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Research Article

Efficient Design of Grid Connected Wind Energy Conversion System using PMSG

R. Varmela, S. Chandrasekaran

Department of Electrical and Electronics Engineering, Arasu Engineering College,
Kumbakonam - 612501. India.

Corresponding author's e-mail: varmela@gmail.com

Abstract

This paper deals with permanent magnet synchronous generator (PMSG) based wind energy conversion system (WECS) integrated with grid with two back to back connected converters with a common DC link. The aim of this research is to model control of direct driven 1.5 MW wind turbine permanent magnetic synchronous generator (PMSG) which feeds alternating current (AC) power to the utility grid .The machine side converter is used to extract maximum power from the wind. In this paper a study of WECS is done by using a constant speed direct-driven wind turbine in Matlab. Moreover, by maintaining the dc link voltage at its reference value, the output ac voltage of the inverter can be kept constant irrespective of variations in the wind speed and load. An effective control techniques to extract maximum power from wind turbine is maximum power point tracking controller (MPPT), grid side controller also called voltage controller, pitch controller, phase lock loop controller (PLL) also used in this project, transformer used for isolation purpose, crow bar circuit used for protection the whole system.

Keywords: Permanent Magnet Synchronous Generator; Wind Energy Conversion; Phase Locked Loop Controller; Maximum Power Point tracking; Designing of wind energy system.

Introduction

In recent years, the electrical power generation from renewable energy sources, such as wind, is increasingly attraction interest because of environmental problem and shortage of traditional energy source in the near future [1]. Nowadays, the extraction of power from the wind on a large scale became a recognized industry. It holds great potential showing that in the future will become the undisputed number one choice form of renewable source of energy. The force that pushes this technology is the simple economics and clean energy. As a consequence of rising fossil fuel price and advanced technology, more and more homes and businesses have been installing small wind turbines for the purposes of cutting energy bills and carbon dioxide emissions, and are even selling extra electricity back to the national grid. The kinetic energy in the wind is converted into mechanical energy by the turbine by way of shaft and gearbox arrangement because of the different operating speed ranges of the wind turbine rotor and generator. The generator converts this mechanical energy into electrical energy. Then generator side PWM converter convert this AC power into DC power, grid side converter converts this DC power into AC power and sends to grid. However, as wind is an intermittent renewable source, the wind source extracted by a wind turbine is therefore not constant. For this reason, the fluctuation of wind power results in fluctuated power output from wind turbine generator. From the point of view of utilities, due to the fluctuation of generator output, it's not appropriate for the generator to be directly connected to the power grid [2].

In order to achieve the condition that the generator output power is suitable for grid-connection, it is necessary to use a controller to manage the output produced by the wind turbine generator. Permanent magnet machines are

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characterized as having large air gaps, which reduce flux linkage even in machines with multi-magnetic poles. As a result, low-rotational-speed generators can be manufactured with relatively small sizes with respect to its power rating. Moreover, the gearbox can be omitted due to low rotational Speed in the PMSG wind generation system, thus resulting in low cost. To increase the efficiency, to reduce the weight of the active parts, and to keep the end winding losses small, direct-drive generators are usually designed with a large diameter and small pole pitch. Compared with the traditional electrically excited synchronous generator, the requirement of a larger pole number can be met with permanent magnets which allow small pole pitch. In addition, permanent magnet synchronous generators (PMSGs) have the high torque density and the absence of excitation losses. Furthermore, the performance of PM's is improving and the cost of PM is decreasing in recent years, the direct-drive permanent magnet wind generators have recently received increasing attention, especially for offshore wind energy [3]. Thanks to the application of high energy PM materials such as neodymium-iron-boron, the volume and cost of this type of machine can be dramatically reduced.

