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Control of Permanent Magnet Synchronous Generator in Wind Energy Conversion System- A Review

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ABSTRACT
The world is now moving forward with an initiative to fasten the growth of renewable sources of energy and to improve the environment quality. Among various renewable sources of energy, wind energy is one of the popular sources which have the potential to fulfill our energy needs. This paper gives an idea about the past papers which provides various concepts about Wind Electric Conversion System using Permanent Magnet Synchronous Generator and to control various parameters like voltage, speed and pitch angle using power electronics converters

Keywords
Permanent Magnet Synchronous Generator, Power electronics converters, Control, Modelling, MATLAB Simulink.

1. INTRODUCTION
Nowadays fossil fuels are not among the attractive solutions to meet the ever increasing energy demand. The world is now moving forward with an initiative to fasten the growth of renewable sources of energy and to improve the environment quality. Among various renewable sources of energy, wind energy is one of the popular sources which can have the potential to fulfill our energy needs. The advantages of using wind energy include, it is green and renewable source of energy, has low energy production cost and is abundant in supply. The area required by the wind turbine is less as compared to other power stations. The wind turbines can be placed in distant locations such as off-shores, mountains and deserts. Wind Energy can prove to be suitable for the supply of electricity, when combined with other sources. The air in motion is called as wind and the kinetic energy associated with wind is called as wind energy. First, with the help of wind turbines, kinetic energy of the wind is converted into mechanical energy and then with suitable wind-energy conversion system, the obtained mechanical energy is converted to other useful forms of energy. When the mechanical energy is utilized to produce electricity, the system is called as wind-electric conversion system. Wind turbine extracts kinetic energy from wind and supplies to generator so as to produce electricity. When wind of high energy passes over specially shaped blades, it induces a lift force. The tangential component of the lift force makes the blade to rotate. In case of low speed wind turbines, low speed is transformed to high speed with the help of gear mechanism. A generator converts the mechanical energy obtained to electrical energy. Power produced by wind turbine is highly sensible to wind speed as wind speeds have high fluctuations with time. So, power produced will be highly fluctuating unless there is a suitable mechanism. Permanent magnet synchronous generator (PMSG) is a type of synchronous generator in which permanent magnets are used in the rotor to create excitation field. The permanent magnets can be mounted on the rotor in various ways. It can be mounted on the surface of the rotor, embedded into the surface of the rotor or it can also be installed inside the rotor. To maximise the efficiency, air gap between the stator and rotor is reduced. Also reduced air gap minimises the amount of rare earth magnet material needed. Permanent magnet design for synchronous generators results in lower cost. It is also used in low power applications.

2. WIND ELECTRIC CONVERSION SYSTEM

2.1 General description
A typical permanent magnet synchronous generator (PMSG) based wind electric conversion system consists of PMSG coupled with wind turbine through drive train. PMSG is connected to grid through power electronics interfaces, namely machine side converter and the grid side converter. Apart from this, the pitch angle of the rotor blade is controlled using pitch angle controller during the wind speed variation to obtain smooth power. The considered PMSG based WECS is shown using a single line diagram in Fig 1.

