Mitigation of Power Swing in Wind Farm Distributed Generation During Balanced Three Phase to Ground Fault

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Abstract

This paper which concentrates mainly to mitigate the Power Swings in synchronous generator due to rotor speed oscillations in the wind farm due to balanced three phase to ground fault occur in the grid. In this paper PSS is used to damp out the rotor oscillation modes to maintain /stability. The analysis is done about the machine speed, load angle , active & reactive power during faulty condition with PSS. The proposed stabilizer is evaluated by simulation done through PSCAD software.

"1.Introduction "

A Power System Stability, which defines as that property of a power system, which enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance [1, 2]. The importance of wind power generation which emphasis mainly on the improvement of the power system behaviour. A power system is defined as the set of inter linked generating plants, transmission lines and distribution systems, which are necessary for electricity systems. This paper focuses mainly on the generation power plants, primarily which are based on wind power generation. If wind power generation is capable of improving the power system stability, and more specifically to increase the damping of the system and control the power swing for better operating equilibrium under normal condition [3, 4,10]. The wind power does not induce new oscillatory modes itself because the generator concepts used in wind turbines does not create disturbance in power system oscillations. For example, synchronous generator connected directly to the grid has intrinsically more damped oscillation modes [4, 5].

A synchronous generator that is connected directly to the grid with PSS helps to enhance the stability of the system. The variable speed of wind turbines and faults in the system affects the rotor speed of synchronous generator. The loss of synchronism, which also may occur in the system because of these powers, swings which gets introduced in rotor speed, active and reactive power. To solve this problem PSS is used to provide the auxiliary damping to the rotor oscillations. On the other hand, the synchronous generator has a power system stabilizer to control power swing which controls the swing to deliver the desired active and reactive power to the grid. In this scheme, the control demands the wind turbine a variation in the power delivery. This power variation modifies the power flow of the whole power system in order to damp the desired oscillation modes [3, 6,10].

The aim of this paper is to propose a power swing control for wind turbines to damp the undesired power system oscillation modes when fault occurs from three phase to ground fault occurs. This paper is organized as follows. In section I, there is an introduction. In section II, an overview and description of distributed generation is presented. The whole concept of Power System Stability is defined in section III. Power System Stabilizer design is presented in section IV. A simulation model of power system in PSCAD with a wind farm is presented and discussed in section V. In section VI results and discussions of the graph is presented. At the end, In section VI, the conclusions are summarized.

"2. Distributed Generation"

Distributed generation (or DG) means small-scale (typically 1 kW – 50 MW) electric power generators which generates electricity at site closer to an electric distribution system. A customer may choose to install a distributed generator based on various criteria. DG is used to generate a customer's overall electricity supply; for peak shaving (generating some part of a customer's electricity onsite to minimize the amount of electricity purchased during peak price intervals); for standby or emergency generation; as an eco-friendly power source (making use of renewable technology); and for increased dependability. In some easily accessible locations, DG can be cheap as it cuts the requirement of cost of distribution or transmission lines [16,10].

Distributed Generation has a low investment because of its compactness (although the investment per unit output i.e. KVA, can be much greater than that of a bigger power plant). It also eliminates the requirement for bigger infrastructure construction because the DG can also be constructed at the desired primary location. If DG provides power for nearby use, it also decreases the pressure on distribution as well as on transmission. With few modern technologies, it produces nearly zero and zero pollutant emissions for entire period of its useful life (not taking into consideration pollutant emissions over the entire product lifecycle). With these technologies such as solar or wind, it is a type of renewable source of energy. It surely increases power source dependability for longer period of time or stand-by power requirement for customers and also provides customers a chance in their hand to decide for their own energy requirement [16,10].

"3. Power System Stability"

Power system stability is defined as the ability to remain in equilibrium during normal operating conditions and to regain an acceptable equilibrium after being subjected to a physical disturbance with most system variables bounded [4]. The stability responses of a power system can be classified as [2, 3, 7]:

- Rotor angle stability, which concerns with the ability of each interconnected synchronous machine of the power system to maintain or restore the equilibrium between the electromagnetic torque and the mechanical torque.

- Frequency stability, it is being related with the capability of a power system to restore the balance between the system generation and the load, with minimum loss of load.

- Voltage stability, which is also dependent on the capability of a power system to hold on in steady state, the voltages of all buses in the system under normal operating conditions and after a disturbance [8].