Proposed System

Model of PMSG Wind Turbine

Structure of PMSG Wind Turbine

The basic of PMSG wind turbine structure shown on fig. 1. The wind turbine generates torque from wind power. The torque is transferred through the generator shaft to the rotor of the generator. The generator produces an electrical torque, and the difference between the mechanical torque from the wind turbine and the electrical torque from the generator determines whether the mechanical system accelerates, decelerates, or remains at constant speed. The generator is connected to a three-phase inverter which rectifies the current from the generator to charge a DC-link capacitor, The DC-link feeds a second three-phase inverter which is connected to the grid through a transformer.

Modeling of Permanent Magnet Synchronous Genarator

Permanent magnet synchronous machines/generators (PMSMs/PMSG)s play key role in direct-drive wind power generation systems for transforming the mechanical power into electrical power. A rigorous mathematical modeling of the PMSG is the prerequisite for the design of the machine control algorithms as well as the analysis of the steady-state and dynamic characteristics of wind energy conversion systems. In this section, the mathematical model of a PMSG in both the natural abc three-phase stationary reference frame and dq synchronously rotating reference frame will be developed.

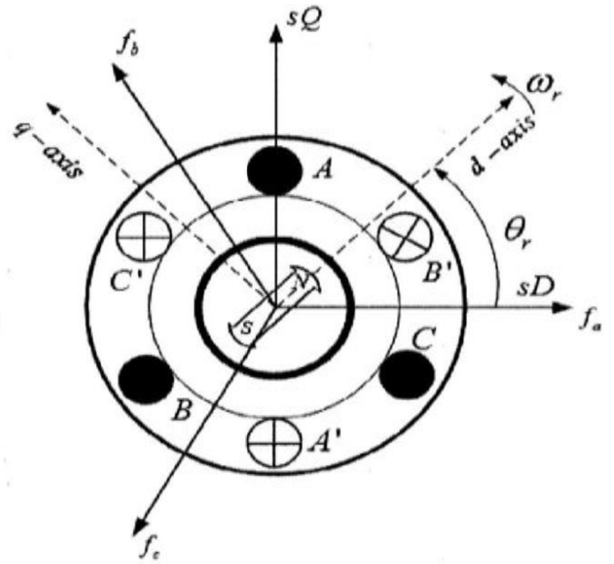

Fig. 2. General wind turbine PMSG system with control schemes

The fig. 2 shows the cross-sectional view of a three-phase, two-pole PMSG [4]. The fixed abc axes denote the direction of the MMFs of the *a*, *b* and *c* phase windings, which are induced by the time varying three-phase AC currents in these stator phase windings. The flux caused by the permanent magnet is in the direction of the *d*-axis fixed at the rotor. Here, the dq-axes are rotating at the same angular speed of the PMs and rotor. Also, ϴ ,denotes the angle between the *d*- axis and the stationary *a*-axis.

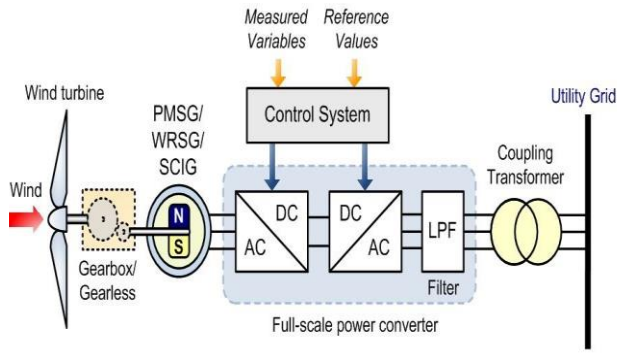

Fig. 2. Cross-section view of the PMSG

Grid-side inverter control

The d-axis output voltage of the grid respectively, ω is the angular frequency in electrical degree of grid, R is the resistance, L is the inductance, id and iq is the d-axis and q-axis current. The d-axis and q-axis moderate to control active and reactive power [5]. The inner current loop is controlled by PI controller similar to generator-side inverter.