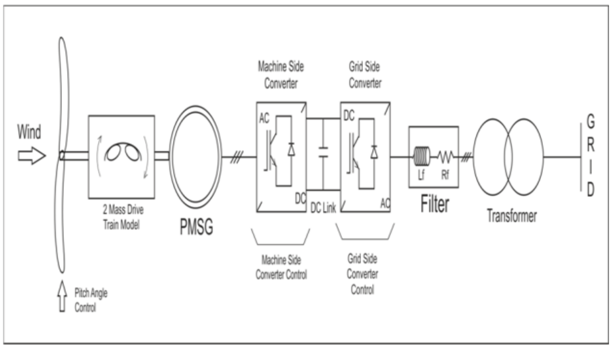

Fig 1: Single Line Diagram of the Wind Electric Conversion System

2.2 Components wise simulation models of PMSG based WECS

2.2.1 Wind Turbine Model
Today the most commonly used Wind Turbine is Horizontal Axis Win Turbine (HAWT). In the Horizontal Axis Wind Turbine, the axis of rotation is parallel to the ground. Wind Turbine control involves the balancing of the requirements like setting upper bounds on, limiting the torque, maximizing the energy production. Figure 4.6 shows the subsystem used in the modelling the system. From the figure it can see that the input to the turbine is the wind speed and pitch angle due to wind speed variation. The other constructional parameters like the radius of the rotor blade and air density are assumed accordingly and are being fed to the model.

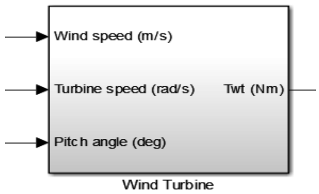

Fig 2: Wind Turbine Subsystem

2.2.2 PMSG Model

A multi-pole Permanent Magnet Synchronous Generator (PMSG) is use for the purpose of modelling the Wind Electric Conversion System. In MATLAB/Simulink, the permanent magnet synchronous machine block is used in the generator mode. The converted torque from the drive train is fed as the input to the input of the Permanent Magnet Synchronous Generator. The output bus of the Permanent Magnet Synchronous Generator includes the necessary signals required for the system modelling. The output signal includes the speed of the rotor in rad/sec, the rotor angle in radian and the electromagnetic torque in N-m. Figure 3 shows the Simulink block of the Permanent Magnet Synchronous Generator.

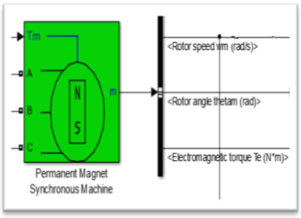

Fig 3: PMSG block in Simulink

2.3 Control Strategies

To analyse the performance parameters of the system, different approaches have been have been taken by different authors. The main objective is to obtain controlled and smooth voltage along with all the protections and the speed should also be within control.

3. LITERATURE REVIEW

Abedini and Nasiri [2] studied the effect of short circuits on a PMSG based wind electric conversion system using a back to back converter.

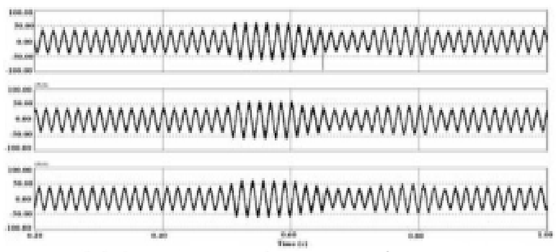

Fig 4: Output Current of the inverter during three phase short circuit with current control algorithm

A model of system was developed to simulate the short-circuit fault in order to evaluate the performance of the system during short circuit fault. Two control algorithms for grid side converter are modelled and their performance is compared.

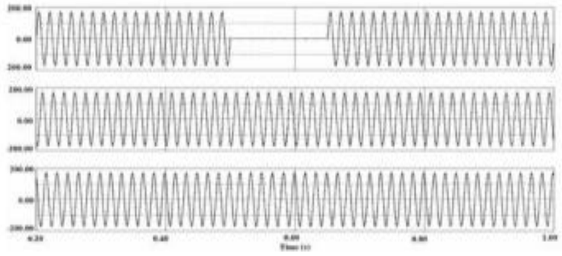

Fig 5: Output Voltage of the inverter during three phase short circuit with voltage control algorithm

Sanchez *et al*. [3] studied the control method and performed dynamic modelling of a wind farm. Variable-speed direct driven PMSG was considered for the study. Wind Turbine Generators (WTGs) that experienced similar wind velocities were all grouped together and was made into an equivalent aggregated WTG model. They introduced a simplified wind farm modelling approach. Simulation results demonstrate the effectiveness of the proposed simplified models and control systems for the individual WTGs and also for the entire wind farm, if the wind distribution across each WTG is regular.

