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Simulation of a Transient Fault Controller for a Grid Connected Wind Farm with Different Types of Generators

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ABSTRACT

The first aim of this paper is to study a wind farm model that includes an active-stall 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 , 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 wind farm 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.Second this paper describes the simulation model of a pitch controller or the so called transient fault controller that enables the wind farm system to ride through transient faults, and allow the turbine to sustain operation in case of faults. The design of the controller is described and its performance assessed by simulations. The control strategies are explained in [5] and the behavior of the turbine discussed. Comparison between the system response before adding a transient fault controller in case of three phase short circuit, and after adding the proposed controller will be done. The model is created in MATLAB software that enables the dynamic and static simulations of electric, electromagnetic and electromechanical systems.

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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 of 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.

One of the standard turbine types, which can be subject to these grid connection requirements are fixed-speed active-stall wind turbines. So we developed a controller that enables active-stall turbines, with conventional hardware, to achieve these requirements.

This controller is presented and its performance discussed in this paper. The main advantage for the development of the transient fault controller is that no hardware modifications in the turbine should be required. The goal is to develop a control strategy that is capable of making a standard active-stall wind turbine fit for transient fault ride through and achieve the grid code requirements.

2. WIND FARM MODEL

Fig.1 shows the wind farm model which represents the wind turbinel subjected to the natura wind speed variation , and three types of generators (three phase synchronous generator , three phase squirrel-cage induction generator and wound rotor 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 stanard models in MATLAB library.

Adetailed description of the system dynamics , parameters and analysis can be found in [5].

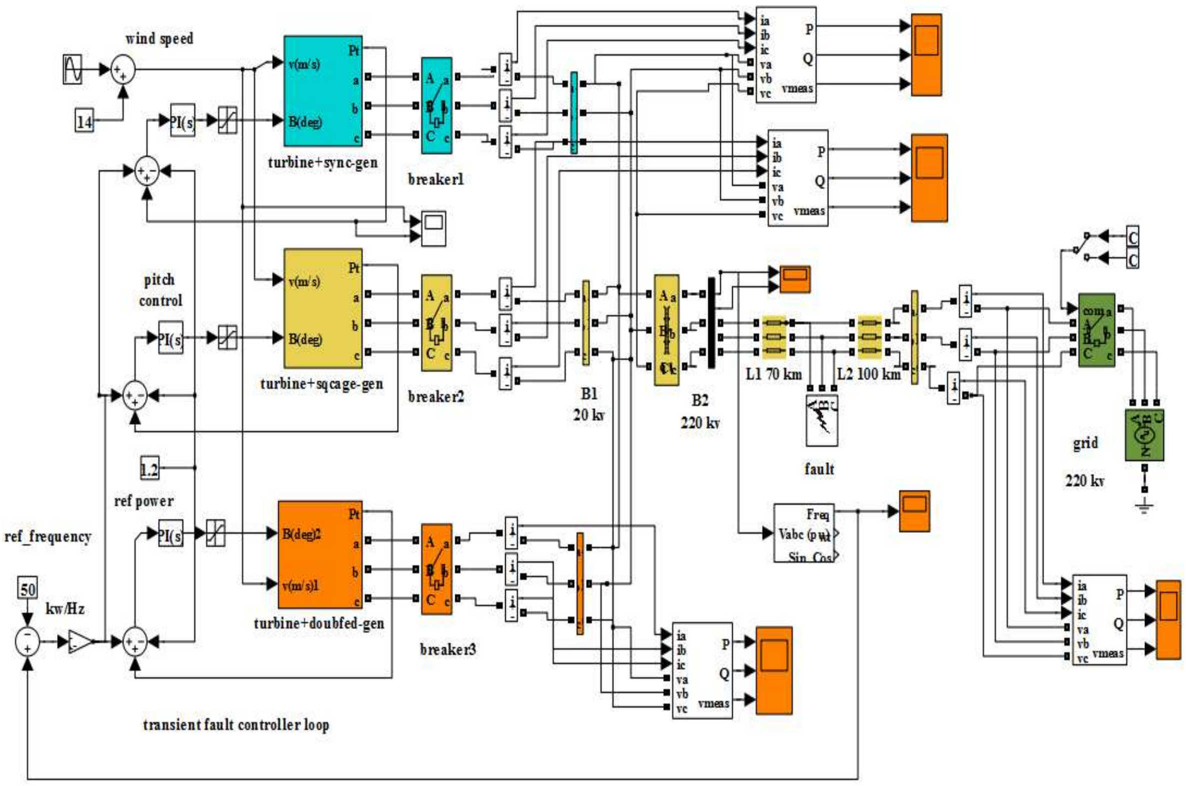


Fig..1 system model Diagram

3. TRANSIENT FAULTS

A transient three phase short circuit fault is a very common disturbance in a power system and the most sever fault. 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 by stabilizer in conventional power plants with synchronous generators. Power system stabilization with synchronous generators is an established technology, which is applied all over the world [2].

