of its rated value, and after fault clearance the frequency and voltage come back to its rated values but after a long time compared to case1.

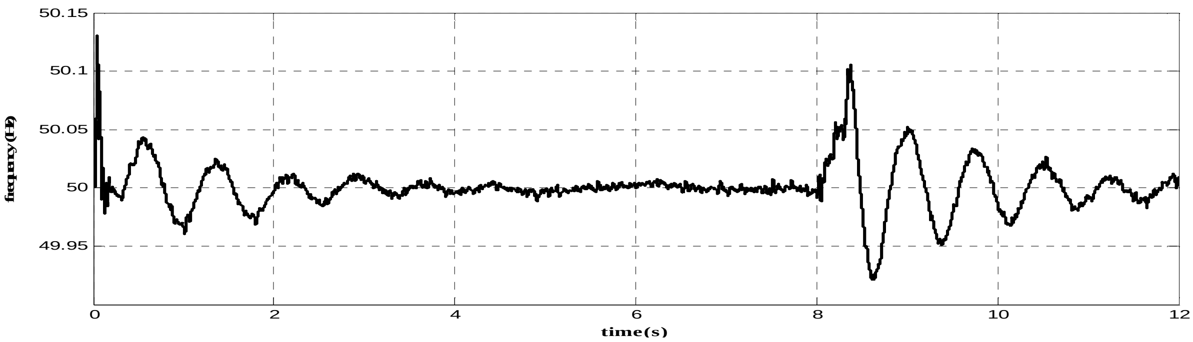

Fig. 7 frequency of the power system at the point of common

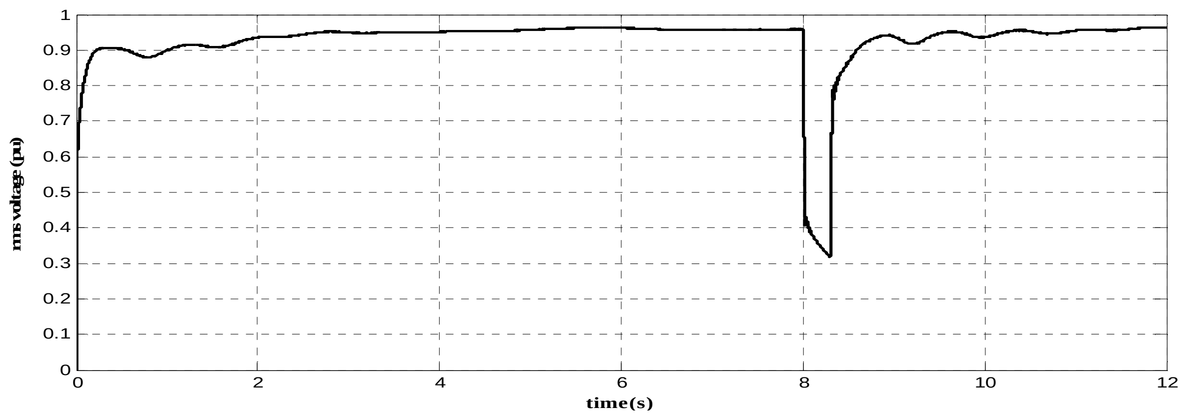

Fig. 8 Rmss_voltage of the power system at the point of common coupling pre- and after fault clearance

Fig. 9 to Fig. 11 show the active and reactive power in pu of the different machines, during the fault period, the machine active power is reduced and the reactive power is increased to compensate the grid voltage. After the fault clearance all values come back to the pre- fault values with a comparative longer time with case 1 , and the system is stable and has a good performance but less than case 1.

