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Performance Analysis of a PMSG Based Wind Energy Conversion System

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***Abstract*— To meet the future energy demand and to provide a quality and pollution free supply to the growing and today's environment conscious population the present world attention is to go for natural, clean and renewable energy sources. These energy sources captures their energy from ongoing natural process. There are so many renewable energy sources such as sun, wind, tides etc. Due to the developments in the power electronics area nowadays wind energy becomes one of the most important forms of renewable energy. It also has the following features, it doesn't cause any kind of pollutions, it is easily available and the space requirement for a wind energy conversion system is also less. The main components of a wind energy conversion system include a wind turbine, generator, interconnection apparatus and control system. To interface the generating station and the grid station there are so many converter topologies are used. Due to the advantages like high efficiency and reliability, PMSG is mainly used in a WECS. So a PMSG based WECS is taken in account for the case study. Whenever fault occurs in a PMSG based WECS it will affect the system performance and system will become unstable. So to make the system stable, and to improve the system dynamic performance some control strategies should be there in the system. Simulations are done using MATLAB/SIMULINK.**

Keywords*— *Wind Energy Conversion System, Permanent Magnet Synchronous Generator,

I. INTRODUCTION

Renewable energy is the energy that comes from resources which are continually replenished such as sun, wind, rain, tides, waves etc. Among all available choices, the direct driven PMSG based wind turbines are preferred. In a permanent magnet synchronous generator the excitation field is provided with a permanent magnet instead of a coil. Synchronous generators are the majority source of commercial electrical energy. They are commonly used to convert the mechanical power output of steam turbines, gas turbines, reciprocating engines, hydro turbines and wind turbines into electrical power for the grid. They are known as synchronous generators because the speed of the rotor must always match with the supply frequency. In a permanent magnet generator, the magnetic field of the rotor is produced by permanent magnets. Other types of generator use electro magnets to produce a magnetic field in a rotor winding. The direct current in the rotor field winding is fed through a slip ring assembly or it provided by a brush less exciter. Permanent magnet generators do not require a DC supply for the excitation circuit and it have high efficiency and low maintenance cost, therefore, they have been considered as a promising candidate for new designs in high power applications. In terms of operating mode, variable speed wind turbines possess several advantages over the fixed speed systems such as the ability to obtain maximum power output from varying wind speed, higher efficiency, and lower mechanical stress. In the fault condition of a PMSG based WECS the fault will affect the entire system performance and will lead to an unstable condition. Without control, system will become stable only after a long time, but if sufficient control is provided the stable condition is attained quickly.

II. WIND ENERGY CONVERSION SYSTEM

Renewable energy resources, especially wind energy, become attracting great attention due to the depletion of existing fossil fuel deposits and increasing concerns about CO2 emissions. Since the late 1990s, variable speed constant frequency (VSCF) wind energy conversion systems (WECS) have been widely adopted in order to maximize the utilization of wind energy. The doubly-fed induction generator (DFIG) and direct-drive permanent magnet synchronous generator (PMSG) are the most popular systems for wind energy conversion. The direct-drive PMSG has attracted more and more attention due to its advantages of high efficiency and reliability. The configuration of a typical direct-drive WECS with PMSG is shown in Figure 1.

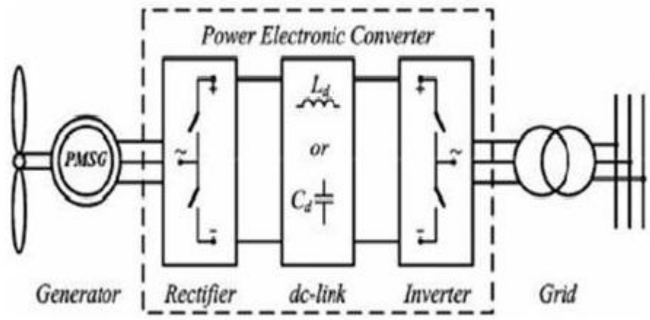

Fig 1 . Wind energy conversion system[1]

The PMSG converts the mechanical power from the wind turbine into ac electrical power, which is then given to the grid through a power electronic converter [1]. Figure 1 shows the general configuration of a PMSG based WECS. The main components of a wind energy conversion system are wind turbine, generator, rectifier, inverter and grid.