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.

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.2 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.

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]. In this paper a controller is presented that enables an active-stall turbine to use its pitch system to perform power system stabilization similar to conventional power plants.

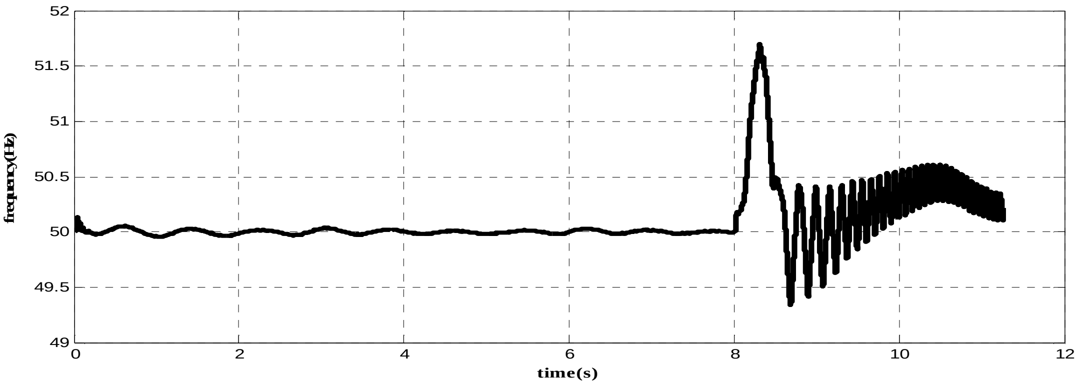


Fig. 2 Frequency of the power system at the point of common coupling with out controller during short circuit

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.

During the three phase fault, the voltage can drop to 70% of the unperturbed voltage as shown in fig .3, for duration of up to 10 seconds. Even under these conditions, the turbines must be able to carry out the control actions required to re-establish stable operation. The wind turbines have to be capable of controlling their output power.