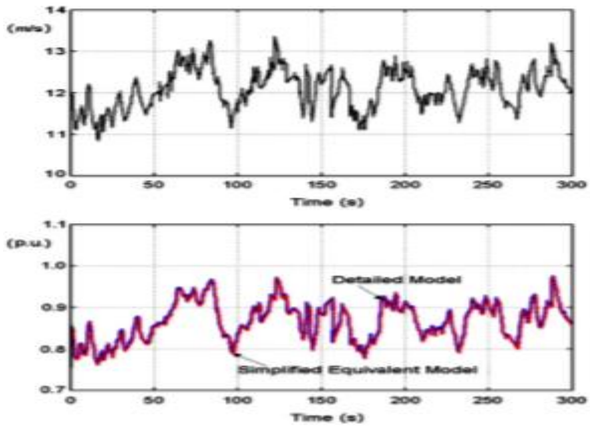

Fig 6: Comparison of wind farm detailed model and simplified equivalent model under real wind wind fluctuation

Jauch *et al*. [4] described the design of a Proportional, Derivative and Integral (PID) pitch angle controller for a fixed speed active-stall wind turbine using the root locus method. The controller functioned to enable an active-stall wind turbine and to perform power system stabilization. The transfer function of the wind turbine was derived from the wind turbine step response and with the help of that, controller was designed. The wind turbine model was connected to the pitch angle controller and then to a power system model. Then the performance of the designed controller was verified by simulation. In the example simulated here the power system oscillations to be damped are grid frequency oscillations. It is found that damping of grid frequency oscillations is possible in most of the wind speeds of the wind turbine's operating range, but not in all.

Busca *et al*. [5] implemented control technique on a PMSG with wind turbine. The control techniques were Direct Torque Control (DTC) and Field Oriented Control (FOC). Two control strategies were analyzed by considering the generator side converter. Results of the control technique showed similar behavior. The controllers were designed considering similar design requirements and same modulation technique was used.

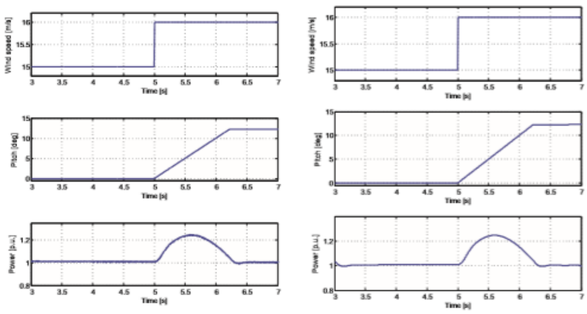

Fig 7: Comparison plot between the DTC Control and FOC control strategy

Results of the WTS simulation were shown for both FOC and DTC-SVM control strategies. Very similar results were obtained with both control strategies as they use the same modulation technique (SVM) and the controllers were designed considering similar design requirements.

Mary *et al*. [6] analysed wind turbine based PMSG system. In the analysed system, rotor shaft was directly coupled to the generator and no gearbox was used. The generator was connected to the grid. An AC/DC/AC converter was used which constituted of an uncontrolled diode rectifier, an internal and a PWM inverter. The DC-Link which was modelled comprises of a capacitor

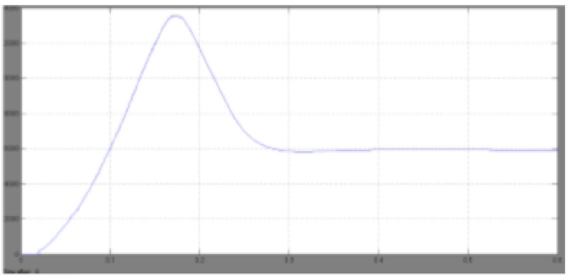

Fig 8: Variation of Power verses Time for Wind Turbine.

