Modelling of Wind Turbine System by Means of Permanent Magnet Synchronous Generator

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Abstract

This paper presents a control scheme for a direct-drive permanent magnet synchronous generator wind turbine system with the objectives to get the optimal power from the wind and make sure a maximum efficiency for this system. Furthermore, in order to remove the electrical speed sensor mounted on the rotor shaft of the PMSG (Permanent magnet synchronous generator) to decrease the system hardware complexity and improve the reliability of the system, a sliding mode observer based PM rotor position and speed sensor less control algorithm is presented here.The most favorable tip speed ratio based maximum power point tracking control is utilized to make sure the maximum power capture for the system. The field oriented control algorithm is applied to control the speed of the PMSG with the orientation of the wind speed. In the grid-side converter control, voltage oriented control algorithm is applied to control the active and reactive power injected into the power grid.

1. INTRODUCTION

The direct-drive wind turbine PMSGs do not have the gearbox among the wind turbine and the PMSG rotor shaft, which avoids the mechanical power losses caused by the gearbox. In addition, the elimination of the gearbox also helps in reducing the cost of the system. The overall configuration of a direct-drive wind turbine PMSG system is composed of a wind turbine PMSG, a rectifier, and an inverter. The wind turbine PMSG transforms the mechanical power from the wind into the electrical power, while the rectifier converts the AC power into DC power and controls the speed of the PMSG. The controllable inverter helps in converting the DC power to variable frequency and magnitude AC power. With the voltage oriented control algorithm, the inverter also possesses the capability to control the active and reactive powers injected into the grid. For the control of direct-drive PMSG systems, the information of the rotor position and speed is required to apply the advanced control algorithms such as the field oriented control (FOC) and direct torque control (DTC). Conventional methods to get the rotor position and speed information are based on an encoder or a transducer mounted on the rotor shaft. However, such electrical speed sensors raise the hardware complexity and system cost. In addition, the rotor mounted sensors have to undergo the constant oscillations of the rotor shaft, which reduces the consistency of the system. According to [7], speed sensor failures cause more than 14% of failures in such WECSs. The failure of the speed sensor will cause the breakdown of the whole system, which will add to considerable losses in power production. Furthermore, the repair of the failed components results in extra cost. Based on this issue, this paper proposes a back EMF based rotor position and speed sensor less control algorithm.

2. PROPOSED METHODOLOGY USED

2.1Wind Generation System

Wind power uses the force of the wind to drive a turbine which drives a generator to generate electricity. Wind power is renewable because it is produced by the energy from the sun that drives the earth's weather patterns. Usually, turbines are clustered in "wind farms" scattered throughout consistently windy areas and often share space with useful agricultural lands. These large installations supply electricity to local power grids for sale to homes and businesses. Smaller installations to meet definite needs are also common where grid electricity is not accessible. Wind farms, similar to other large scale electricity generation services, are connected to the electricity grid. It is delivered to homes and businesses just like other sources of electricity.

2.2. Wind Turbines

A wind turbine is a rotating machine which enables the change of kinetic energy in wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill. If the mechanical energy is then converted to electricity, the machine is called a wind generator, wind turbine, wind power unit (WPU), or wind energy converter (WEC). For a given temperature and pressure, the power contained in the wind at a particular location is proportional to the cube of the wind speed. Ideally, the maximum power that a turbine can extract is 0.593, the Betz coefficient, times the power contained in the wind. However, the maximum extractable power from a practical turbine is limited to 35 – 40 % of the wind power. For a given turbine, this limit is possible for a specific ratio of the turbine’s rotational speed to the wind speed. At other ratios, the turbine output reduces. So, with constant change in wind speed, a natural incidence, it is desirable for the turbine speed to be adaptable to the wind speed in order to maximize the output.

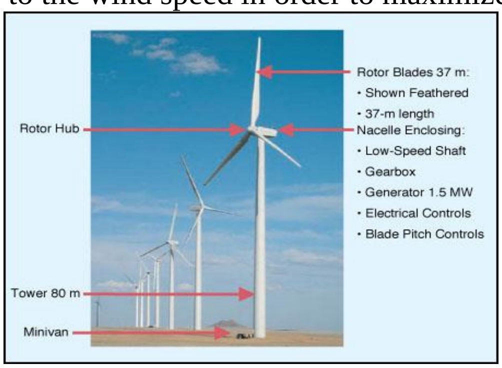

Fig-1 A modern wind turbine installed in a wind farm.