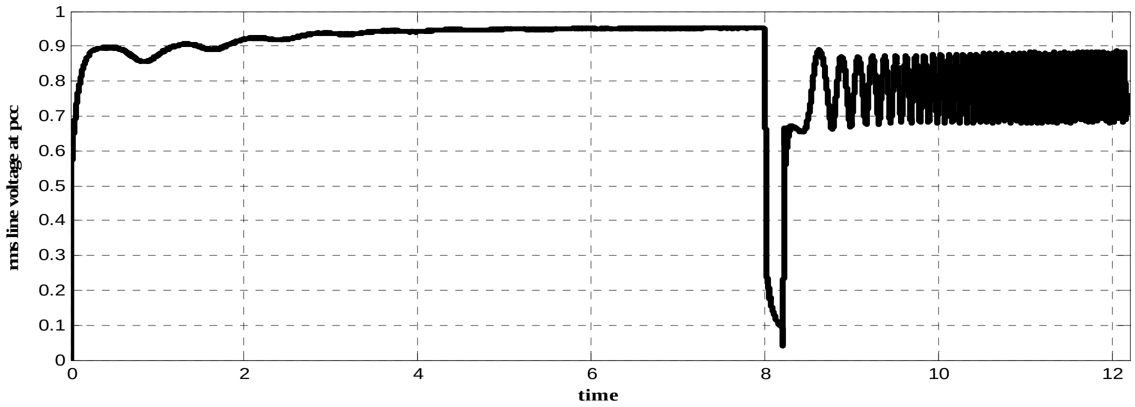
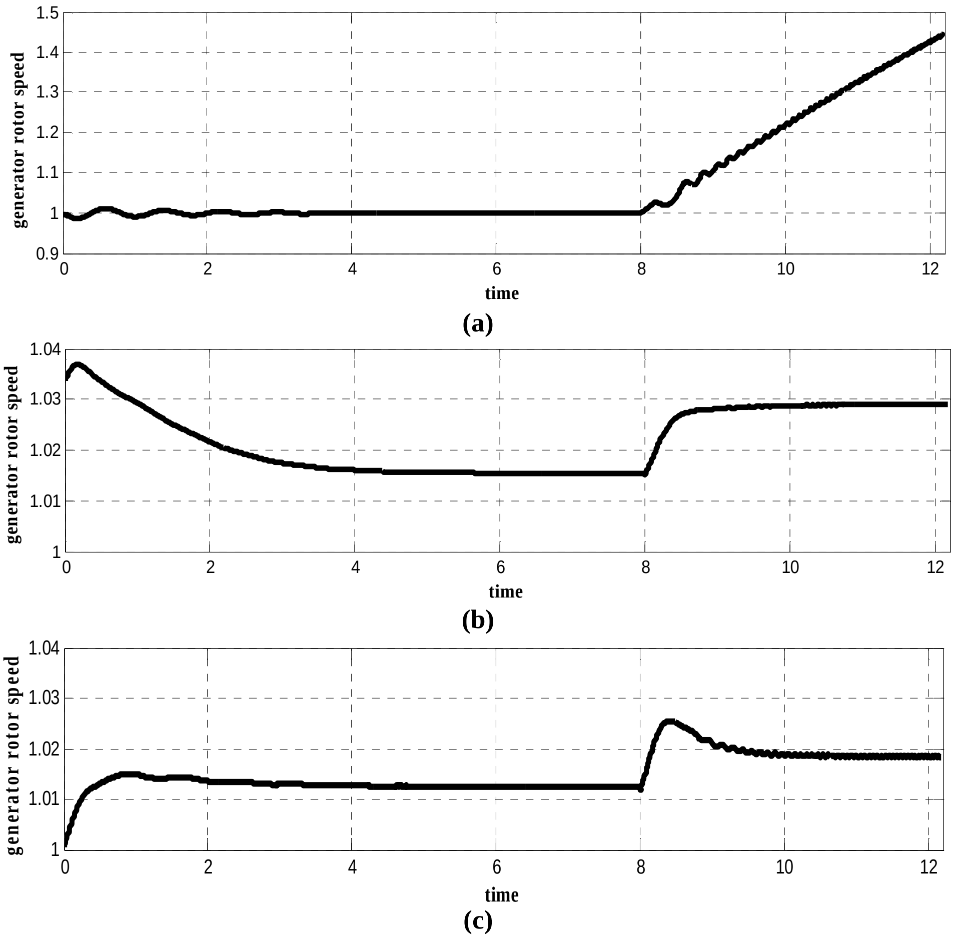


Fig.3 Rms_voltage of the power system and at the point of common coupling pre and after fault clearance without controller



(a)

(b)

(c)

Fig. 4 rotor speed and after fault clearance without controller
of (a) synchronous generator (b) squirrel-cage induction generator (c) doubly-fed induction generator

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.4, which increases steeply in induction generators and rapid linear in synchronous generator. The generator accelerates for two reasons: the first 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.

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.5, Fig. 6, and Fig. 7.

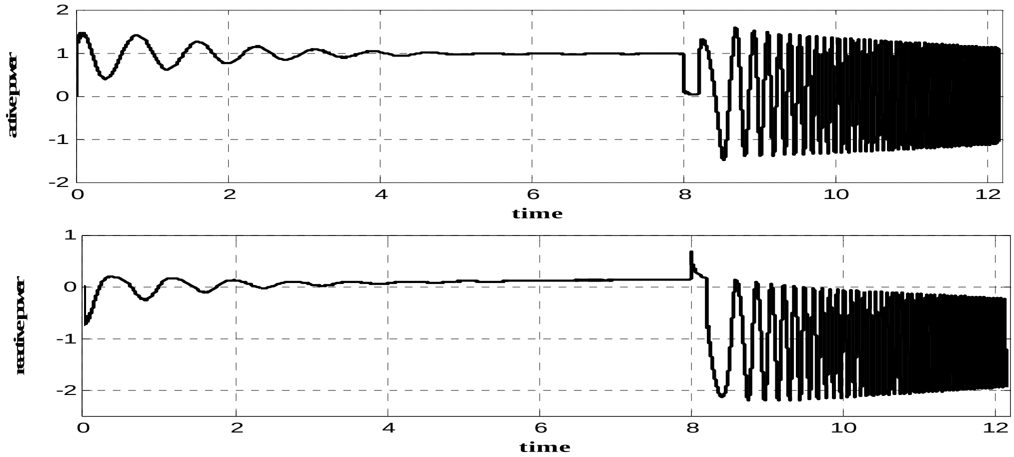


Fig. 5 active power, and reactive power of the synchronous generator during 3-phase short circuit without controller