3.1 POWER SWING

Power Swing is caused due to the large disturbances in the power system which if not blocked could cause wrong operation of the distance relay and can generate false or undesired tripping of the transmission line circuit breaker. And if not prevented from the generator could cause severe damage to the machine [2, 7].

Whenever there is an unbalance between the torques acting on the rotor, the net torque causing acceleration (or deceleration) is

$$T_a = T_m - T_e$$

Where,

T_a = accelerating torque in N-M
T_m = mechanical torque in N-M
T_e = electromagnetic torque in N-M

The combined effect of inertia of the generator and prime mover is accelerated by the unbalance in the applied torques. Hence the Swing Equation is

$$J\frac{dw_m}{dt} = T_a = T_m - T_e$$

Where,

J = combined moment of inertia of generator and turbine, kg.m^2

W_m = angular velocity of the rotor, mech.rad/s

T = time, seconds

"4. Power System Stabilizer"

The basic function of a power system stabilizer (PSS) is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signals. To provide damping, the stabilizer must produces a component of electrical torque which is in phase with the rotor speed deviations. From the 1960s, PSSs are widely used to add damping to electromechanical oscillations [9]. The PSS is also an additional control system, which is often applied as a part of an excitation control system. The PSS is being used to apply a signal to the excitation system, producing electrical torques to the rotor in phase with speed differences that damp out power oscillations. They used to perform within the generator's excitation system to create a part of electrical torque, called damping torque which is, proportional to speed change. The PSS represents in fig 1 consists of three blocks such as a gain block, a signal washout block, and a phase compensation block which have two blocks for lead-lag compensation. The phase compensation block provides the appropriate phase-lead characteristics to compensate for the phase lag between the exciter input and the generator electrical torque. The signal washout block acts as a high-pass filter with the time constant that allow the signal which is associated with the oscillations in rotor speed to pass unchanged[2, 7, 8,10]. The commonly used structure of the PSS is shown in Fig. 1.

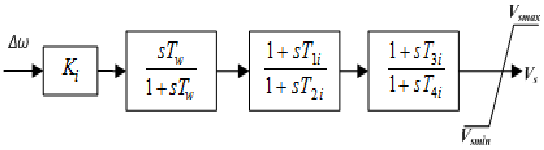

Fig 1: PSS Structure

4.1 Balanced Three Phase to Ground Fault

Faults may generally occur in a power system due to insulation failure, flashover, and physical damage or may be human error. These faults may be either three phase in nature involving all three phases in a symmetrical manner, or may be unsymmetrical where usually only one or the two phases may be involved. Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases.

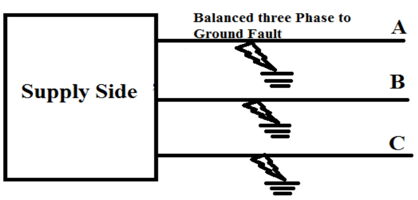

Fig.3: Balanced Three Phase to Ground Fault

4.2 PSS for Wind Turbine

In order to design a power system stabilizer which will stabilise and control the purpose of rotor oscillations, it should be taken into consideration to the fact that wind power should not induce new oscillations to the existing power system. Also, if the wind farm is attached to the grid which is very far away from synchronous generators, it is impossible to attenuate the existing with the induced oscillations in the synchronous generators. So, it is important to have a complete knowledge about the power system and to decide which rank of inter-area modes can be rectified [9, 10].

The proper design of the control scheme of variable speed wind turbines are based on the power system stabilizer technique as previously used. How so ever, the outputs can also vary. As it has been specified, the input may be any signals which are the result of the affect of the oscillations. This fact explains and directs the selection of the point of common coupling (PCC) as point for measurement, to avoid the filtering effect induced due to transformer which exists in between the grid and the wind farm. The output can be vary which is capable of varying the delivery of power as output to the grid [2, 3, 7,10].

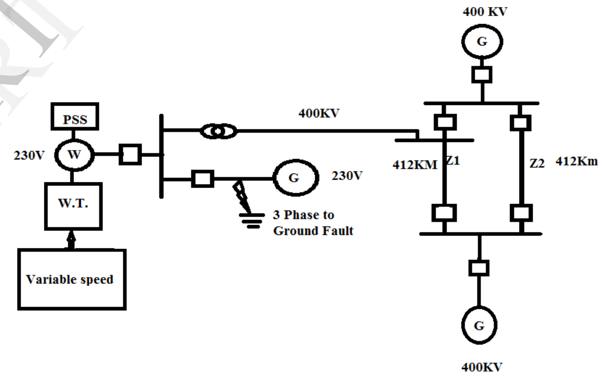

Fig 3: Block Diagram of wind farm distributed generation connected to the grid.