Fig.1 shows a schematic diagram of a wind turbine along with a nacelle is installed over a tall tower of height 60 – 80m. Recent wind turbines deployed throughout the world today have three-bladed rotors with diameters of 70m to 80m. The turbine power output is controlled by rotating the blades about their long axis to change the angle of attack with respect to the relative wind as the blades spin about the rotor hub, which is referred to as “ controlling the blade pitch’’. The turbine is sharp into the wind by rotating the nacelle about the tower, which is called “yaw control’’. Almost all recent turbines operate with the rotor placed on the windward side of the tower, which is referred to as an “upwind rotor”. Wind sensors on the nacelle tell the yaw controller where to point the turbine, and when combined with sensors on the generator and drive train, inform the blade pitch controller to control the power output and rotor speed and to avoid overloading structural mechanism. The fig.2 shows the power curve for a typical modern turbine and illustrates the different control regions for the turbine. Typically, a turbine will cut in and begin to generate power at a wind speed of about 12 mph. It will attain its rated power at about 28 to 30 mph, where the pitch control system starts to limit power output and avoid overloading the generator and drive train. At around 50 mph, the control system pitches the blades to stop rotation to stop overloads and harm to the turbines mechanism.

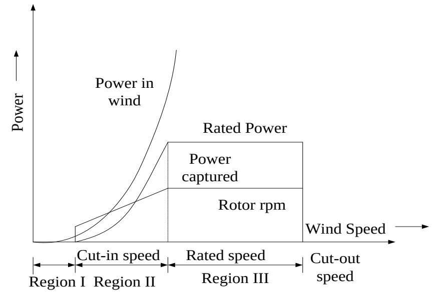

Fig.2 A typical power output versus wind speed curve.

2.3 Wind Generators

In the early days, dc generators were used, which still find application in low-voltage, low-capacity wind power systems charging storage batteries to operate lights and small appliances. For larger machines, dc machines have been phased out, mainly due to the problems associated with commutators. Ac generators, namely, induction and synchronous generators are used by all major wind turbine manufacturers. Hence it is necessary to study ac generators in detail to understand their operation with wind turbines. There are two ways of exciting an induction generator. Based on the method of excitation, induction generators are classified into two basic categories, namely, constant-voltage, constant-frequency generators and Variable-voltage, variable-frequency generators. There are other ways of classifying induction generators, but these are generally related to the method of operation of the machine, based on certain control schemes.

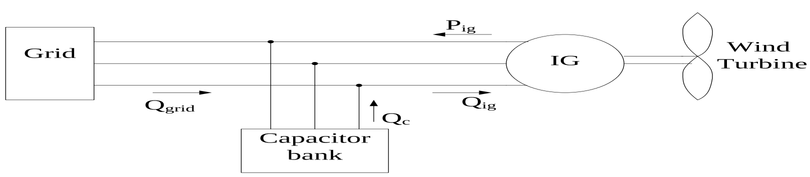

Fig.3 Induction generator feeding to a utility grid with exciting capacitor.

In the constant-voltage, constant-frequency category, the generator derives its excitation from the utility bus as shown in fig.3. Such induction generators are called as "Grid Connected Induction Generators (GCIG) ". The generated power is fed to the supply system when the rotor is driven above the synchronous speed. Machines with a cage-type rotor feed only through the stator and generally operate at low negative slip. But wound rotor machines can feed power through the stator as well as the rotor to the bus over a wide speed range.

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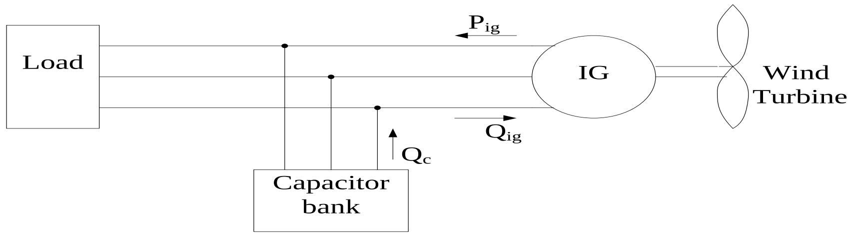


Fig.4 Self-excited induction generator feeding a load.

The fig.4, presents the second type, which is similar to a self-excited dc generator. A capacitor, when connected across the induction machine, helps build up the terminal voltage. Such induction generators are called as "Self-Excited Induction Generators (SEIG)". But the build-up of voltage also depends on factors such as speed, capacitor value, and load. The squirrel cage machine is normally used as a self-excited induction generator. With the stator winding remain connected to the utility gird, if the rotor is driven by a prime mover above the synchronous speed in the direction of the air-gap field, the mechanical power of the prime mover is changed into electrical power.