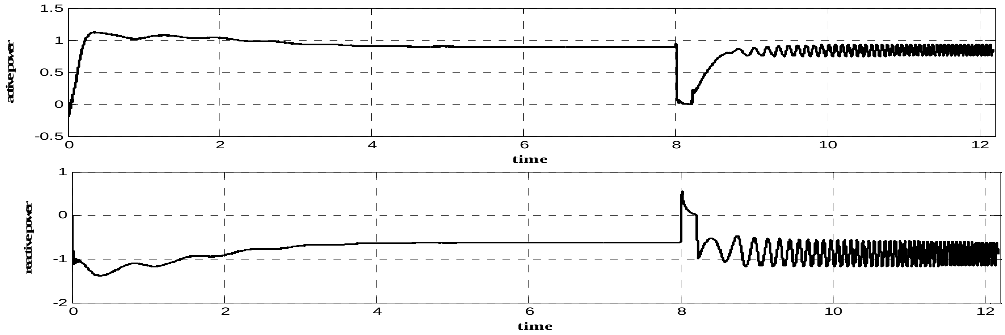


Fig. 6 active power and reactive power of the squirrel-cage induction generator during 3-phase short circuit without controller

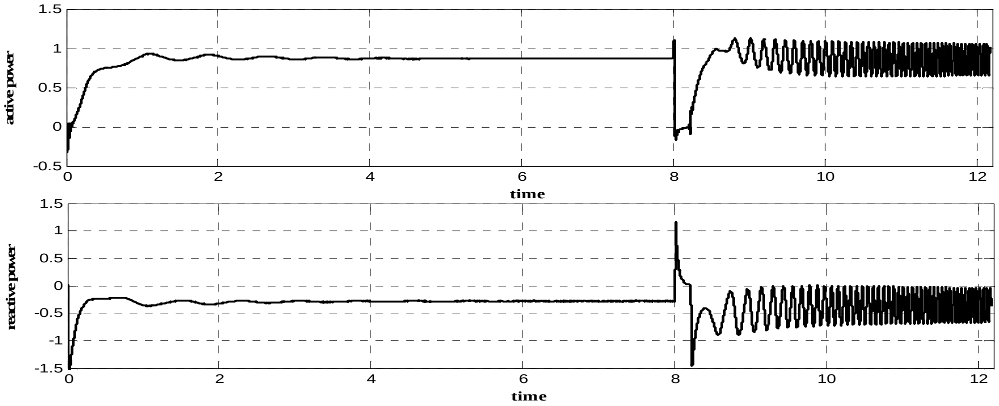


Fig. 7 active power, and reactive power of the doubly-fed induction generator during 3-phase short circuit without controller

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 oscillations are too lightly dampened and so they increase.

In practice the over speed protection system of the turbine would stop the turbine to prevent damages. The mechanical structure of the turbine would ultimately suffer severe damage from such extensive speed oscillations.

The three phase short circuit of the transmission system is chosen such that this kind of fault leads to instability as in [5], i.e. the grid cannot supply enough reactive power to let the voltage recover quickly and hence suppress the oscillations.

4. DESIGN OF PITCH CONTROLLER

The generators speed, the active power of all generators and the voltage at the point of common coupling are used to monitor the condition of the grid. A transient fault is detected when the active power of the generator drops very steeply.

A drop in the voltage at the generator terminals also indicates a fault. After a fault, the voltage is monitored to check whether the system has recovered. The generator speed is monitored to detect if the generator goes into over speed. If no abnormality is detected in either the active power, or the voltage, over speed is an indicator of islanding operation. If a wind turbine becomes isolated from the rest of the system, the voltage will not drop, since the compensation unit of the turbine will keep the generator excited. Instead the turbine is likely to run into over speed, because the power dissipated in this part of the system is most likely less than the power produced by the turbine. As a result of this imbalance, the turbine accelerates. The active power of the generator might not clearly indicate an islanding incidence, since a steep drop in active power will only be observed if the dissipated power in the system is much less than the generator power. This however depends on the size of the island and the operating point of the turbine. After the clearance of a fault, the actions of the transient fault controller must have brought the speed back to its normal range, before the controller attempts to resume normal operation.

