Analysis of PMSG Based Wind Energy Conversion System using MATLAB/Simulink

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ABSTRACT
This paper presents study on a variable wind turbine equipped with a permanent magnet synchronous generator. At different wind speeds, the PMSG based wind energy system's performance is presented. It has good performance, especially at low wind speeds and its voltage harmonics are lower than fixed speed turbines. This system model was verified using MATLAB/Simulink.

Keywords: permanent magnet synchronous generator, wind energy conversion system, wind turbine

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INTRODUCTION
Strong growth of renewable energy resource (RES) suggests that they will eventually be a substantial generation part of many electric power systems in the upcoming years. However, the rising penetration level poses the difficulty on operators because of their intermittency. In this paper, study focuses on wind energy conversion systems. Indeed, wind energy has become a major producer of renewable electric energy. A wind turbine generator system (WTGS) transforms the wind energy into electrical energy [1].

In fact, wind turbines generate mechanical forces such as windmills of the past. Through their blades, wind turbine captures the wind kinetic energy and transforms it into mechanical one. Then this later was transformed into electric energy by a generator. There are many types of generator available for wind energy conversion; as example induction

Generator in all its forms like wound rotor asynchronous generator, dual stator induction generator, etc.

The permanent magnet synchronous generator is selected for many reasons. A permanent magnet synchronous generator is characterized by the absence of gearbox and reduced active weight, besides having a high power density and a high efficiency (disappearing of the copper losses in rotor). Generally, the wind turbine generator based on rotational speed can be splitted into two types: fixed and variable speed WTGS. Fixed speed turbines are easier to interface with the electrical grid. However, variable speed turbines are able to extract more energy from the wind and are the design preferred by the wind industry. A comparison between the variable speed wind turbine and the constant speed wind turbine shows that variable speed reduce mechanical stresses: gusts of wind can be absorbed, dynamically compensate for torque and power pulsations caused by back pressure of the tower. This backpressure causes noticeable torque pulsations at a rate equal to the turbine rotor speed times the number of rotor blades. The advantages of PM machines over electrically excited machines can be summarized as follows

according to literatures: Higher efficiency and energy yield, No additional power supply for the magnet field excitation, Improvement in the thermal characteristics of the PM machine due to the absence of the field losses, Higher reliability due to the absence of mechanical components such as slip rings.
Lighter and therefore, higher power to weight ratio. However, PM machines have some disadvantages, which can be summarized as high cost of PM material, difficulties to handle in manufacture,

demagnetization of PM at high temperature.

In recent years, the use of PMs is more attractive than before, because the performance of PMs is improving, and the cost of PM is decreasing. The trends make PM machines with a full- scale power converter more attractive for direct-drive wind turbines [2]. Considering the performance of PMs is improving and the cost of PM is decreasing in recent years, in addition to that the cost of power electronics is decreasing, variable speed direct-drive PM machines with a full-scale power converter become more attractive for offshore wind powers. On the other hand, variable speed concepts with a full-scale power converter and a single or multiple-stage gearbox drive train may be interesting solutions not only in respect to the annual energy yield per cost but also in respect to the total weight. For example, the market interest of PMSG system with a multiple-stage gearbox or a single-stage gearbox is increasing.

Both induction and synchronous generators can be used for wind turbine systems [3]. Mainly, three types of induction generators are used in wind power conversion systems: cage rotor, wound rotor with slip control and doubly fed induction rotors. The last one is the most utilized in wind speed generation because it provides a wide range of speed variation.

However, the variable-speed directly-driven
multi-pole permanent magnet synchronous generator (PMSG) wind architecture is chosen for this purpose and it is going to be modeled: it offers better performance due to higher efficiency and less maintenance because it does not have rotor current. PMSG can be used without a gearbox, which implies a reduction of the weight of the nacelle and reduction of costs.

VARIABLE SPEED WIND TURBINE CHARACTERISTICS

Turbines usually need to be shut down when wind movement is too fast or slow [4]. But a variable speed wind turbine can use winds of almost any speed and are up to 40% more energy efficient.