2.3.1 Grid Connected Induction Generators (GCIG)

The grid connected induction generators can be divided into two types, i.e., single output system and double outputs system.

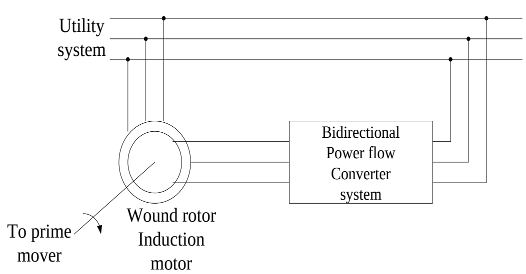
2.3.1.1Single Output System

The system in general sense implies the use of the squirrel cage induction generator, which provides the power output through the stator winding. The generator all the time draws reactive power from the network. Capacitors are used to balance this lagging VAR. These capacitors may source the induction machine to self-excite, leading to over voltages at the time of the detachment of the wind turbine from the electrical system if proper protective measures are not in use. Fixed-speed System: As the induction generator is coupled to the grid, its speed varies over a very small range above the synchronous speed, usually around 1%. As the speed deviation is small, the system is commonly known as a fixed-speed system. For such a system the tip speed ratio varies over a large range, make the rotor efficiency undergo at wind speeds other than the rated wind speed. The gear box ratio is chosen for optimal value of power coefficient for the most frequent wind speed. In a well-designed system, fixed-speed operation can take out about 80% of the energy existing from a fully variable speed system over a year. Fixed speed wind turbines employing either blade pitch regulation or stall regulation to limit the power at high wind speeds are used. It is necessary to do so because if the input mechanical power is more than the power corresponding to the pull-out torque, the system becomes unbalanced. Generally, the turbine accelerates the induction machine to synchronous speed using wind power; the machine is then linked to the grid. The direct connection of an induction machine to the supply produces high inrush current, which is unwanted, particularly in the case of electrical networks with low fault acceptance levels. Such a link can also cause torque pulsations, leading to gear box harm. In order to reduce the magnetizing current surge, soft-starter circuits utilizing phase-controlled anti parallel thyristors are regularly employed to control the applied stator voltage when the induction machine is connected to the network. A few seconds later when the normal current is establish, these starting devices are bypassed.

2.3.1.2 Semi-Variable-Speed Operation: The advantages of a grid coupled fixed-speed squirrel cage generator are its lower capital cost, simple system arrangement and robust mechanical design. As the rotor speed is nearly constant, fluctuations in wind speed result in torque excursions, which may direct to unwanted grid voltage fluctuation and strains on the turbine components. Wind gusts in particular lead to large torque variations. Limited variable-speed operation in this single-output system can bring down the pulsations in grid power and mechanical stress. If some of the generator shaft input can be dissipated in the rotor, the grid input power can be leveled under fluctuating wind speed situation. The rotor electrical power is proportional to the slip. It then becomes possible to achieve speed control of energy degenerate in the rotor resistor. The deviation of rotor resistance with speed keeps both the rotor current and the air-gap power constant. Hence the main aim of the control strategy will be to keep the rotor current at a set value, irrespective of the speed variation within a range, for constant power output from the stator.

2.3.1.3 Double-Output System

With a slip-ring induction machine, power can be fed into the supply system over a large speed range by suitably controlling the rotor power from a variable-frequency source. The provision for bidirectional flow of power through the rotor circuit can be achieved by the use of a slip-ring induction motor with an ac/dc/ac converter connected between the slip-ring terminals and the utility grid. The basic configuration of the system is shown in the fig. 5. The system is known as as a double output induction generator (DOIG) because power can be tapped both from the stator and from the rotor.



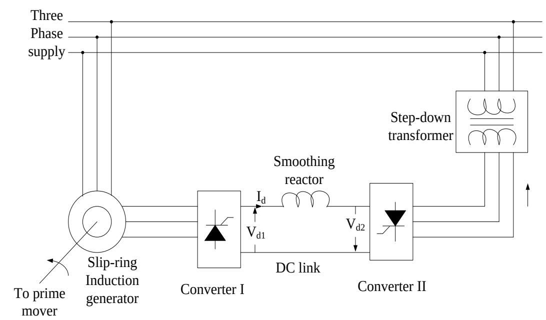


Fig.5 Double-output induction generator system. **Fig.6** Double-output system direct current link.