"5. PSCAD Simulation"

PSCAD/EMTDC is an integrated and very much capable of electromagnetic transient's simulation purpose of program. It is an industries standard simulation tool. The user friendly graphical presentation of the software makes it extremely easy to make the circuits and to test and then to get the results which helps to manage the enormous data in a completely fully systematic and integrated graphical environment. PSCAD which also provides interesting creative, intuitive, interactive control inputs, meters, and also online plotting functions as well as graphs too. PSCAD is now been fully adopted worldwide by variety of utilities, number of manufacturers, research & educational institutions, and consultants as well to be primary and basic tool for transient simulation.

Because of its graphical interface the time expenditure for the development of the program has dramatically been reduced [16, 10].

PSCAD/EMTDC which uses sub-systems, which splits the entire job into numerous smaller units and makes the understanding very easy. In EMTDC the user can write and edit his program accordingly, which is best suited, within in a single integrated environment. Because of its presence of the artificial simulation and ease of integrated procedure to the main program, the PSCAD graphical user friendly interface it drastically increases the existing power and sustained usability as well as reliability of the simulation environment. It in addition also allows the user to construct a circuit schematic in a most effective and efficient manner, & run a simulation, to synthesise analyze and then finalize the results, and related graphs [16, 10].

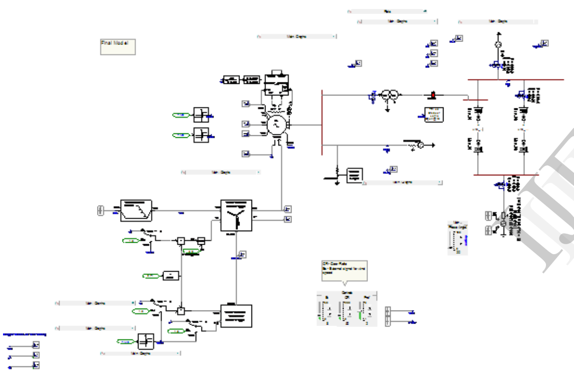

Fig 4: The Simulation Model of the Wind farm Distributed generation when Balanced Three phase to ground Fault

Above fig shows the Simulation Model of the wind farm distributed generation which is connected to the grid in which the wind mill is directly connected to the wind turbine which is governed by the wind turbine governor. The wind turbine is directly connected to the synchronous generator which converts mechanical energy of turbine into electrical energy. The exciter is also connected to excite the system and also the PSS is connected with the exciter to provide required damping. The three phase line of synchronous generator is generally connected to 230V bus and it is stepped up to 400 KV through the use of step up transformer and as well as feeding to be 230V. The 400 KV supply is connected to the one of the bus of the two area system. There are two Thevenin's equivalent loads which are connected to two 400KV bus bars which are separated by a distance of 412 km. The second line of 230V supply is connected to another Thevenin's equivalent source. In this 230V supply line the block timed fault logic is connected, which is to create balanced three phase to ground fault in the line.

"6. Results & Discussions"

This paper shows the various results in wind farm with and without using PSS in PSCAD.

A. *During Normal Condition without using PSS*

1) Graph between wind speed (m/s) and time (sec.), when the wind speed is 14.0m/s and the wind farm DG system connected to the grid under normal condition.

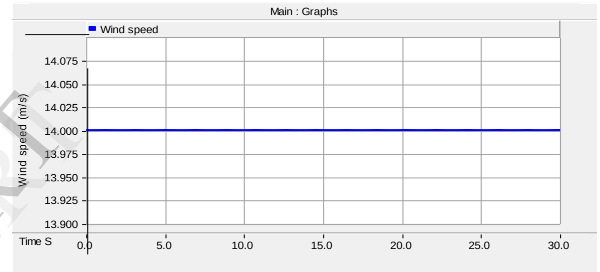

Fig 5: wind speed during normal condition

2) Graph between instantaneous Voltage (KV) and Time (sec.) where instantaneous three phase voltage is generated by wind generator without using PSS.