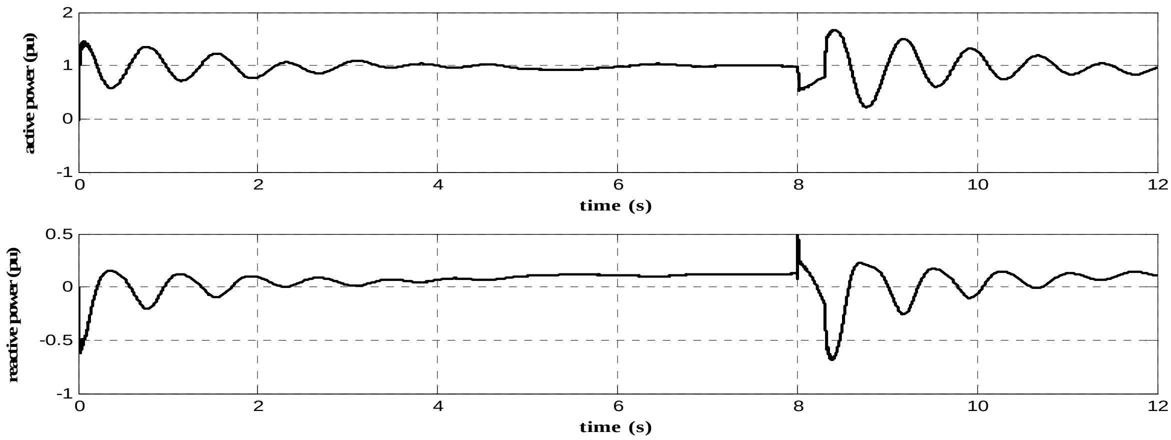

Fig.9 active and reactive power of the synchronous generator pre- and after fault clearance

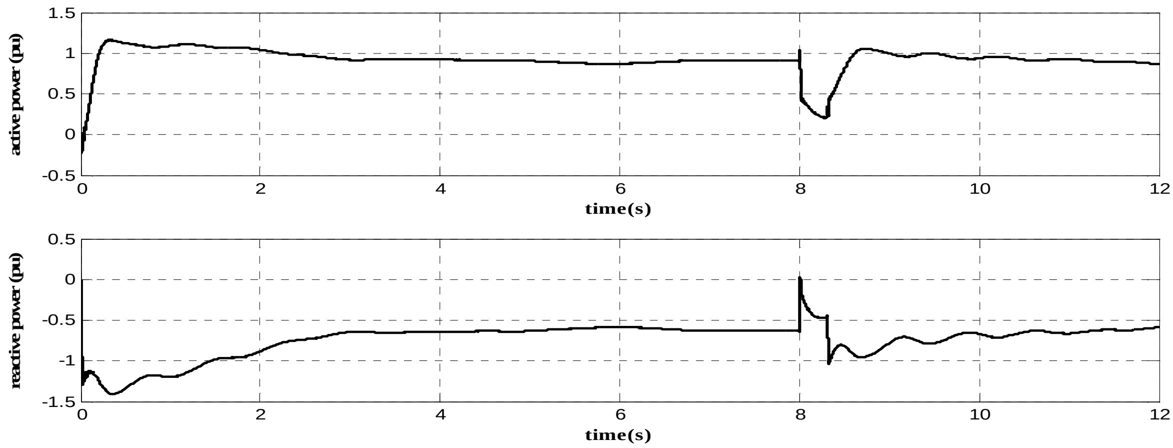

Fig.10 active and reactive power of the squirrel- cage induction generator pre- and after fault clearance