GENERATOR MODEL

The PMSG has been considered as a system which makes possible to produce electricity from the mechanical energy obtained from the wind.

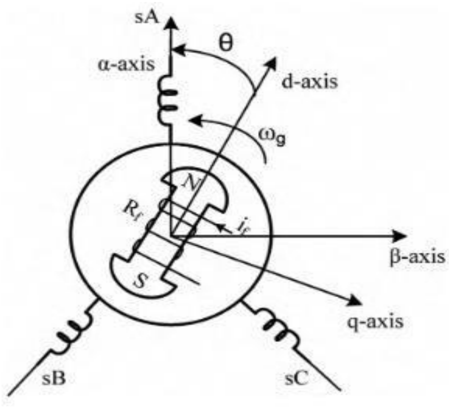

Fig. 1. *d-q and α-β axis of a typical salient-pole synchronous machine.*

The dynamic model of the PMSG is derived from the two- phase synchronous reference frame, which the q-axis is 90° ahead of the d-axis with respect to the direction of rotation. The synchronization between the d-q rotating reference frame and the abc: three phase frame is maintained by utilizing a phase locked loop (PLL) [5]. Figure 1 shows the d-q reference frame used in a salient-pole synchronous machine (which is the same reference as the one used in a PMSG), where "e" is the mechanical angle, which is the angle between the rotor d- axis and the stator axis.

The mathematical model of the PMSG for power system and converter system analysis is usually based on the following assumptions [6], [5]: the stator windings are positioned sinusoidal along the air-gap as far as the mutual effect with the rotor is concerned; the stator slots cause no appreciable variations of the rotor inductances with rotor position; magnetic hysteresis and saturation effects are negligible; the stator winding is symmetrical; damping windings are not considered; the capacitance of all the windings can be neglected and the resistances are constant (this means that power losses are considered constant).

THE POWER OF WIND

Wind is made up of moving air molecules which have mass–though not a lot. Any moving object with mass carries kinetic energy in an amount which is given by the equation:

Kinetic Energy = 0.5 × Mass × Velocity^{2+}

where the mass is measured in kg, the velocity in m/s, and the energy is given in joules.

Air has a known density (around 1.23 kg/m3 at sea level), so the mass of air hitting our wind turbine (which sweeps a known area) each second is given by the following equation:

Mass/sec (kg/s) = Velocity (m/s) × Area (m^2) × Density (kg/m^3)

And therefore, the power (i.e. energy per second) in the wind hitting a wind turbine with a certain swept area is given by simply inserting the mass per second calculation into the standard kinetic energy equation given above resulting in the following vital equation:

Power = 0.5 × Swept Area × Air Density × Velocity^3

$$P_w = c_P \frac{1}{2} \rho A v_w^3$$

where power is given in Watts (i.e. joules/second), the swept area in square metres, the air density in kilograms per cubic metre, and the velocity in metres per second. Figure 2 shows scheme of proposed system.

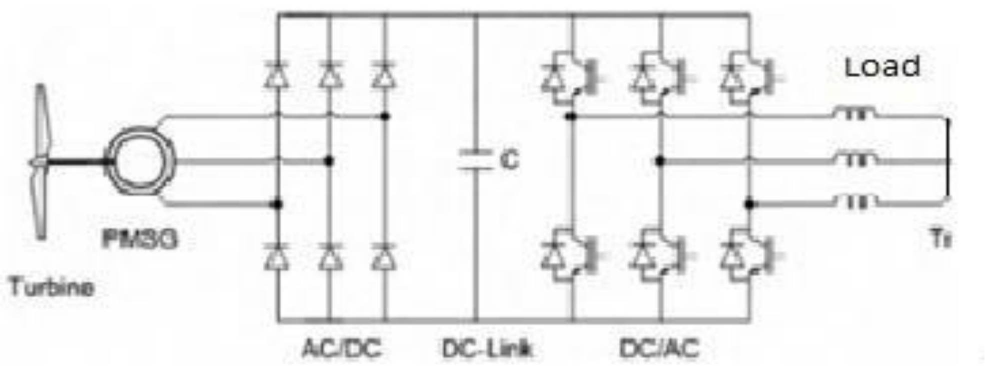

***Figure 2** Electrical scheme of a variable speed wind turbine equipped with a direct-drive PMSG.*

Figure 3 (a) (b) and Figure 4 shown below are subsystems in the MATLAB/Simulink.