The inverter control uses SVPWM technique. The model has been implemented in MATLAB/Simulink in order to validate it. Power-time characteristics have been obtained.

López-Ortiz *et al*. [7] presented the implementation and simulation of a controlled PMSG wind turbine in the *dq0* reference frame under Simulink environment**.** They considered a current control subsystem, a PMSG model, a mechanical subsystem, a pitch angle controller and a wind turbine model in their simulation.

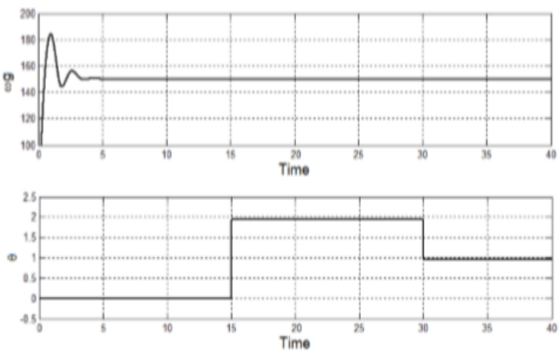

Fig 9: Generator speed and angle variation during wind speed variation

The results presented show that the speed and the pitch angle controller of the PMSG developed in this investigation produce satisfactory control actions and can be used to control a PMSG WT.

Mahersi *et al.* [8] presented the modelling of a wind power generation system based on PMSG. In the study, two control strategies, namely the vector control and the sliding mode control, were applied to a PMSG directly connected to the wind turbine. Simulation results show that the PMSG is suitably adapted for wind power generation systems with high performance of the speed, flux and torque with the vector control.

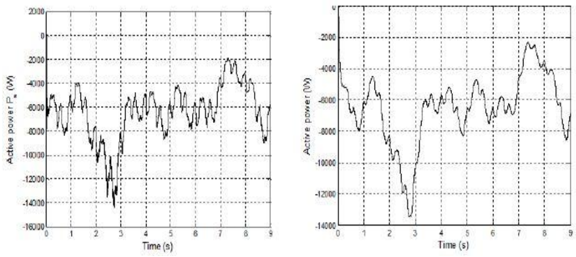

Fig 10: Comparison plot for stator active power using vector control and sliding mode control method

To show the validity of the mathematical analysis and to investigate the performance of the proposed nonlinear control scheme, simulations works are carried out for the drive system using MATLAB SIMULINK.

González-Longatt *et al*. [9] presented a simplified model of variable speed wind turbines for simulation.

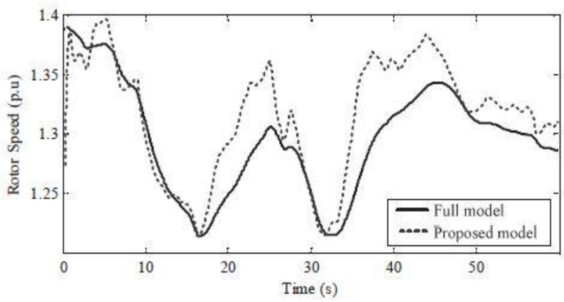

Fig 11: Rotor speed verses time of the proposed system theoretical results and simulation results

The model was prepared on the basis of the use of controls oriented system. It included permanent magnet synchronous generator for supplying voltage to bus system. The model also included torque/load properties. The flux linkage equations were used to model the system. The simulation of the PMSG was fast and was not complex. All the required parameters were obtained from the experimental results.

Kim *et al*. [10] presented variable-speed wind turbine equipped with a permanent-magnet synchronous generator. They presented the control scheme of the system. The system implemented full-scale back-to-back voltage source converter. Wind-turbine control and the power-converter control were both considered as control scheme to study the system. The detailed models of an industrial site with multiple wind turbines were developed and were used to perform simulation studies and evaluate alternative control solutions. To ensure reliable operation of the supervisory reactive power control scheme, can be applied to larger wind farms and network configurations.