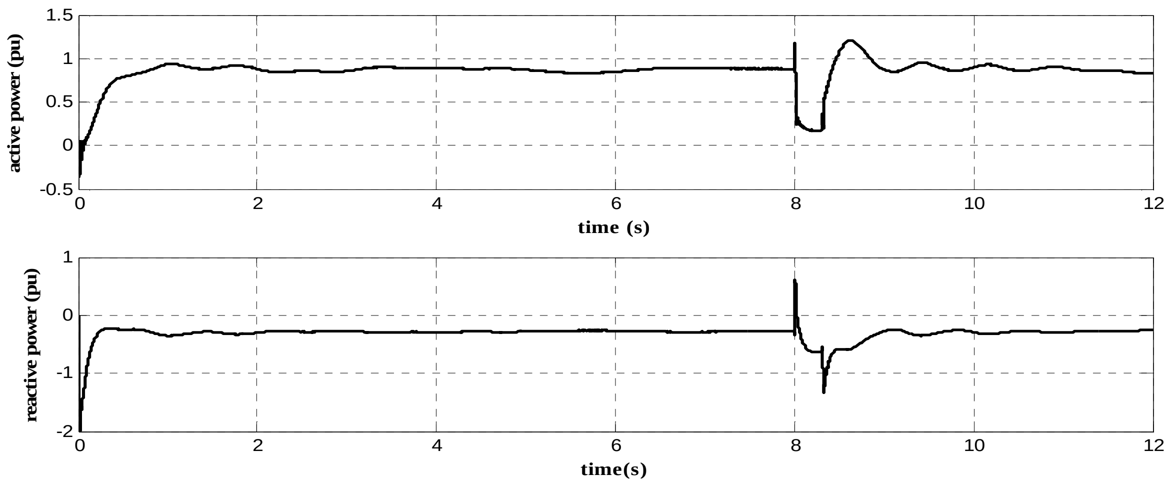

Fig. 11 active and reactive power of the doubly-fed induction generator pre- and after fault clearance

5. Double -lines to ground fault

Case 3 represents a double-lines to ground fault where phase A and B are selected to be shorted with the ground from the time 8 sec to 8.3 sec for 300 ms at 70 km distance from the point of common coupling, the following Fig.s show the effect of this fault on the grid frequency, voltage, and the wind system.

Fig. 12 and Fig. 13 show the grid frequency and voltage at the point of common coupling pre- and after the fault, during the fault period the frequency has high oscillations as in case 2 and the remaining voltage become 15% of its rated value, after the fault clearance the frequency and voltage come back to its rated values.

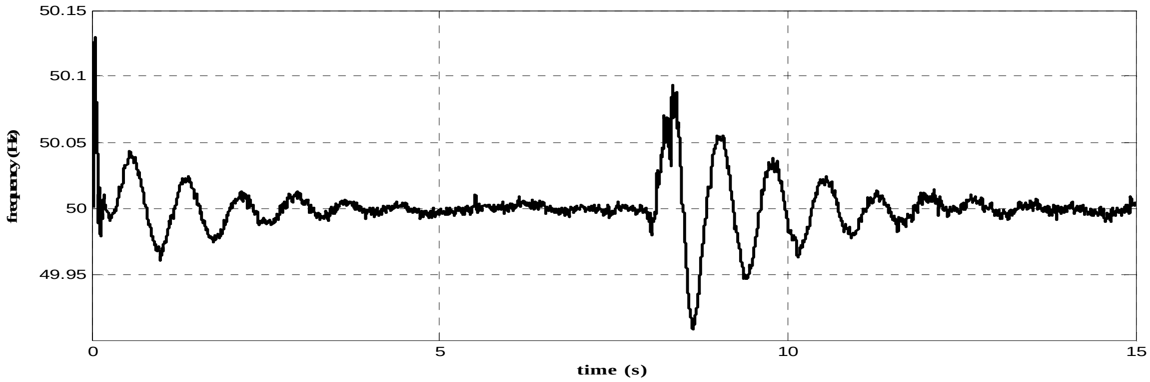

Fig.12 frequency of the power system at the point of common coupling

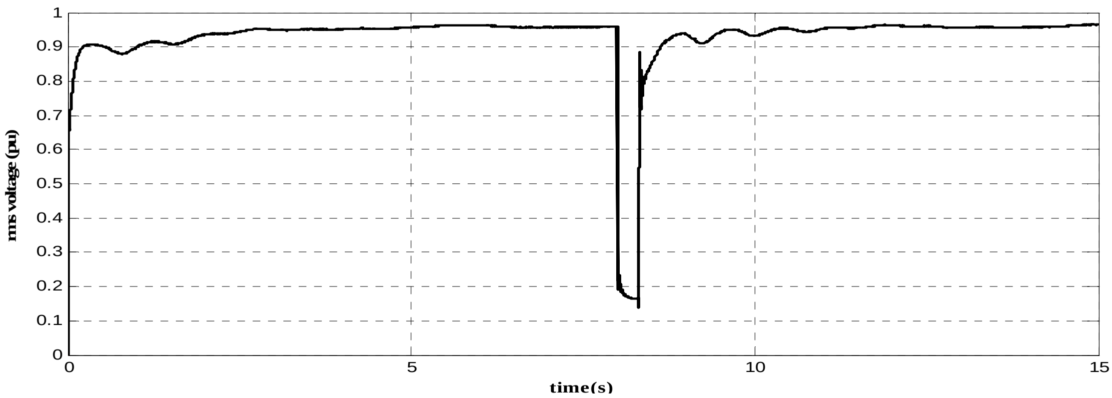

Fig.13 Rms_voltage of the power system and at the point of common coupling pre- and after fault clearance

Fig. 14 to Fig. 16 show the active and reactive power in pu of the different machines, during the fault period the machine active power is reduced and the reactive power is increased to compensate the grid voltage. After the fault clearance all powers come back to the pre- fault value, and the system is stable and has a performance similar to case 2.