A. Types of Wind turbine

Nowadays, many kinds of wind turbine systems (WTS) compete in the market. They can be gathered in two main groups. The first group operates with almost constant speed that is the Danish concept. In this case, the generator directly couples the grid to drive train. The second one operates with variable speed, in this case, the generator does not directly couple the grid to drive train. Thereby, the rotor is permitted to rotate at any speed by introducing power electronic converters between the generator and the grid.[2].

Fixed Speed Wind Turbine:

The constant speed configuration is characterized by stiff power train dynamics. Here the electrical generator is locked to the grid and hence, just a small variation of the rotor shaft speed is allowed [2]. The construction and performance of this system are very much dependent on the mechanical characteristic of the mechanical subsystems, pitch control time constant, etc. In addition, the turbulence and tower shadow induces rapidly fluctuating loads that appear as variations in the power. These variations are undesired for grid connected wind turbine, which results in mechanical stresses that decrease the lifetime of wind turbine and decrease the power quality. Furthermore, with constant speed there is only one wind velocity that results in an optimum tip speed ratio. Therefore, the wind turbine is often operated off its optimum performance, and it generally does not extract the maximum power from the wind.

Variable Speed Wind Turbine:

Early wind energy conversion systems were based on generators directly connected to the grid, hence the speed of these systems was constant (with synchronous generators) or quasi-constant (with asynchronous generators). The evolution of power semiconductors has contributed enormously to variable speed wind energy conversion systems by interfacing the constant frequency of the grid to the variable frequency of the generator [2]. Variable speed operation of wind turbines demands the application of variable speed generators operating on the constant frequency of the grid. Different types of generators can be used, usually induction generators (with cage or wound rotor) or synchronous generators (with field winding or permanent magnets), all of them require the use of a suitable electronic power converter. Variable speed operation of wind turbines presents certain advantages over constant speed operation. Basically, variable speed wind turbines use the high inertia of the rotating mechanical parts of the system as a fly wheel, this helps to smooth power fluctuations and reduces the drive train mechanical stress. Also, variable speed systems could lead to maximize the capture of energy during partial load operation. Alternatively, variable speed configurations provide the ability to control the rotor speed. This allows the wind turbine system to operate constantly near to its optimum tip-speed ratio.

B. Generators Used in WECS

The generators used for the wind energy conversion system are of either DFIG or PMSG type. DFIG have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and grid. In DFIG the converters have to process only about 25-30 percent of total generated power (rotor power connected to grid through converter) and the rest being fed to grid directly from stator. Whereas, converter used in PMSG has to process 100 percent power generated.(100 percent refers to the standard WECS equipment with three stage gear box in DFIG) Majority of wind turbine manufacturers utilize DFIG for their WECS due to the advantage in terms of cost, weight and size. But the reliability associated with gearbox, the slip rings and brushes in DFIG is unsuitable for certain applications[2]. PMSG does not need a gear box and hence, it has high efficiency with less maintenance. The PMSG drives achieve very high torque at low speeds with less noise and require no external excitation.

B. Converters Used in WECS

Numerous power-converter topologies are there for direct-drive PMSG based wind turbines [3]. The typical structure of a converter consists of a generator-side rectifier and a grid-side inverter inter connected through a dc-link element, which can be a capacitor in voltage source converters (VSCs) or an inductor in current source converters (CSC). For each configuration the generator side rectifier and grid side inverter is varying. The generator side rectifier may be a controlled or uncontrolled one. Similarly grid side inverter is either a VSI or a CSI. The different topologies are compared as follows.

Topologies	**Advantages**	**Disadvantages**
Thyristor supply side inverter	Continuous control of firing angle.	Harmonic distortion created
PMSG with diode rectifier converter	Robust in construction	Lost control flexibility
Back to Back two level VSC	Good performanecharacteristics	Voltage sharing issue
PMSG WECS using CSC	No switching harmonics	Poor stability of the system.
Back-to-back PWM converter	Separate control can be provided	Short life time
Multilevel VSC	Less Switching losses and Higher voltage and power capability	Voltage imbalance

Table 1: Comparison of converter topologies

III. SYSTEM MODEL

In a PMSG based WECS the mechanical output of the wind turbine is directly fed into the rotor of the generator. Since it is a direct driven wind turbine system, gear box is not required. The ac output of the generator is given to the grid through a power electronic converter. The main components of the system are wind turbine, drive train, and PMSG.

