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Grid Interactive Inverter Used for Wind Energy Conversion Systems

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ABSTRACT: Wind energy systems (WES) are the latest trend in the growing energy system in the world because being clean, economic and reliable energy systems. The wind speed is not always stable, so the amplitude and frequency of the voltage of the produced AC energy vary continuously. Electrical energy's transfer to the utility grid or load directly is not possible in terms of efficiency and usability. Thus, many WES have an AC-DC-AC pattern. On the AC-DC pattern, uncontrolled diode rectifier is usually used as they are simple and inexpensive. On the dc-ac pattern, grid interactive VSI controlled by Space Vector Pulse Width Modulation is extensively used. Electrical energy obtained from the WES is preferred to transfer to grid instead of storing energy. In order to transfer energy to the grid, many conditions such as fixed-frequency, continuity of electrical energy, sinusoidal-shaped waveform, being balanced of the phase voltages, to be within certain limits of current harmonics must be carried out. In this sense, the grid interactive inverter and its control technique is fairly important.

KEYWORDS: Wind Energy Conversion System, Permanent Magnet Synchronous Generator, Grid Interactive Inverter.

I. INTRODUCTION

Due to the fast depleting conventional energy resources and the concerns over climatic changes, the renewable energy sources are gaining popularity around the globe. Among all the available renewable energy resources wind energy is wind energy is one of the best and fastest growing energies. Permanent magnet synchronous generator is also developing very fast among all available wind turbines. Since it does not use gear box it can be used to form a direct-drive structure which will increase the system reliability. Therefore, the direct drive wind energy conversion system (WECS) using PMSG has received much attention worldwide [1].

Grid interactive inverters can be either a current source inverter (CSI) or voltage source inverter (VSI). CSI has some superiority such as showing high resistance to short circuits and blocking reverse voltage, VSI are preferred in many applications due to less conduction losses and easier control. Recently, many methods have been recommended for controlling the three-phase grid interactive VSI. Some of these methods are hysteresis current control (HCC), sinusoidal pulse width modulation (SPWM) and SVPWM. In HCC method, dynamic response is good, but switching frequency and harmonics of current are variable. SPWM method is not difficult to implement, but it has high switching losses, needs reference and carrier signals, and cannot use DC link voltage effectively. In recent time, due to the drawbacks of HCC and SPWM, SVPWM method is largely used to control the three-phase VSI. The main advantage of SVPWM method are lower switching losses, low harmonic content, fixed switching frequency, and higher DC link usage [2]-[4].

The power that grid interactive inverters transfer to utility grid can be realized as a controlled voltage or current. In grid interactive inverters controlled by voltage, the obligation of monitoring the grid voltage sensitively makes it both difficult to control algorithm and increases the cost of processor required for controlling. In case of not being monitored the grid voltage precisely, if a small synchronization error occurs, grid interactive inverter will be overloaded and so faults will take place. In current controlled grid interactive inverters, since inverter is much less sensitive to this