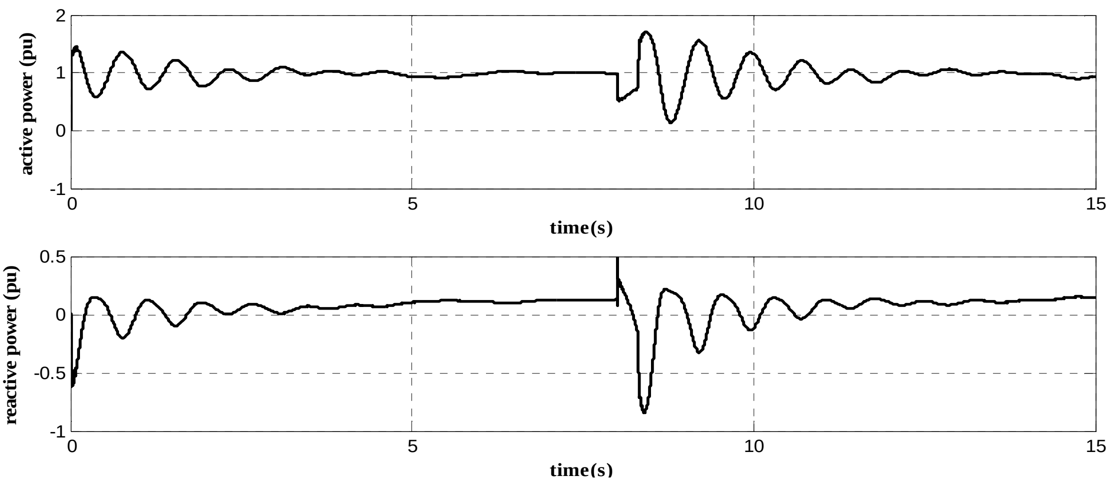

Fig.14 active and reactive power of the synchronous generator pre- and after fault clearance

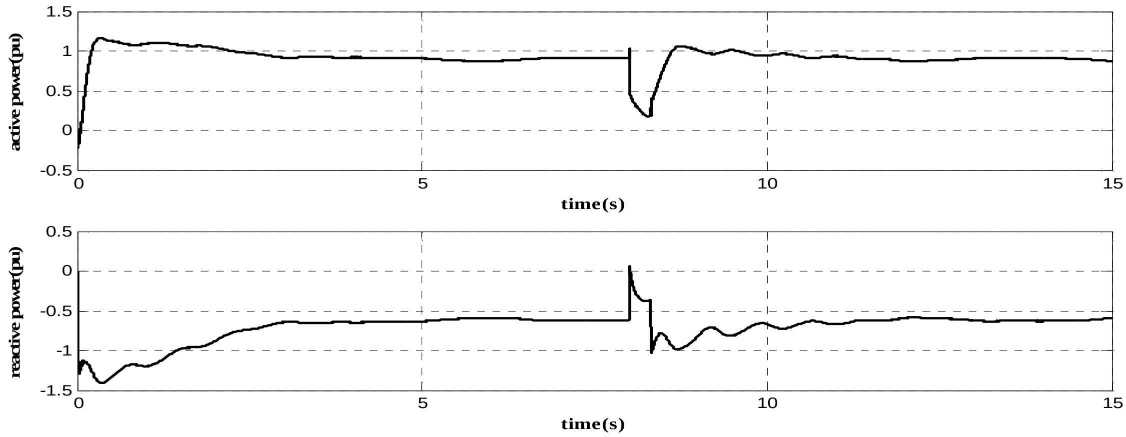

Fig.15 active and reactive power of the cage generator pre- and after fault clearance