Fig. 8 shows the block diagram of the control circuit, a PI controller has been developed that enables an active-stall turbine to cope with the transient faults.

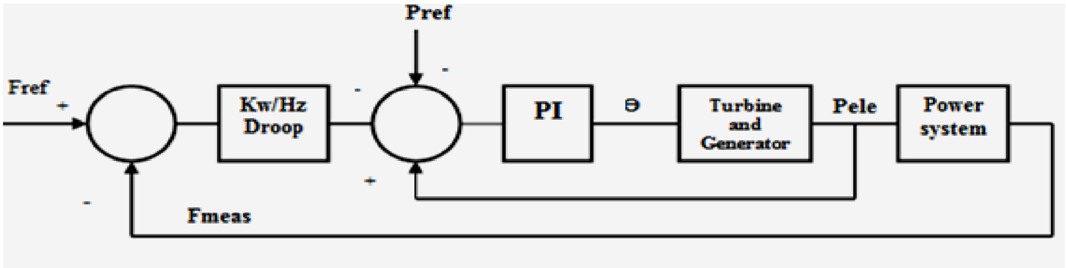


Fig. 8 Transient fault controller embedded in wind turbine pitch control system.

The transient fault controller is essentially an open-loop feed-forward controller. When a grid fault is detected, the transient fault controller puts the pitch angle set point in a step change to a value where the aerodynamic power is zero. After the fault is cleared, the pitch angle set point is ramped up again to its initial value.

5. CONTROL SEQUENCE

The basic principle of the transient fault controller is to reduce the aerodynamic power of the rotor as soon as a grid fault is detected. The general sequence of the transient fault control strategy is as follows:

1. Detection of fault
2. Controlling pitch angle to get zero power during fault period, and check that
3. Check whether grid voltage has recovered and generators speed is in normal range , and re adjust the pith angle to the value pre fault to resume normal operation.

If at least one of the conditions for a grid fault is given (steep drop in power, under voltage or over speed) the controller steps the pitch angle set point to the value of no power (see Fig. 9).

When the transient fault controller steps the pitch angle set point to this value, the pitch system ramps the pitch angle with its maximum pitch rate to the new set point.

Once this pitch angle is reached, the fault has to be cleared by the grid protection system, and the grid has to have recovered from the fault, i.e. the voltage and the frequency returned to its normal range. In addition, the speed of the turbine must have returned to a value below its maximum allowed value as shown in Fig. 9.

If a new fault condition occurs while the pitch angle is returned to its normal case, the whole sequence starts from the beginning, i.e. the pitch angle set point is immediately stepped to the angle of zero power, and so on.

6. THREE PHASE SHORT CIRCUIT SIMULATION

A 3-phase short circuit fault on the Fault Bus (Fig. 1) that lasts for 300 ms and gets cleared by permanent isolation of the Fault Bus is assumed . After the clearance of the fault, the drive train is excited into tensional oscillations. These oscillations can be seen in the speed and the active power signal. Two frequency components can be observed: A high frequency, which is the natural frequency of the small inertia on the high-speed shaft of the drive train. The superimposed low frequency component is the natural oscillation frequency of the wind turbine rotor with its large inertia on the low-speed shaft of the drive train.

By detecting the fault case (three phase short circuit) and controlling the pitch angle to control or disconnect the wind turbine during the fault period and reconnect it after that the system become stable, as shown in Fig. 9, Fig. 10, and Fig. 11.

As shown in Fig. 14, which represents the grid frequency against the time pre and after fault clearance, and with the operation of the pitch angle controller, the frequency is returned to its normal value with a good response. By comparing the frequency response in Fig. 2 and in Fig. 14, it can be concluded that the controller was stabilize the system.

In the same manner as shown in Fig. 15 , which represents the grid root mean square voltage at the point of common coupling against the time pre and after fault clearance , and with the operation of the pitch angle controller , the voltage is returned to its normal value after the fault clearance . By voltage in case of no controller as in Fig. 3 and with controller as in Fig. 15 , it can be concluded that the controller has a good performance and stabilize the system.