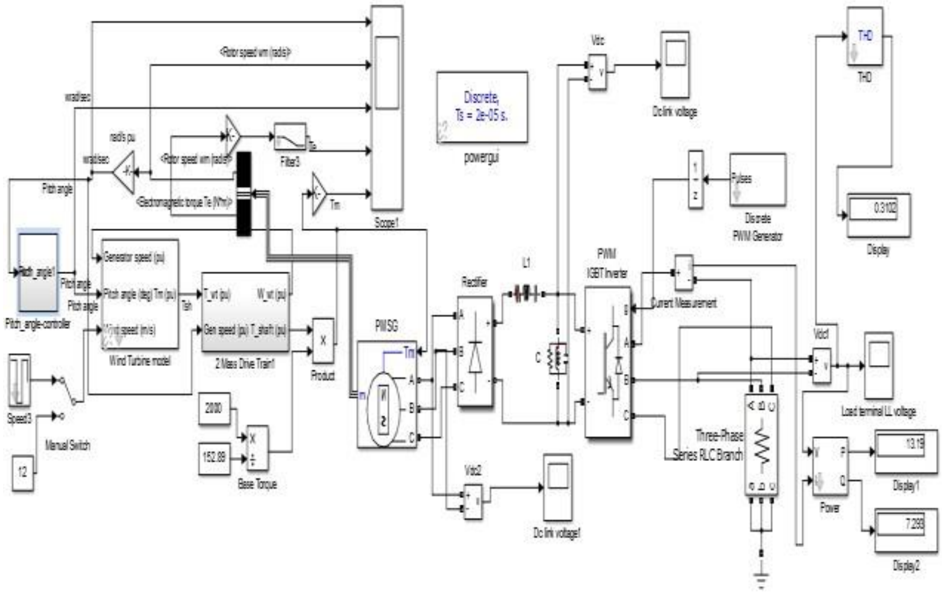

Fig. 3. *(a) MATLAB Simulated model of PMSG wind system connected to local load.*