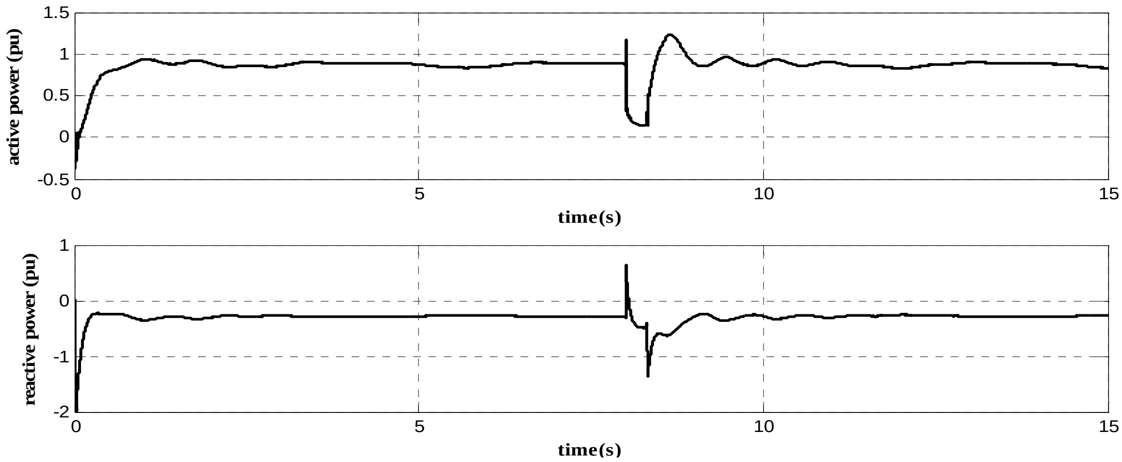

Fig.16 active and reactive power of the doubly-fed induction generator pre- and after fault clearance

6. Three-line fault

Case 4 represents a three-line short circuit not to ground and to ground they are nearly the same [5], these types of faults are a very common disturbance in a power system and are the most sever faults. Such a short circuit fault leads to sub-synchronous system oscillations that have to be damped before the system becomes unstable. Traditionally such oscillations are damped in conventional power plants with synchronous generators, by using power system stabilization with synchronous generators is an established technology, which is applied all over the world [15].

A transient short circuit fault can be considered a step change, as the short circuit current constitutes a step in load. If the short circuit happens close to a generator, the voltage at the generator terminals will be suppressed so the generator cannot export active power, hence a step change in generation occurs. In any case, a short circuit upsets the balance between load and generation in a step change. If, as described above, generators cannot export electrical power during a short circuit fault it has to accumulate the mechanical energy, with which the prime mover drives the generator. A rotating machine can only accumulate energy by accelerating. Hence the generators accelerate during the fault, and, after the fault is cleared, it tries to export as much electrical power as possible to decelerate again. As a result, the rotor speed of the generators oscillates.

In an interconnected AC power system a fault in one area and the subsequent rotor speed oscillations of the generators in this area lead to power swings (inter-area oscillations) between different areas in the whole system. 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. As described above, and as shown in Fig.17 frequency oscillations are caused by an imbalance between generated power and consumed power. Hence, grid frequency oscillations (as well as inter-area oscillations) can be counteracted with a controlled active power injection into the grid [5].

If wind turbines are to take over such damping tasks they have to have a very effective means of controlling their electrical output power. A common wind turbine type is the fixed speed active-stall wind turbine, which has a pitch system that allows the turbine to vary the pitch angle of the blades. If an active-stall turbine is to limit its power, it pitches its blades to an angle where the airflow around the blades gets detached from the surface of the blades and becomes turbulent, i.e. the blade stalls [3].

Fig. 17 and Fig. 18 show the grid frequency and voltage at the point of common coupling pre- and after the fault, during the fault period the frequency has a very high oscillations and the remaining voltage become 5% of its rated value, and after fault clearance the frequency and voltage don’t come back to its rated values , the system become unstable and needs a type of control system [5] to dampen the oscillations or disconnection of the wind turbine to avoid its failure or damage.