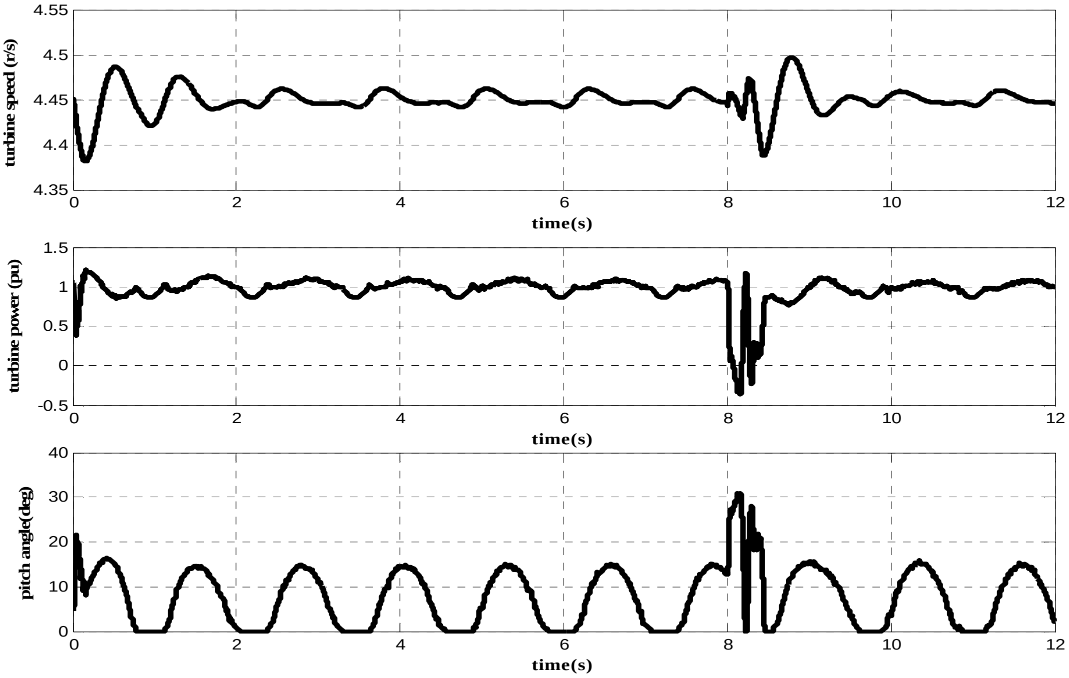


Fig. 9 turbine speed, turbine power, and pitch angle during 3-phase short circuit with transient fault controller