Control of PMSG Wind Turbine

Generator side inverter control

The generator side inverter is controlled to catch maximum power from available wind power. To control electromagnetic torque we have to control q axis current iqs with the assumption ids is zero [6]. The tip speed ratio λ taken into account. The error ω(ref) is produced. Therefore the error of w(ref) and w(s) is rescued to PI controller to produce q-axis current component iqs(ref) which put into SVPWM. The d-axis current ids(ref) is set to zero because d-axis current control is adopted [7].

Pitch angle control

The system of aerodynamic control plays an important role in regulating the mechanical power. Pitch angle controller is based on the principle which is changing the blades angle at the revolutions over the maximal generator speed as well as protecting the generator before overloading at high wind speeds [8]. The optimal angle for the wind speed below the nominal value is approximately zero and then it increases with the wind speed growing.

MPPT control

The MPPT is a control method which control the wind turbine rotor speed by controlling torque of the generator. The blade pitching drive is a mechanical equipment which has a delay in response time in rapidly changing wind condition. However in, order to maximize the power production the rotor speed of the generator can be controlled electrically. This is usually done by adopting the rotor speed to the optimum tip speed ratio.

PLL Control

It is a control system that generates an output signal whose phase is related to the phase of an input signal. It is easy to initially visualize as an electronic circuit consisting of variable frequency oscillator and a phase detector. The oscillator generates a periodic signal .The phase detector compares the phase of the signal with the phase of the input periodic signal and adjust the oscillator to keep the phase matched [9].

Back to Back PWM Inverter

WECS consist of a PMSG connected to a AC-DC IGBT-based PWM rectifier and a DC-AC IGBT based PWM inverter, with a LCL filter. This filter increase quality of the current. The given simulation model based on the principle is that a fixed wind speed is consider in this model ,the kinetic energy of wind speed is converted in electrical energy with the help of turbine shaft and PMSG [10]. In this model we used several controller (MPPT controller, PLL controller, Pitch controller, Grid side Inverter controller, Generator side Inverter controller) which help us to send this electrical energy to the National Grid (Fig. 3).