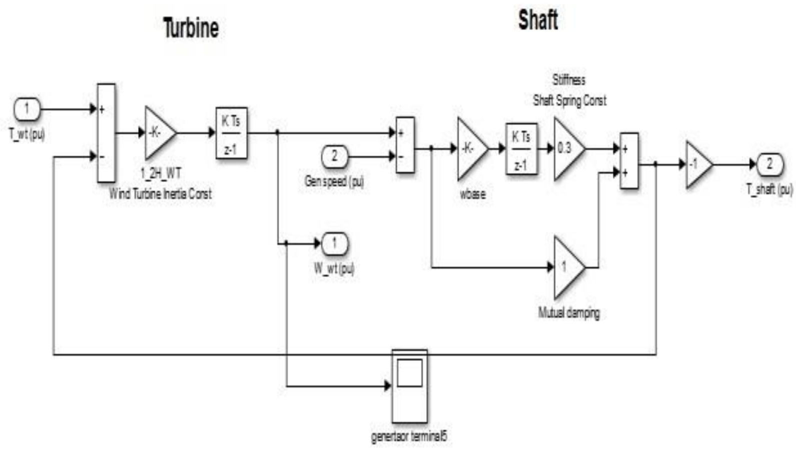

Fig. 3. (b) *Two mass drive train-Turbine and shaft simulink model.*

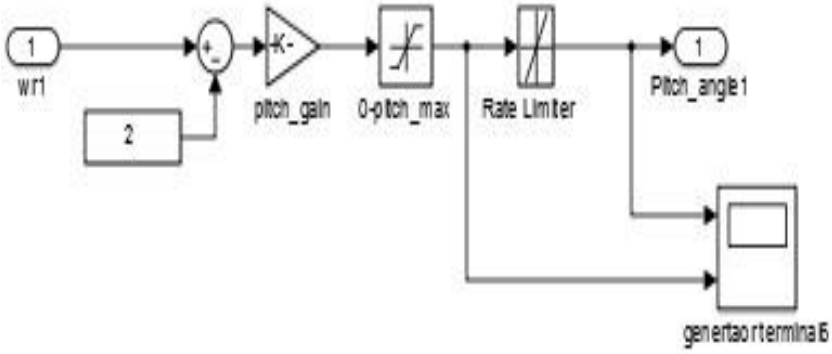

Fig. 4. *Pitch angle control Simulink model.*

SIMULATION RESULTS

The simulation is carried out using MATLAB/Simulink. Rotor speed, Torque, DC link voltage and load voltage wave forms are observed.

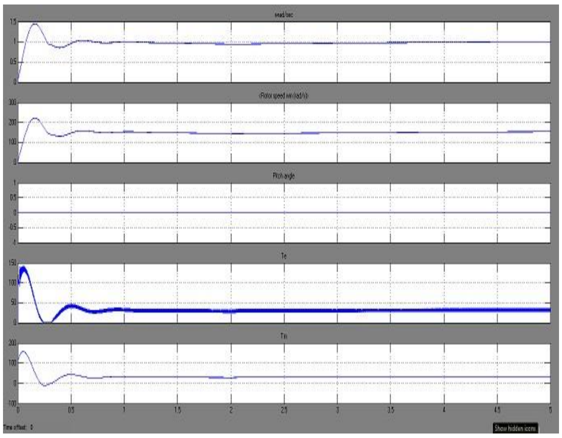

***Fig. 5**. Angular speed, rotor speed, pitch angle, electromechanical torque, generator shaft torque.*

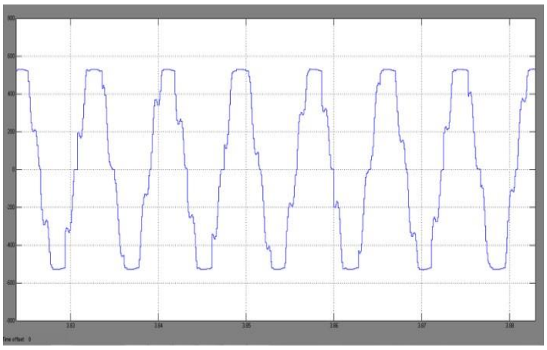

***Fig. 6.** DC Link voltage waveform.*

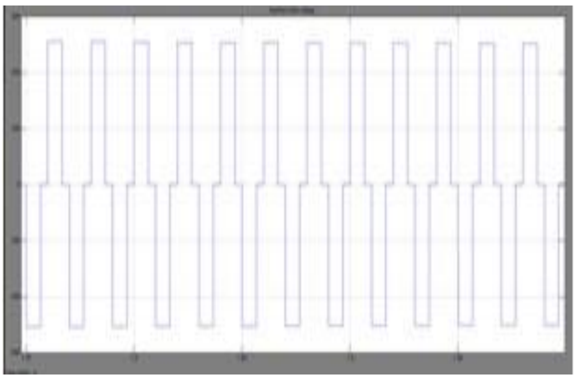

***Fig. 7.** Load voltage waveform.*

Figure 5, Figure 6 and Figure 7 shows the obtained waveforms of various parameters related wind energy conversion system. It was observed that the percentage of total harmonic distortion for the load voltage is 4%.

CONCLUSION

A variable speed wind energy conversion system has been presented which is based on a synchronous generator with a frequency converter based on a two level inverter. Simulation results show the dynamic performance of variable speed PMSG based WECS.

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