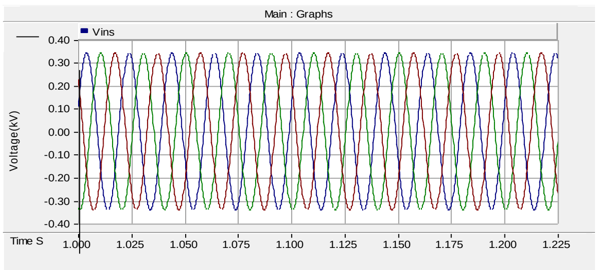

Fig 6: Three phase instantaneous voltage during normal condition

3) Fig shows the graph between grid voltage (KV) with time (sec) where instantaneous value of 400 KV, three phase grid voltage is applied and one cycle is completed with time duration of 0.02 sec.

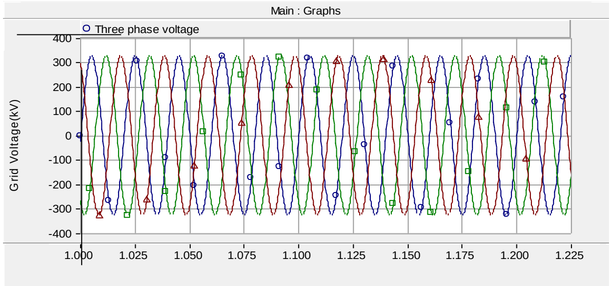

Fig 7: Three phase grid voltage during normal condition

4)Fig shows the Machine rotor speed (pu) and its Power swing when wind mill starts without PSS where the power swing is clearly observed after 2 sec.

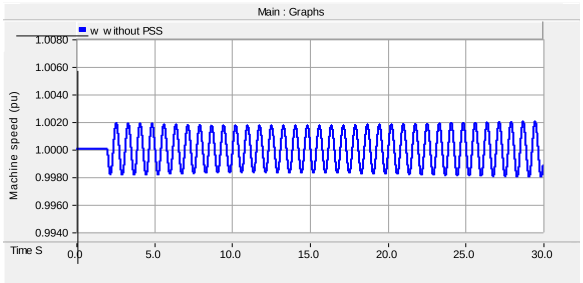

Fig.8: Machine speed in per unit without PSS

5) Fig. shows the generated active power and its Power swing when wind mill starts without PSS where the power swing is clearly observed after 2 sec and the maximum value of generated active power is 2MW.

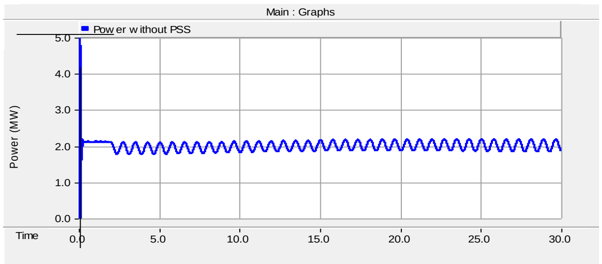

Fig.9: active Power in MW during normal condition

6) Fig shows the generated reactive power and its Power swing when wind mill start without PSS Where the power swing is observed after 2 sec and the maximum value of generated active power is 0.9MVar.

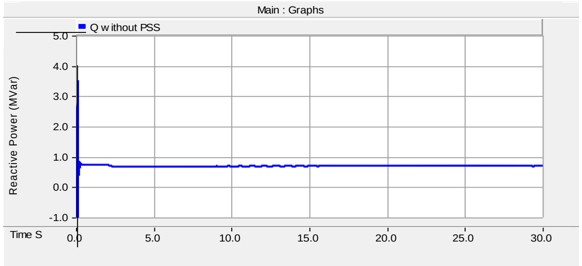

Fig.10: Reactive Power in MVar during normal condition

B. During Normal Condition using PSS

1)Fig shows the Machine rotor speed (pu) and its reduction of Power swing when wind mill start with PSS where the power swing is clear after time period of 5sec.