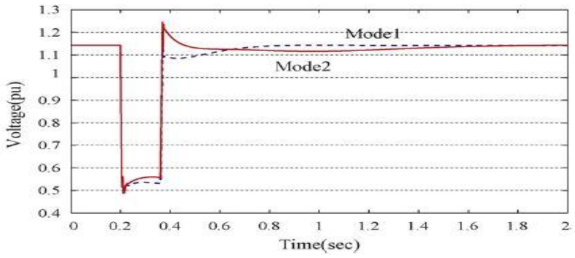

Fig 12: Voltage observed at the PCC due to Fault

Colak *et al*. [11] studied the modelling of a permanent magnet synchronous generator with wind turbine on LabVIEW. The voltage control of the model was done with artificial neural network. Considering the dynamic nature of the wind, the excitation circuit was controlled by artificial neural network.

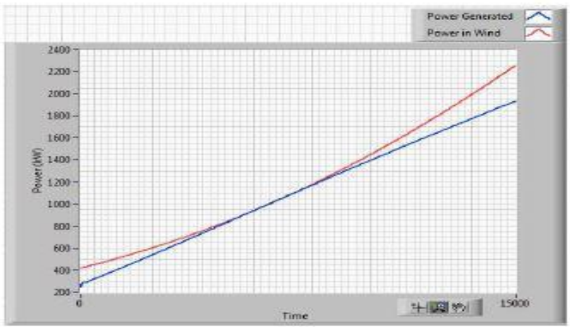

Fig 13: Power results

In this study modeling of a wind turbine with PMSG was carried out. The developed simulation includes a horizontal axis wind turbine, electrical and mechanical models of PMSG and power electronics circuits. As a result of the simulations performed, it is observed that in power control, ANN controller gives fast responses.

Sim *et al*. [12] presented a ride-through skill of PMSG based wind energy conversion system under the distorted and unbalanced grid voltage dips. To reduce the extracted power from wind during a grid fault, two methods were used, pitch control to reduce power coefficient and the blade speed control to change the tip speed ratio. In the proposed method, the grid voltage phase is detected with positive sequence voltages and current reference correction is used to reduce the harmonics of the active and reactive currents to the grid.

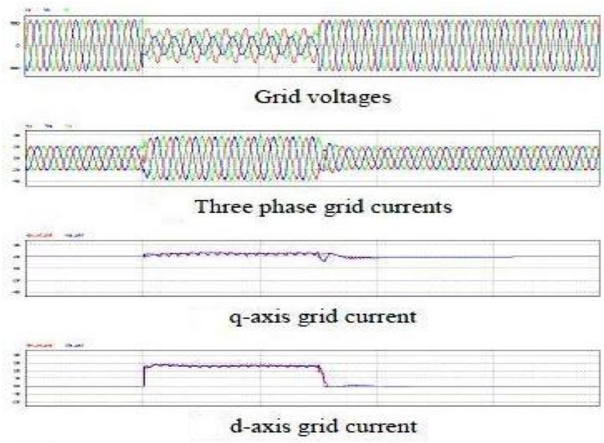

Fig 14: System performance results under distorted unbalanced grid conditions

4. CONCLUSION AND DISCUSSION

The main purpose of this paper is to give an idea on the research activities on permanent magnet synchronous generator (PMSG) based wind electric conversion system.

For voltage control, different techniques using several combination of power electronics converter are designed and tested and the results are hence compared.

For speed, Direct Torque control (DTC) and Field Oriented Control (FOC) techniques are compared and results for the two are analyzed.

Pitch regulated Techniques and Stall regulated techniques are compared for different power ratings and the results are analyzed.

From all the above studies, it is clear that Permanent magnet Synchronous Generator coupled with Wind turbines suitable for a range of power application with lower cost applications.

5. ACKNOWLEDGMENTS

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