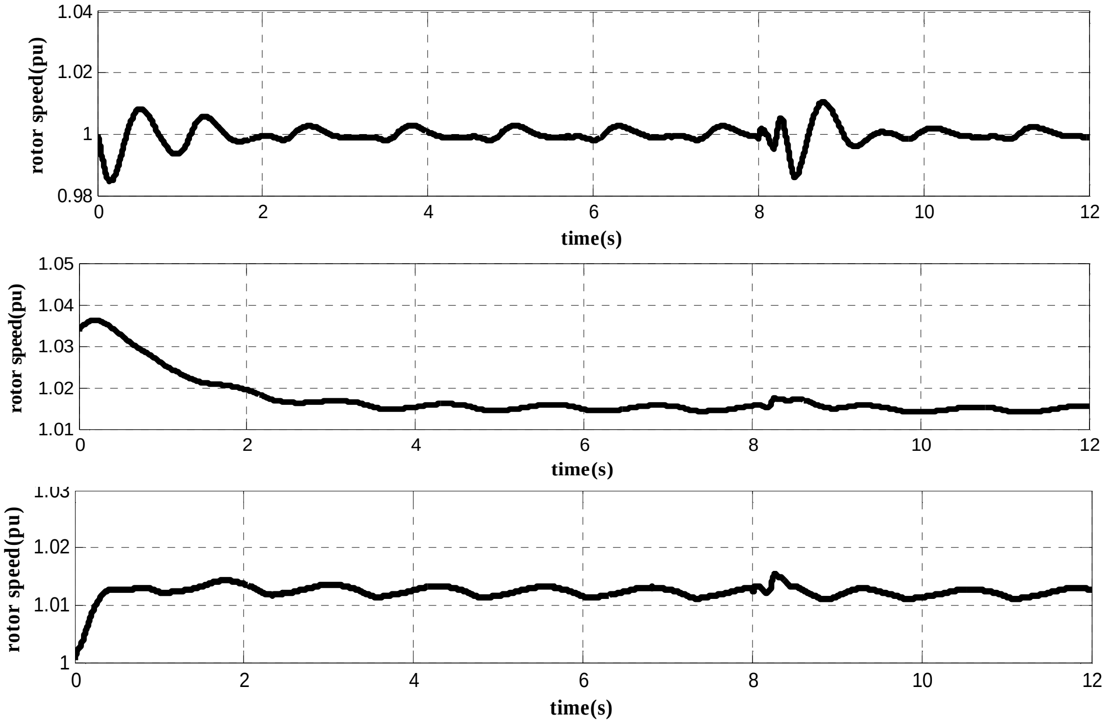


Fig.10 rotor speed of synchronous, squirrel-cage, and doubly-fed induction generators pre and after fault clearance with controller

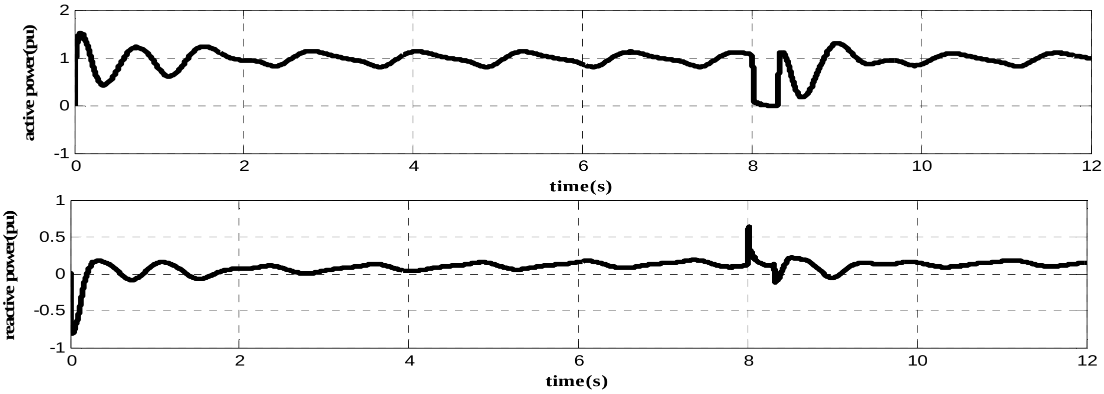


Fig.11 active power, and reactive power of synchronous generator with transient fault controller

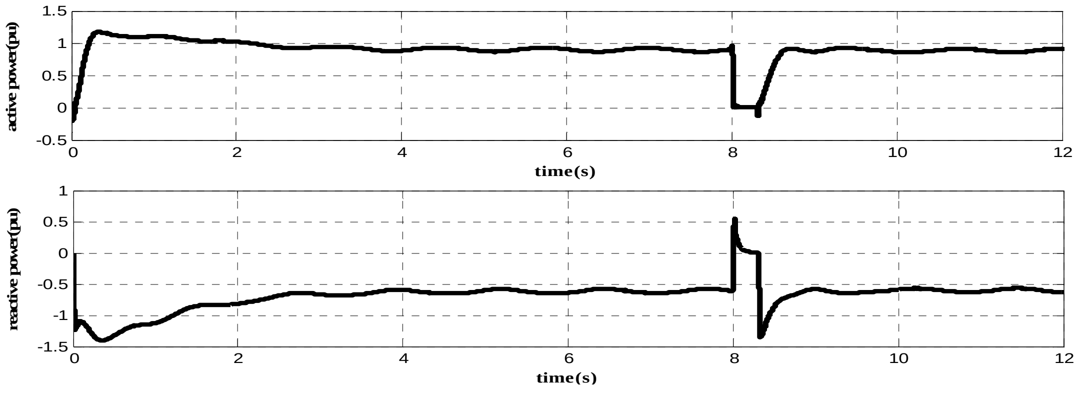


Fig.12 active power and reactive power of the squirrel-cage induction generator with transient fault controller