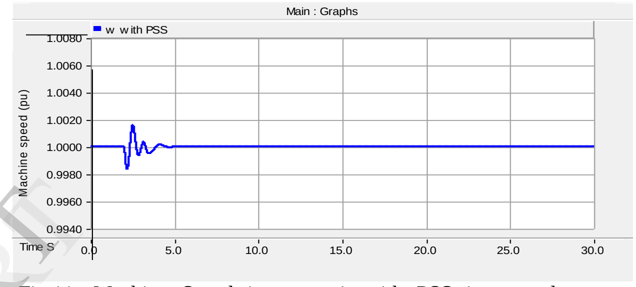

Fig.11: Machine Speed in per unit with PSS in normal condition

2)Fig shows the generated active power and its reduction of Power swing when wind mill starts with PSS where the power swing is clear after time period of 4sec.

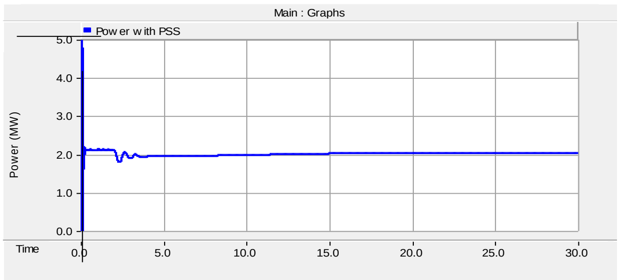

Fig.12: Active Power in MW with PSS in normal condition

3)Fig. shows the generated reactive power and its reduction of Power swing when wind mill starts with PSS where the power swing is clear after time period of 4.0 sec.

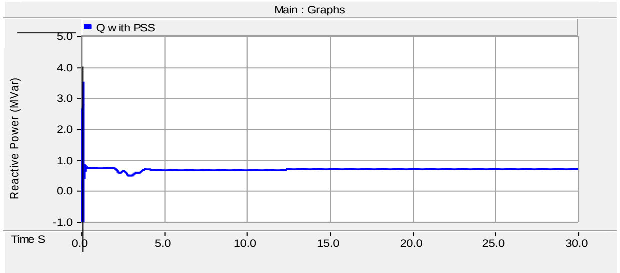

Fig.13: Reactive Power in MVar with PSS in normal Condition

C.When Three Phase to Ground fault occurs at the system for particular time period without PSS

1) Graph between instantaneous Voltage (KV) and Time (sec.) where instantaneous three phase voltage is generated by wind generator without using PSS when three phase to ground fault occurs for 0.05sec.

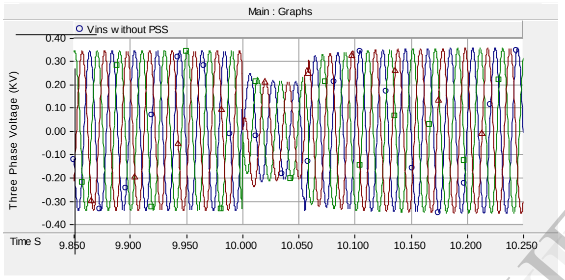

Fig 14: Instantaneous voltage in KV without Using PSS

2) Graph between Current (KA) and Time when three phase to ground fault occurs at the line A. The fault was occurred after 10sec from the starting of the machine for the duration of 0.5sec.

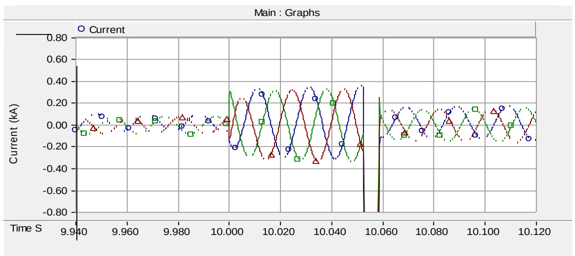

Fig.15: Fault Current in KA when Threee phase to ground fault occur

D. When three phase to ground Fault occurs The Comparison of two with PSS and without PSS.

1) Fig shows the comparison of two cases in the system with PSS and without PSS for reduction of power swing in mechanical rotor speed in the presence of fault. After applying the PSS the Power swing is decreases.

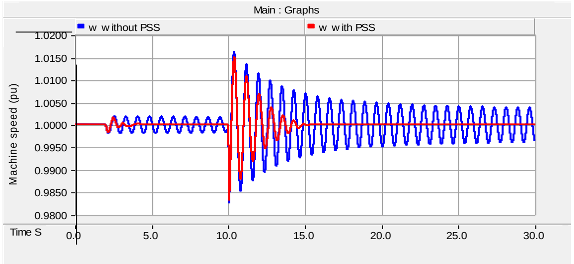

Fig.16: Machine Speed in per unit with PSS and without PSS

2) Fig. shows the effect of PSS in the system for active power in the presence of fault. Where the PSS provide the additional damping to reduce the power swing.