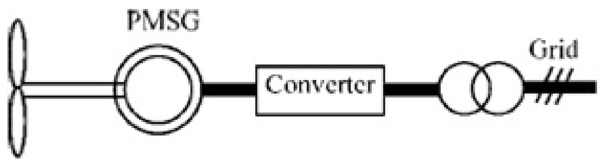

Fig 2. Grid-connected PMSG for direct-drive wind turbine [2]

Wind Turbine :

The basic principle of wind turbine is to convert the linear motion of the wind into rotational energy, which is used to drive an electrical generator, allowing the kinetic energy of the wind to be converted to electric power [8]. The captured power of the wind for a wind turbine is given by:

$$P = 0.5\, C_P \rho A V^3 \text{.....................} (1)$$

Where,
ρ = Air density in $K_g\backslash M^2$
A= Area of the turbine blades in m^2
V= Wind velocity in m\s
C_P = Power coefficient : The power coefficient C_P the fraction of the kinetic energy that is converted into mechanical energy by the wind turbine. It is a function of the tip speed ratio λ and depends on the blade pitch angle for pitch-controlled turbines.

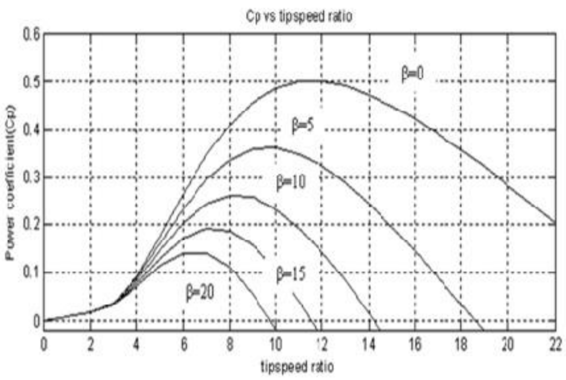

Fig 3: Power Coefficient of the Wind Turbine Model[3]

The coefficient of power is defined as the ratio of actual power to the theoretical power. That is:

$$C_p = P_{actual} / P_{theoretical} \text{...............................} (2)$$

Pitch Control :

The pitch angle of the blade is controlled to optimize the power extraction of the WT as well as to prevent over rated power production in high wind [10]. When the generator speed exceeds the rated rotor speed, the pitch control is active and the pitch angle is tuned so that the turbine power can be restricted to its rated value. Here in wind turbine system, pitch control is provided.

IV. SIMULATIONS

Simulations have been performed in MATLAB/SIMULINK. As shown in the fig, the Wind energy conversion system is integrated in to the grid.

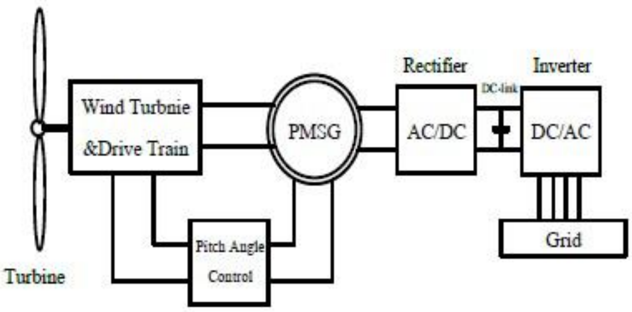

Fig.4: PMSG Based on WECS

The main system model, is as shown in fig. Wind energy conversion system can deliver power to both loads and to the grid. In the wind energy conversion system, the output of the wind turbine is directly connected to the permanent magnet rotor of the generator. And the generator output is given to the grid through a diode rectifier and a PWM VSI. System performance are analysed under normal operating condition.

To analyse the performance of the system under faulted condition, a fault is applied to the main system as shown in figure 3.4. Whenever a fault occur, the load, wind power generating station and grid side cannot meet the voltage and power requirements.