Double-Output System with a Current Converter fig. 6, presents the main components of the solid-state system for the controlled flow of slip power at variable speed through current converters. The in-between smoothing reactor is needed to keep current continuity and reduce ripples in the link circuit. For the transfer of electrical power from the rotor circuit to the supply, converters I and II are operated, respectively, in the rectification and inversion modes. On the other hand, for power flow in the reverse direction, converter II acts as a rectifier and converter I as an inverter. The step-down transformer between converter II and supply extends the control range of the firing delay angle of converter II.

Double-Output System with a Voltage Source Inverter. The drawbacks of naturally commutated or line-commutated converters and low-frequency forced-commutated converters can be conquer by the use of dual PWM voltage-fed, current-regulated converters, connected back to back, in the rotor circuit, as shown in the fig. 7.

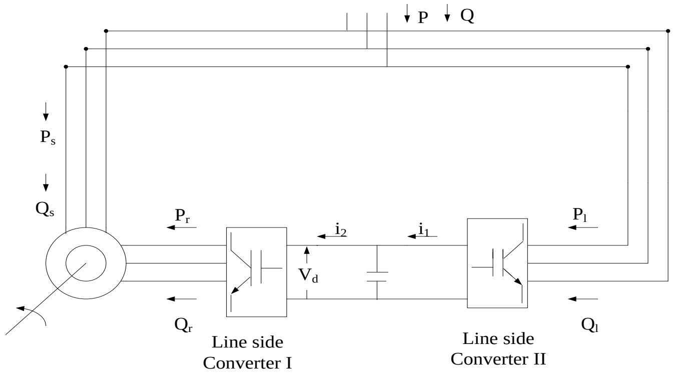
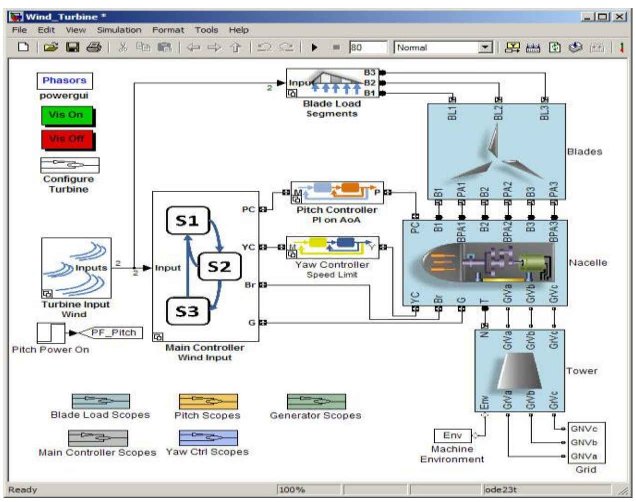


Fig. 7 Power flow in slip power control scheme with dc link voltage.

3. SIMULATION AND RESULTS

To simulate the Wind Energy Generation System with PMSG system a MATLAB test bench is created and simulated the different performance with following parameters.

The fig. 8 show that the simulation of Wind energy generation system.



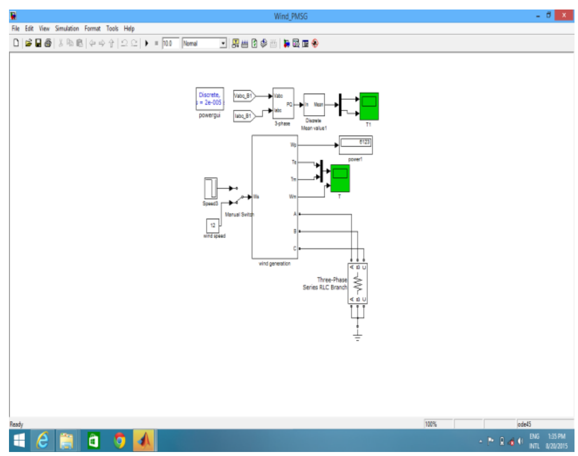
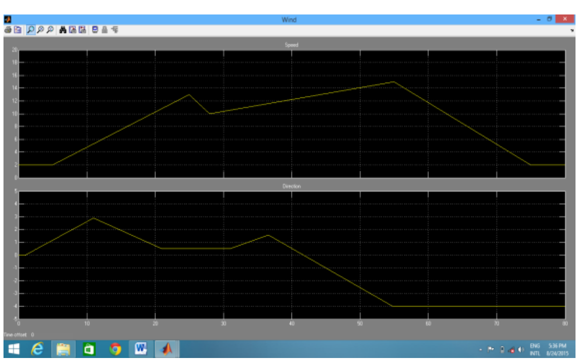