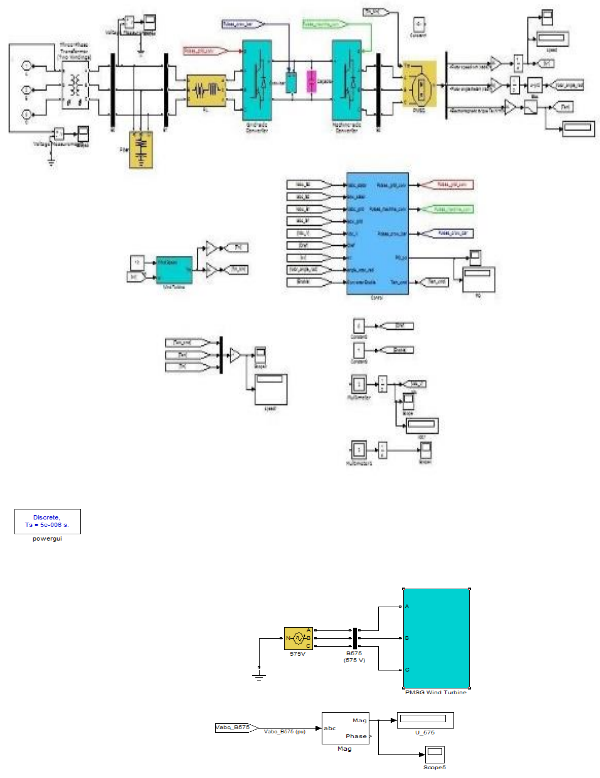

Fig. 3. Simulation of wind energy conversion system in MAT LAB

Simulation Results

The simulation Out-put result gives us Rotor speed of wind turbine, wind turbine torque, turbine pitch, Torque (mechanical, electrical, tortional), voltage across the capacitor, finally output voltage which send to the grid. The presented method and simulation results are conducted in MATLAB/SIMULINK.PMSG model; wind turbine model and two-mass drive train data is shown in the figure respectively. In this paper, the base wind speed is considered as 12m/s. Fig. 4 shows the rotor speed of Wind turbine, Fig. 5 shows wind turbine torque, Fig. 6 shows wind turbine pitch, Fig. 7 shows Torque (Mechanical, electrical, torsional) and Fig. 8 shows voltage across the capacitor. Blade pitch angle are controlled by pitch angle control model to adjust (pc) it only active in high wind speed. This paper uses variable wind speed as 12 m/s and change to 16m/s at t =3second. At time = 8s, pitch angle is increased. Because the rotor speed in system is over limit.