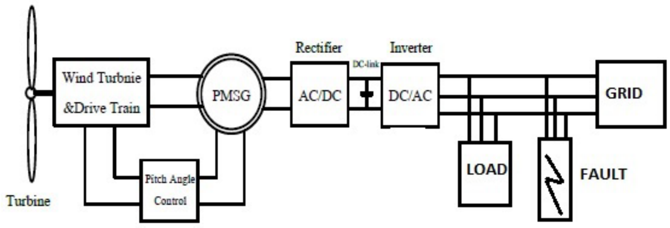

Fig 5: PMSG Based on WECS Under fault

For the above system a three phase fault is applied for a duration of 0.2 to 0.3 sec. Then the system performance are analysed under this faulted condition as shown in the figure .

V. ANALYSIS

The PMSG wind turbine is connected to the grid for the analysis of performance. Analysis are carried out firstly under normal operating condition, and a fault is applied to the main system, and performance are analysed with this fault.

A. Wind energy conversion system

In wind energy conversion system, wind active power, wind reactive power, wind voltage, etc, are taken in account.

Wind Active power : Figure 6 shows the active power at the wind energy conversion system under normal operating condition. Since the system contain a variable speed wind turbine the power is varying. But the power fluctuations are limited by the pitch angle controller. The wind turbine provide output power only after it reaches its cut in speed.

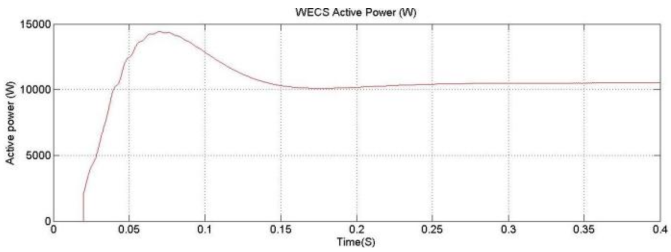

Fig 6: Wind active power under normal operation

Figure 7 shows the wind active power under faulted condition. A three phase fault is applied for a duration of 0.2 to 0.3 sec., the power at the wind system is decreased.

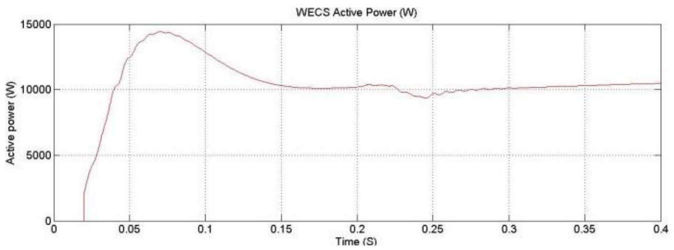

Fig. 7: Wind active power under faulted operation

Wind Reactive power : Figure 8 shows the wind reactive power under normal operation, due to the cut in speed requirement, power at the starting is found to be zero.

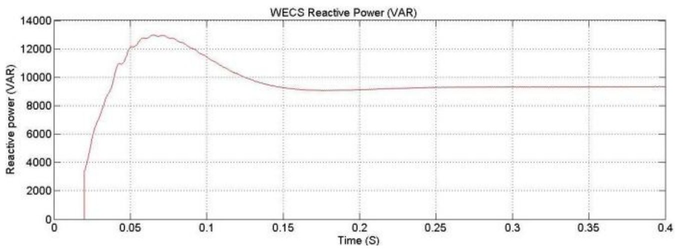

Figure 8: Wind reactive power under normal operation

Figure 9 shows the wind reactive power under faulted condition. A three phase fault is applied for a duration of 0.2 to 0.3 sec. In this duration the reactive power is found to be oscillating, so the system can't meet the requirements of loads.

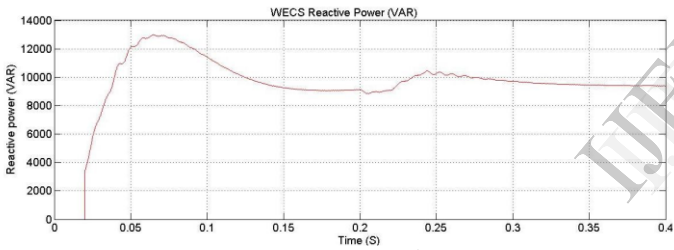

Fig.9: Wind reactive power under faulted condition

Wind Voltage profile : Figure 10 shows the voltage profile at the wind system. About 22 kV voltage is available at the wind system.