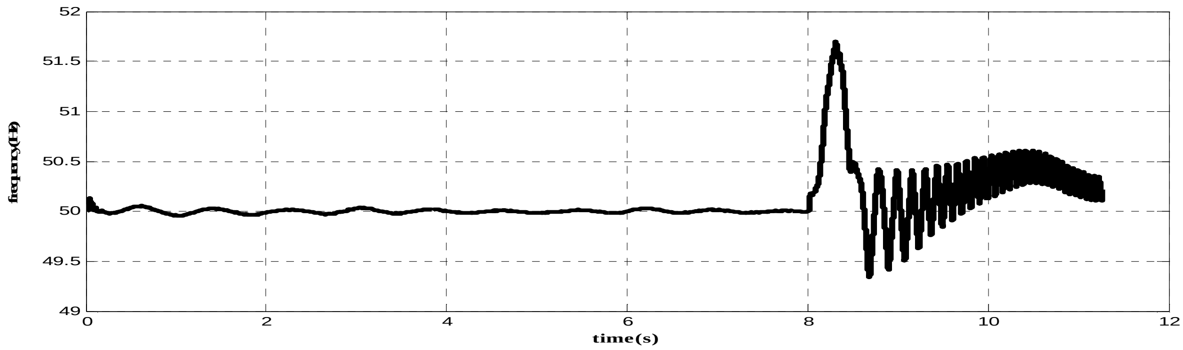

Fig.17 frequency of the power system at the point of common coupling pre- and after fault

Wind farms have to stay connected and stable under a 3-phase fault with permanent isolation of the fault. Generally no auto-re closure is to be expected in case of a 3-phase fault. For 3-phase faults the typical fault clearance time is 300 ms [3]. During the three-phase fault, the voltage can drop to 70% of the unperturbed voltage as shown in Fig .18, for duration of up to 10 seconds. Even under these conditions, the turbines must be able to carry out the control actions required to reestablish stable operation. The wind turbines have to be capable of controlling their output power.

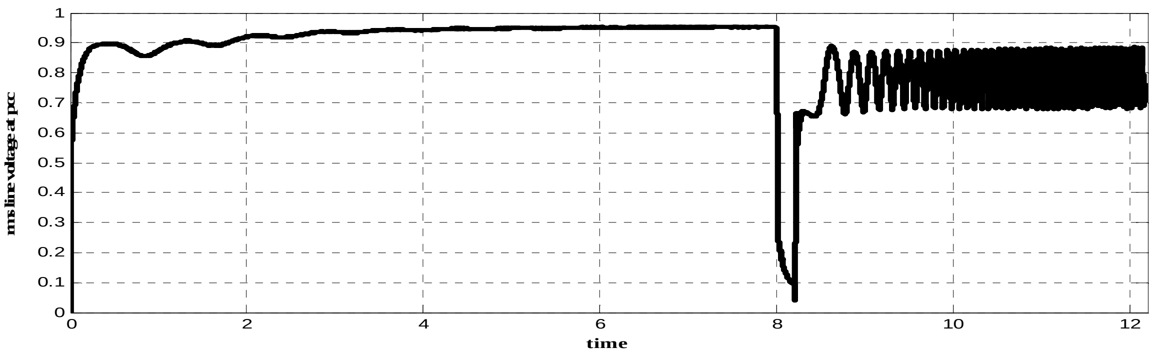

Fig.18 Rms_voltage of the power system and at the point of common coupling pre- and after fault clearance

During the fault the voltage at the generators terminals drops and hence also the active power drops to close to zero. Since the wind turbine controller does not attempt to reduce the mechanical power input, the turbine accelerates. This can be seen from the generators speed as shown in Fig.19, which increases steeply in induction generators and rapid linear in synchronous generator. The generator accelerates for two reasons: One reason is that the rotor accumulates rotating energy during the fault, since there is still mechanical power input, although no power can be exported during the fault. The second reason is that the drive train acts like a torsion spring that gets untwisted during the fault.

In practice the over speed protection system of the turbine would stop the turbine to pre-vent damages. The mechanical structure of the turbine would ultimately suffer severe damage from such extensive speed oscillations. By the time the fault is cleared, the generator has accelerated considerably beyond its rated speed. This implies that the reactive power demand of the generator has also risen considerably as shown in Fig.20, Fig.21, and Fig.22.