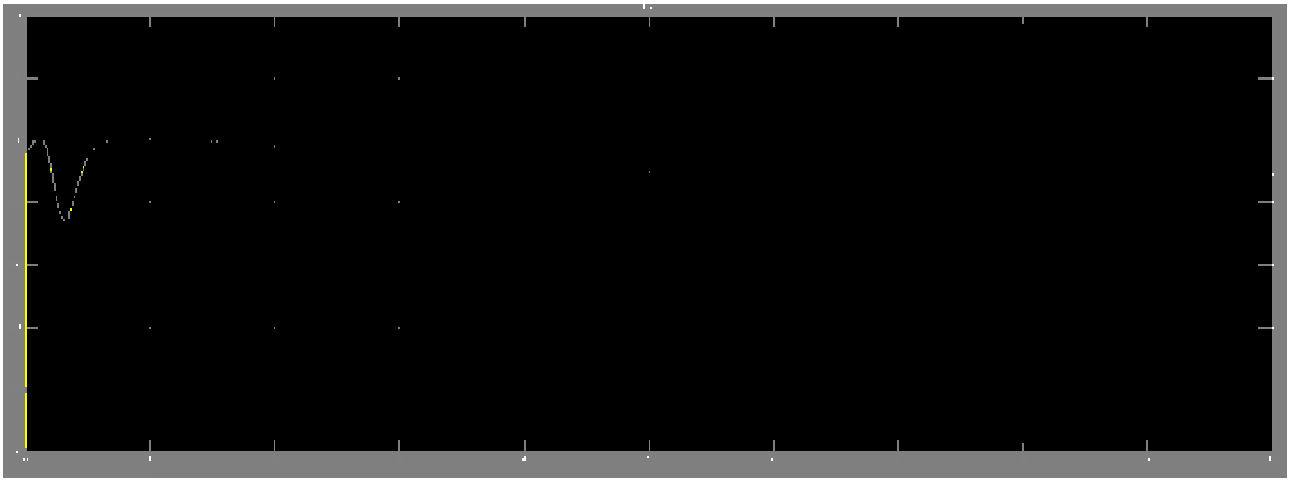

Fig.4: Rotor speed of Wind turbine

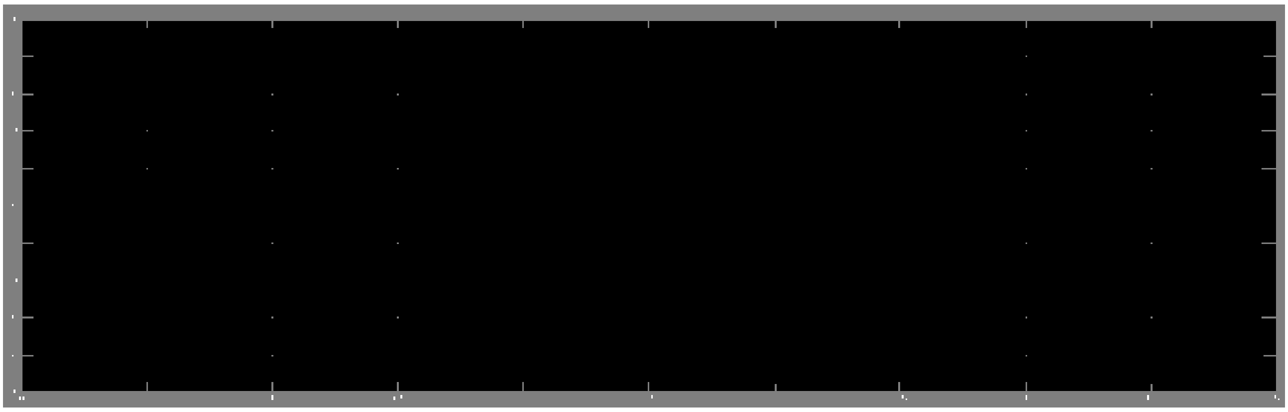

Fig.5: Wind turbine torque

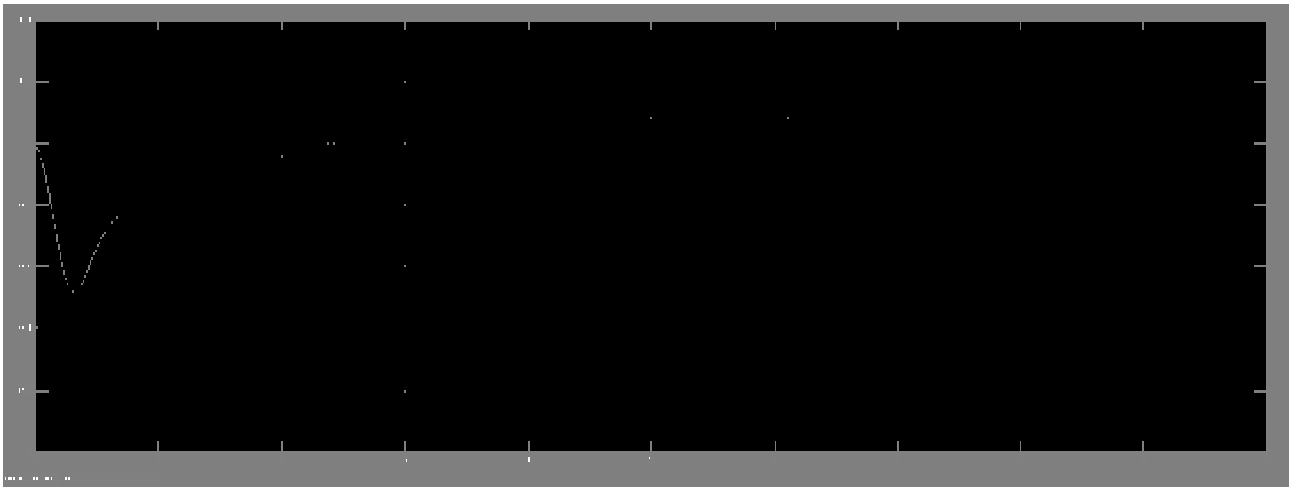

Fig. 6. Wind turbine pitch

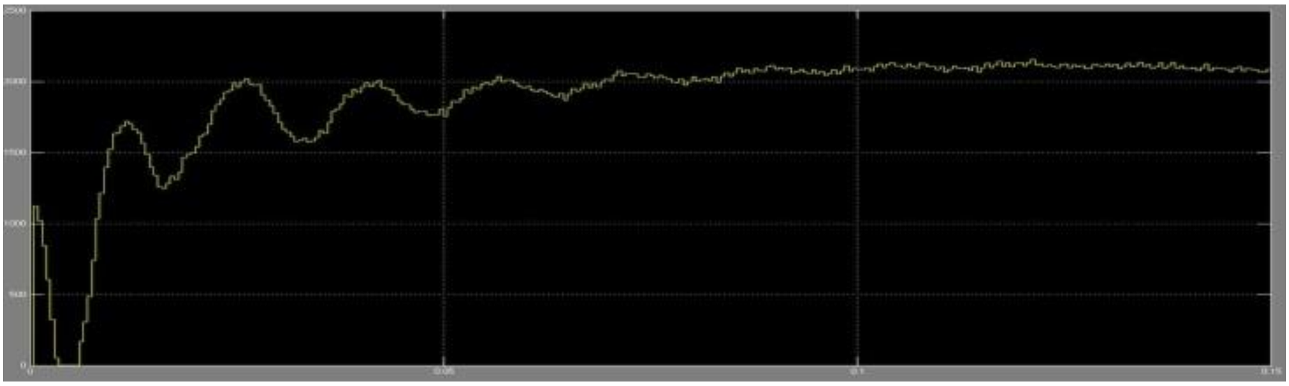

Fig. 7. Torque (Mechanical, electrical, tortional)

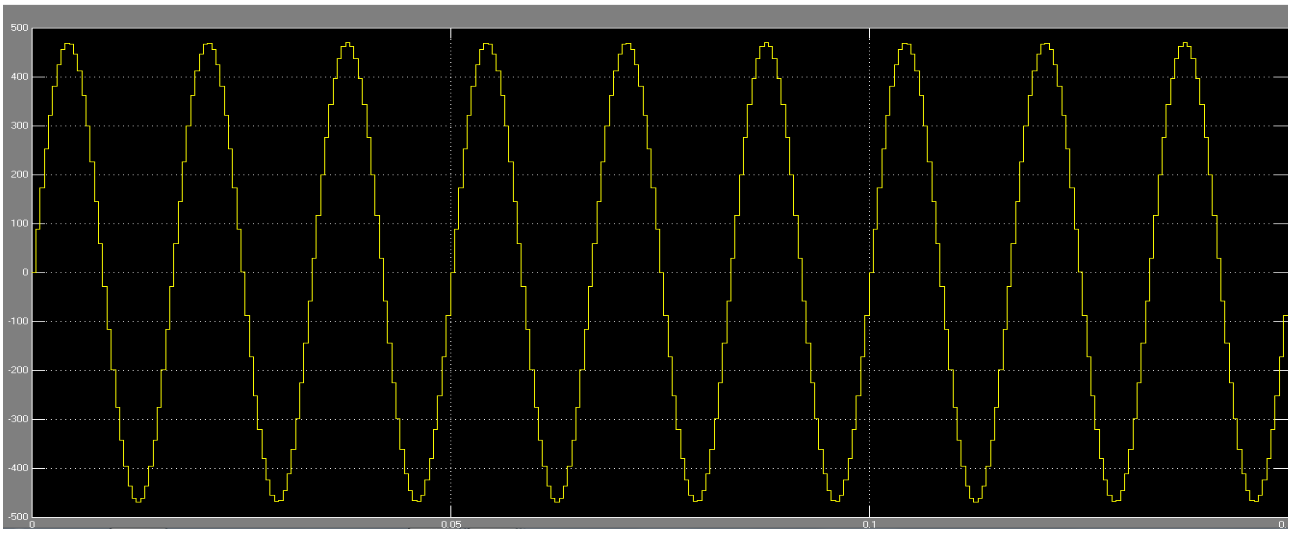

Fig. 8. Voltage across the capacitor

Conclusions

This study analyzes the control strategies as well as models and designs and simulates the whole autonomous system of PMSG wind turbine feeding AC power to the utility grid in Matlab Simulink. The simulation results show that the combination of pitch angle controller, generator-side inverter controller, and grid-side inverter controller has good dynamic and static performance. The maximum power can be tracked and the generator wind turbine can be operated in high efficiency. DC-link voltage is kept at stable level for decoupling control of active and reactive power. Hence, the output will get the optimum power supply for the grid.

Conflict of interest

Authors declare there are no conflicts of interest.

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