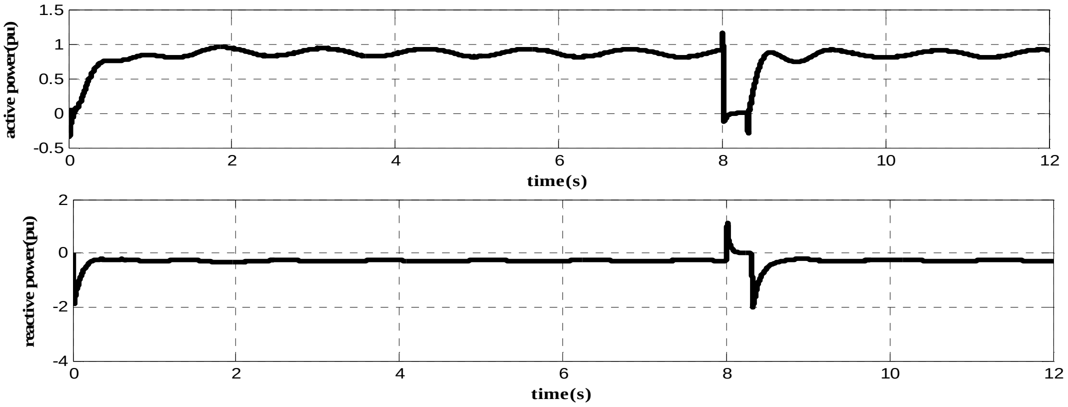


Fig.13 active power and reactive power of the doubly-fed induction generator with transient fault controller

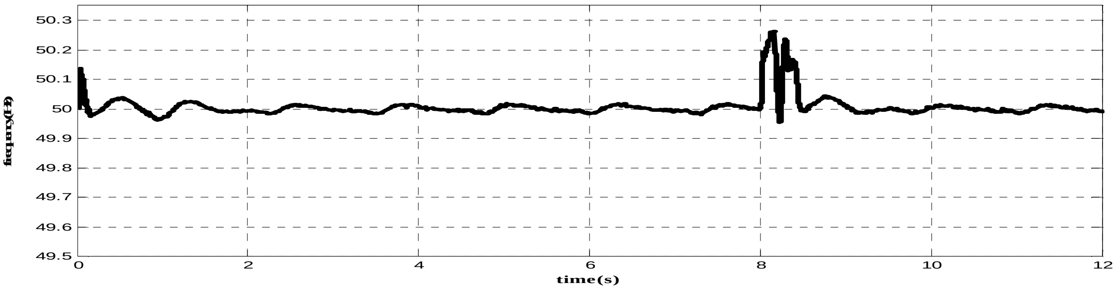


Fig.14 frequency of the grid at point of common coupling with a transient fault controller

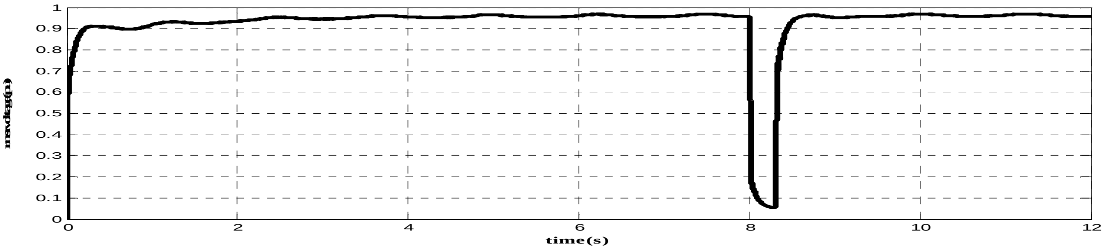


Fig.15 Rmss_voltage of the grid and at the point of common coupling after adding the transient fault controller

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. In the example simulated here the power system oscillations to be damped are grid frequency oscillations. It is found that the damping of grid frequency oscillations is possible in most of the wind speeds of the wind turbine’s operating range. The PI controller designed here enhances the wind turbine to high performance despite the limitations imposed by the pitch system.

The controller presented in this paper enables an active-stall turbine to ride through transient faults as demanded by the grid connection requirements issued by Egypt transmission system operators. Thanks to the proposed controller where the voltage and the frequency returned to the normal values by only controlling the turbine pitch angle without any added external hardware.

Even with standard hardware, the turbine performs well. It does not burden the power system such that the voltage cannot recover after a transient fault. The turbine itself is also protected against mechanical damage caused by excessive speed excursions. The transient fault controller manages to keep the turbine stable and in safe conditions.

It is shown in this paper that the doubly-fed induction generator is more robust and smooth characteristics than squirrel-cage induction generator than synchronous generator respectively but needs a complicated control system.

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