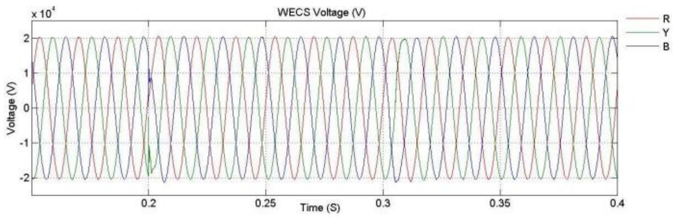

Fig.10: Wind voltage profile under normal operation

Under the occurrence of the three phase fault for the duration of 0.2 to 0.3 sec, the voltage profile is reduced to 10 kV, mitigation of this voltage dip is of high importance in terms of system stability.

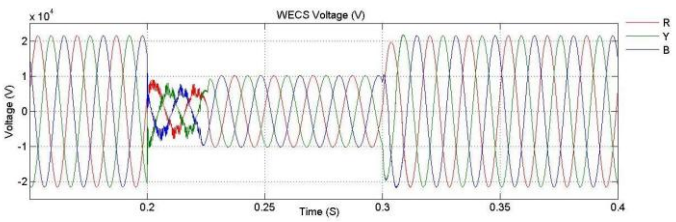

Fig.11: Wind voltage profile under fault

B. Wave forms at grid

Grid Active power : Figure 12 shows the active power at the grid. Under normal operating condition the grid active power is found to be nearly which is nearly 7 MW.

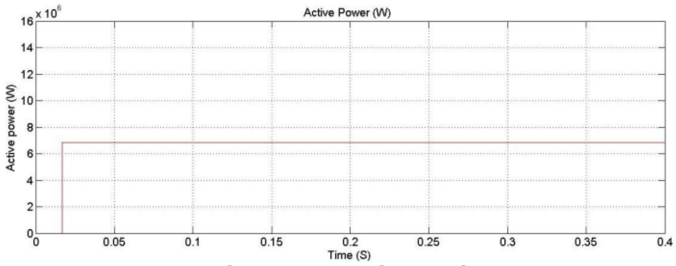

Fig.12: Grid active power under normal operation

When a three phase fault is applied for the duration of 0.2 to 0.3 sec, since the system is not a strong grid system, the grid is affected by the fault. So that the active power at the grid is reduced also there is large fluctuations in the power.

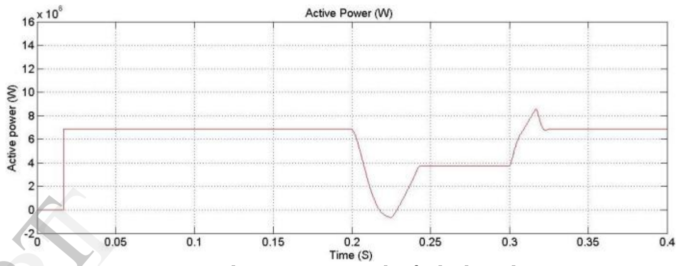

Fig.13 : Grid active power under faulted condition

Grid Reactive power : Figure 14 shows the reactive power at the grid. Under normal operating condition, the grid reactive power is found to be 4 MVAR.

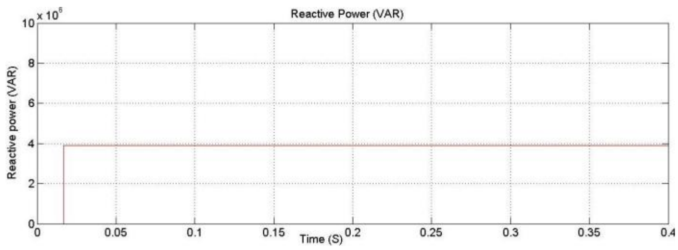

Fig. 14: Grid reactive power under normal condition

Under the occurrence of the three phase fault in the duration of 0.2 to 0.3 sec, the reactive power at the grid is reduced and also there is large fluctuation in the system.