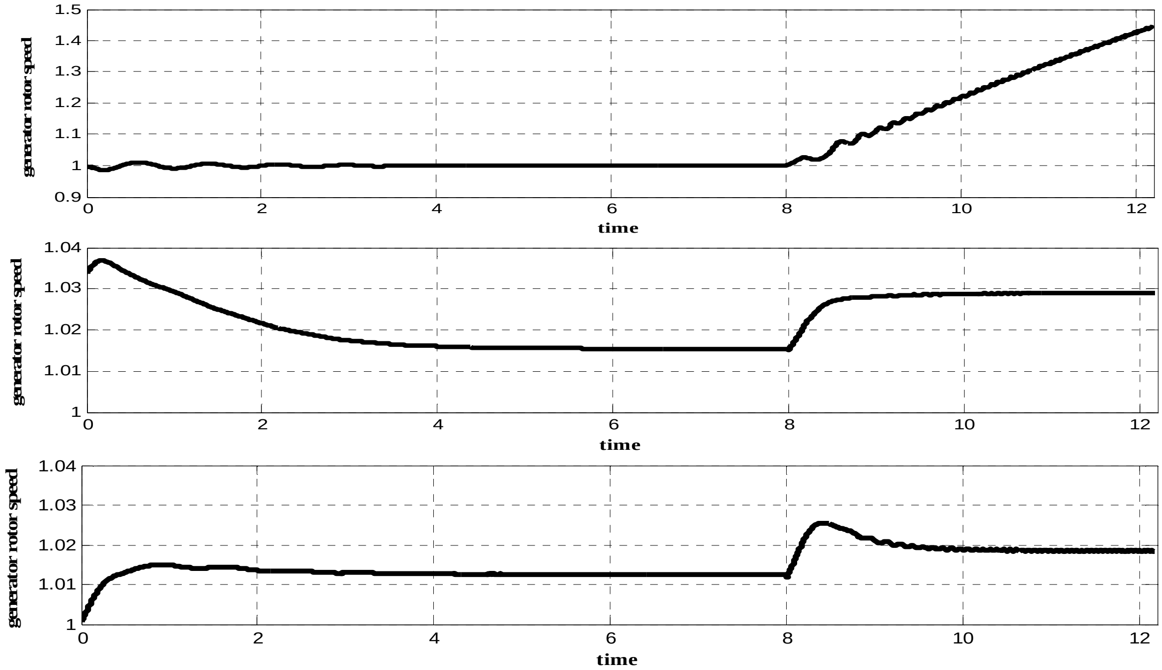

Fig.19 rotor speed of synchronous, squirrel-cage, and doubly-fed induction generators respectively pre- and after fault clearance

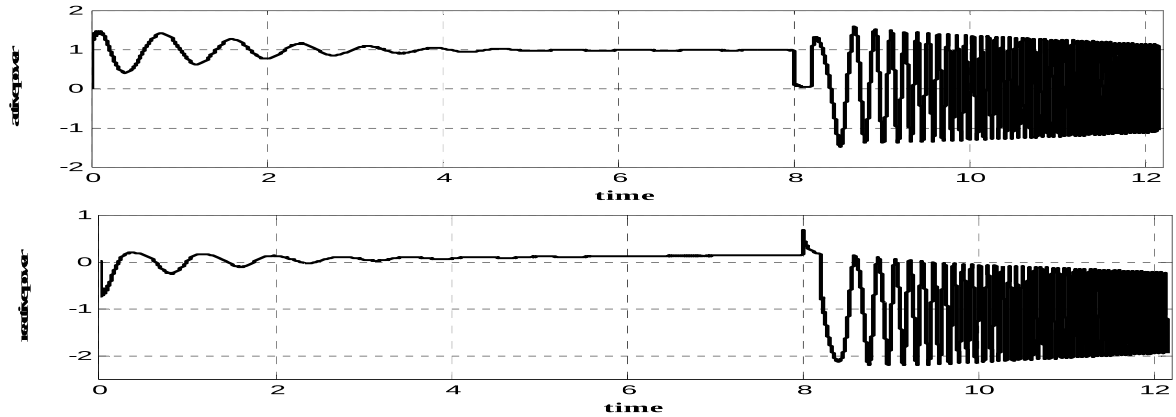

Fig. 20 active and reactive power of the synchronous generator pre- and after fault clearance