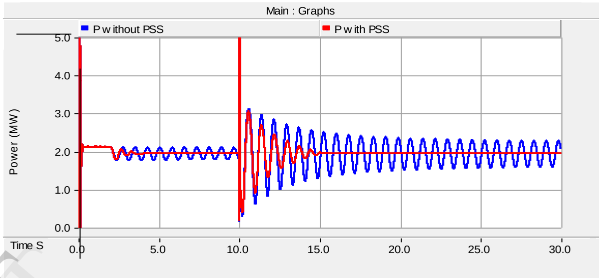

Fig.17: Active Power in MW with PSS and without PSS

3) Graph between Reactive Power and Time and also comparison of two with PSS and without using PSS in the presence of fault.

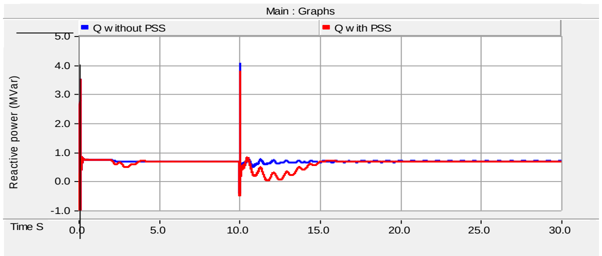

Fig.18: Reactive Power in MVar with PSS and without PSS

4)Graph between Load Angle (degree) and Time & also comparison of two with PSS and without using PSS in the presence of fault where the value of load angle is 23.606 degrees.

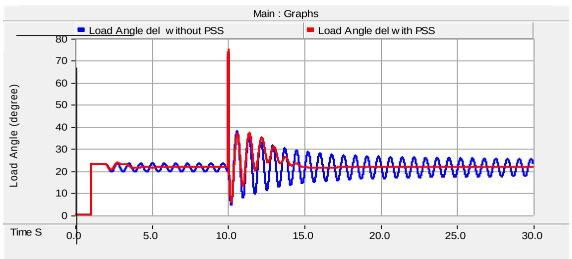

Fig.19: Load Angle in degrees with & without using PSS

5)Graph between Turbine Torque and time during balanced three phase to ground fault occur.

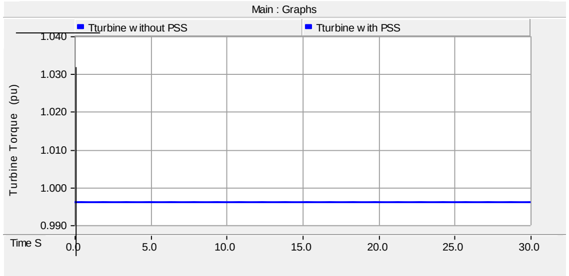

Fig.20: Turbine Torque in Per unit with & without using PSS

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"7. Conclusion"

In this paper a brief explanation is oriented about power system stability for the wind power in wind farm distributed generation in which power system stabilizer is designed to solve the problem of power swing during balanced three phase to ground fault condition and maintain the stability. PSSs are used to control the undesired active and reactive power injected into the grid by the wind farms and also control the rotor speed. To illustrate the application of PSSs in this area, a network consisted of synchronous generators and a wind farm with a PSS has been analyzed. The study of different cases show the ability of the wind farms, the PSS is used to increase the damping of inter-area oscillation modes to reduce the power swing and also the changes in power and speed under normal operation and under fault in the grid.

TABLE I

Parameters of Synchronous Generator

Armature Resistance (Ra)	0.0025 pu
Stator Leakage Reactance	0.14 pu
Field resistance (Rf)	0.00043pu
Field leakage Reactance	0.2004 pu
Unsaturated Reactance [Xd]	0.920 pu
Unsaturated reactance [Xq]	0.510 pu
Rated RMS line current	2.89855 KA
Base angular Frequency	50 Hz
Armature time constant[Ta]	0.332 sec

TABLE II

Parameters of Wind Turbine

Generator Rated MVA	2 MVA
Machine Rated mech. Speed	16.6667 Hz
Rotor Radius	40 m
Air Density	1.229
Gear Box Efficiency	0.97 pu

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