Fig. 8 Simulation of wind energy generation system. **Fig. 9** Simulation model of PMSG



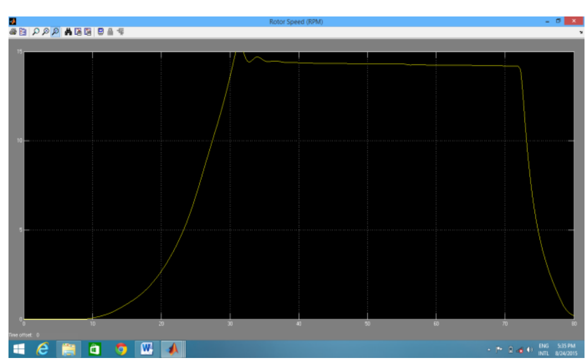


Fig. 10 Rotor speed

Fig. 11 Speed of turbine and direction of air

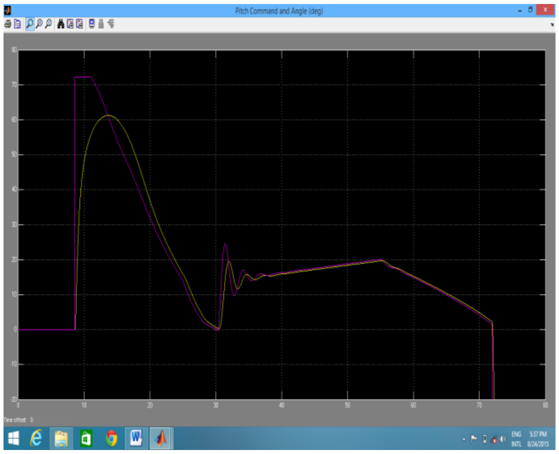


Fig.12 Pitch command and

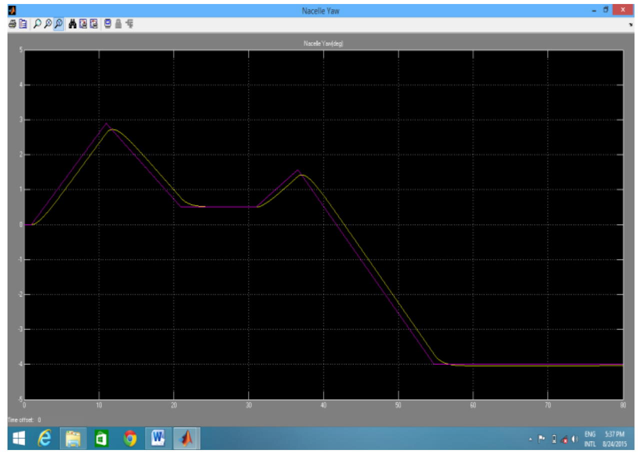


Fig.13 Nacelles yaw angles of rotor

4. CONCLUSION

In this paper, a number of important control algorithms for the wind turbine PMSG systems were studied and analyzed. In order to further validate the control methods, the control algorithms were applied to a case study 2 MW wind turbine PMSG system and a simulation study was performed in this paper. For the generator-side converter control, the most favorable tip-speed ratio based MPPT control algorithm and vector control scheme were applied. From the simulation results, the MPPT method has shown the ability of controlling the wind turbine PMSG to generate the maximum power at different wind speeds. In addition, the high dynamic performance of the vector control method was also indicated in the simulation results, that is, when the wind speed changed, the generator speed which was controlled by the vector control algorithm reacted to the wind speed change very fast. Thus, for the wind turbine PMSG systems require high dynamic performance and high power capture efficiency, the optimal tip-speed ratio based MPPT control and vector control algorithms are qualified candidates.

For the grid-side converter control, the voltage oriented control algorithm was useful in this case study. By decoupling the active and reactive power components of the grid current, the voltage oriented control algorithm has the capability to control the active power and reactive power injected into the grid easily with high dynamic performance. Thus, for the wind generation systems need to output the power with controllable power factor, the voltage oriented control method is a ideal choice. In order to eliminate the PMSG rotor shaft sensor which would increase the hardware complexity as well as the cost of the system, a sliding mode observer based PMSG rotor position and speed self-sensing control was applied in this system. The simulation results indicated that the projected rotor position and speed correspond to their actual values well. However, the chattering effect will increase the torque ripples of the PMSG and bring extra mechanical stress on the rotor shaft.

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