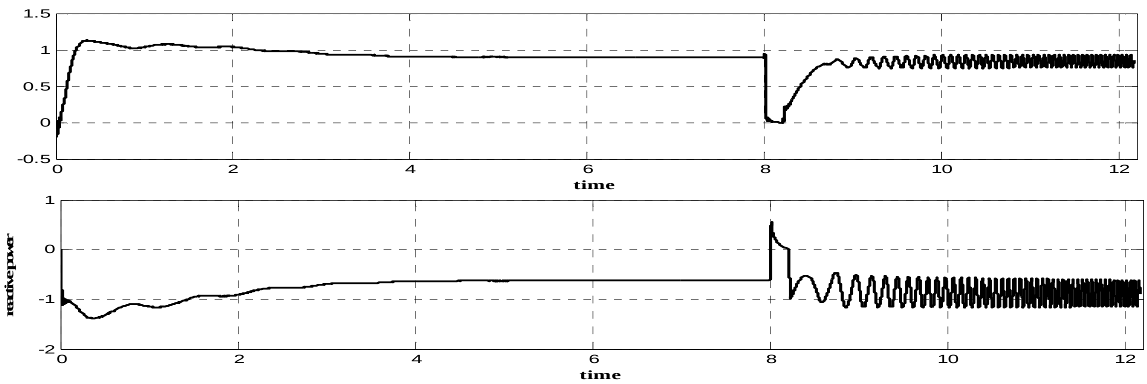

Fig.21 active and reactive power of the squirrel-cage induction generator pre- and after fault clearance

The reactive power demand of the generator lets the voltage recover only slowly. Due to the torsion spring characteristic of the turbine drive train, the generator speed oscillates. This oscillation leads to oscillations in active and reactive power, which in turn leads to oscillations in voltage as in Fig.4. The shown oscillations are too lightly dampened and so they increase.

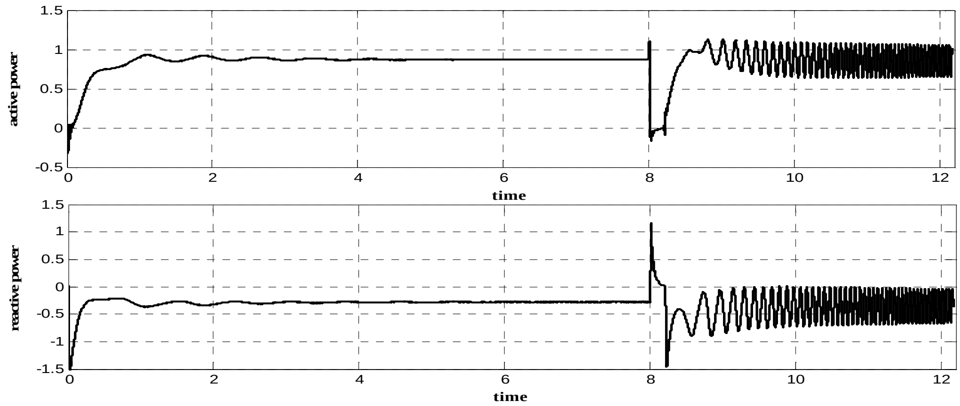

Fig.22 active and reactive power of the doubly-fed induction generator pre- and after fault clearance

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 different faults, but in case of three-phase faults the system oscillations are very danger and may damage the system, so an effective controller must be designed to dampen the oscillations, or disconnecting the wind turbine system. It is found that damping of grid frequency oscillations is possible in most of the wind speeds of the wind turbines operating range. The only control in this paper is a PI controller designed here to control the turbine mechanical output power as the wind speed varied.

The three-phase short circuit of the transmission system is the kind of fault leads to instability, i.e. the grid cannot supply enough reactive power to let the voltage recover quickly and hence suppress the oscillations. 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.

Since the rotor in the synchronous generator 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 during faults before the whole system becomes unstable. In a conventional power plant, SG equipped with power system stabilizers dampens these oscillations. In a future work a pitch controller should be designed to measure the grid frequency during faults and takes an action to control the pitch angle to damp the oscillations .

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