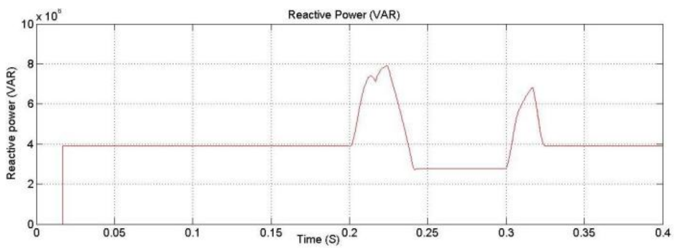

Fig. 15: Grid reactive power under faulted condition

Voltage Profile at Grid : Figure 16 shows the voltage profile at grid. Under normal operating condition the grid voltage is found to be 39 kV.

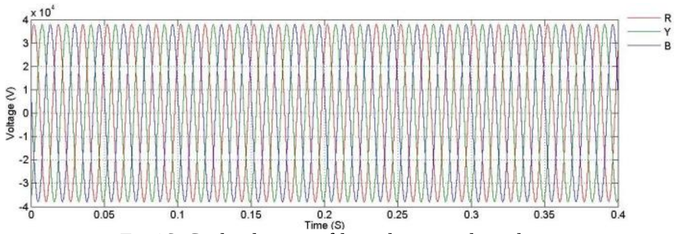

Fig.16: Grid voltage profile under normal condition

In the figure 17 a three phase fault is applied for the duration of 0.2 to 0.3 sec, under this faulted condition voltage profile is reduced to 18 kV. Mitigation of this voltage dip is of higher importance for the system stability.

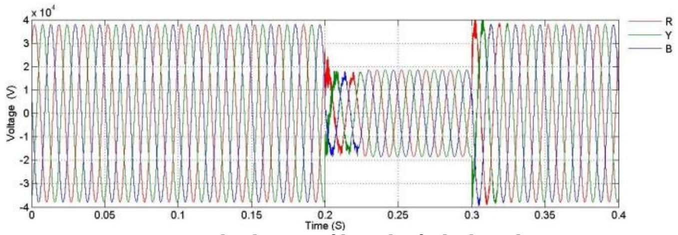

Fig.17: Grid voltage profile under faulted condition

In the normal operating condition of a PMSG Based wind energy conversion system, acctive power, reactive power, voltages, all are lies within the limited value. But under the occurrence of a a three phase fault ,all the system parameters are fluctuating. There will be voltage dip and power dip in the system. This will leads to system instability. To overcome this voltage instability, there should be some control strategies with in the wind turbine. With these control strategies, the system can reach its normal values within few time, otherwise it will take more times to recover from the fault.

VII. CONCLUSION

The permanent magnet synchronous generator (PMSG) is proposed as a wind turbine generator due to its properties of self excitation and of low speed which result in direct-drive wind energy conversion system (WECS). Thus, costs and mechanical complexities of gear boxes are avoided. The stator winding is connected to the load, and is insulated. The rotor is provided with a permanent magnet pole system. PMSG also has advantages of high efficiency and reliability, since external excitation and conductor losses are removed from the rotor. To supply the grid with active power at fixed voltage and frequency, the PMSG is connected to grid via a line power converter. Reasons for this are that variable speed of the PMSG gives variable frequency and variable amplitude of the terminal output voltage.

One of the most important problems related to integration of wind generators to grid is the disconnection of the generators in the case of a decrease of network voltage under a certain value, i.e. voltage dip. A voltage dip is a short time (10 ms to 1 min) event during which a reduction in rms voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage dip magnitude ranges from 10 to 90 percentage of nominal voltage, with duration from half a cycle to 1 min. In a 3-phase system, a voltage dip is a 3-phase phenomenon, which affects both the phase to phase and phase to ground voltages. With high wind energy penetration, disconnection of wind generators is not acceptable by grid operators. Also, with PMSG connected to grid via Isolated Gate Bipolar Transistor (IGBT) power electronics inverter, occurrence of a voltage dip leads to an increase in the current beyond the inverter limitation. It leads to an increase in DC capacitor voltage dangerously. Hence, fast removal of voltage dip is important for voltage instability, for that there should be some control strategies within the system for better system performance.

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