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situation, this method is proposed to control in the practices of power transmission to the utility grid. Moreover, while active and reactive power cannot be controlled in voltage controlled inverter, in current controlled mode, active and reactive power can be controlled independently. Because of this reason, current controlled Grid Interactive inverter can operate to unity power factor. Here both current control method is used in order feed the WECS power to grid. Various control techniques such as fuzzy logic, hysteresis, and PI have been developed for current controlled inverter. In fuzzy logic controller based inverters, the control algorithm becomes difficult and consequently the processor cost increases. Another method used in the inverter current control is the hysteresis controller method. In this method, the current is constantly kept within the selected reference band, and the gate signals which are necessary for the switches are produced by the current position in the reference band. Also additional algorithms needed to in the hysteresis method, are restricted in this method in terms of using on single-phase systems. PI controller resulted from the combination of the proportional and integral control action, and successfully used in different application areas is one of the control techniques. In this technique, as being simple algorithm structure reduces the processor cost, this technique can be easily used in three-phase system. Therefore, in the current control of grid interactive three-phase inverter, PI control technique has been generally applied. An algorithm must be run for the grid interactive inverter with the utility grid to operate synchronously. That is to say, the current injected to the grid have to be in same phase with the grid voltage. For this reason, synchronization algorithm plays a major role for wind energy systems. To accomplish this, the grid voltage's phase angle must be accurately determined to control the inverter. To determine the grid voltage's phase angle, the zero crossing detection, filtering of grid voltages, and phase lock loop (PLL) are used as methods. In the zero crossing detection method that is one of the simplest methods for assessing the phase-angle, the zero crossing points of the grid voltages are obtained. As the zero crossing points are able to be just obtained at every half cycle of the grid voltage frequency accurately, the dynamic response of this method is not good. Besides, since the zero crossing method is very susceptible to noise and distortion on the grid, it is only suitable for using where the utility voltages are stable and have sinusoidal-shape waveform. Nowadays, the most extensively accepted synchronization method is 58 phase lock loop because of drawbacks of the zero crossing detection and filtering of grid voltages methods. PLL method can be widely used in different industrial areas such as communication systems owing to its perfect noise rejection capability, the speed control of electric motors, contact-free power supplies and induction heating power supplies. In grid interactive applications, PLL method is used for synchronization between three-phase VSI and the utility grid. PLL has a better compensation of grid harmonics, disturbances, flickers, sags, swells and notches; however, in order to be up to grid unbalance, it needs extra improvements such as various filtering techniques. Moreover, PLL has a very fast and precise detection capability of phase-angle during change of wind speed. Hereby, because the system will be affected negatively in case of determining phase-angle falsely, PLL constitutes of the heart of the system [5]-[6].

The grid side converter permits the wind energy transfer to grid and enables the control of amount of active and reactive power delivered to grid. The grid side inverter requires a control scheme to control the amount of active and reactive power given to grid, to maintain synchronization with grid. Here control scheme utilizes Synchronous Reference frame based control scheme [7]-[9].

The controller senses dc voltage, grid ac voltages, grid ac currents for performing the control of various parameters. The grid side inverter has voltage source topology. With help of series inductance introduced by transformer leakage as well as LC filter choke, the VSI output can be converted into controlled current when connected to grid. The need for controlling dc bus voltage is that, in the VSI with controlled/ regulated dc bus, any increase/ decrease in power will be reflected as dc voltage pulsation. This can directly generate the command for active power reference or reference. Hence dc bus control PI controller output directly gives the I_d reference. For the above conversion, there will be current controller implemented in d-q frame. The 3 phase quantities of output currents are converted into α - β quantities then to d-q quantities, in alignment with grid based unit vectors.

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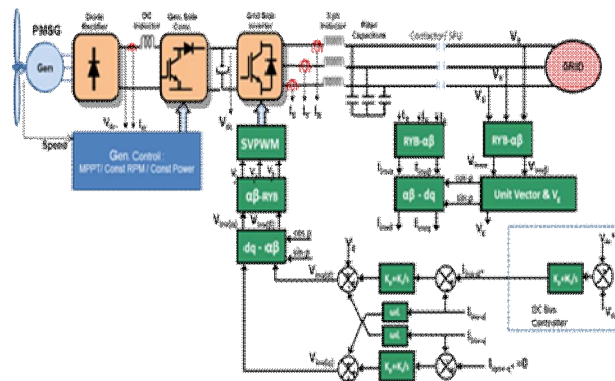


Fig 1: Grid Interactive Inverter

This can directly generate the command for active power reference or reference. Hence dc bus control PI controller output directly gives the I_d reference. For the above conversion, there will be current controller implemented in d-q frame. The 3 phase quantities of output currents are converted into α - β quantities then to d-q quantities, in alignment with grid based unit vectors. The control algorithm will be implemented as a separate control module in digital controller, which in turn generates active power reference for inverter controller. Since inverter is only supposed to feed active power, the reactive power q quantity of inverter current is maintained as zero [10].

II. SYSTEM CONFIGURATION

The system under consideration is shown in Fig. 2. In order to reduce cost we are going for a diode bridge rectifier, while a boost converter will adjust turbine power by means of duty cycle regulation. The WECS is connected to the utility grid through an inverter. Usually, the grid-tied inverter is controlled in a way of power balancing, more specifically, it is controlled to inject all the generated power to the utility grid. As a result, it is reasonable to use an ideal voltage source on the dc bus to simplify the system structure. The block diagram of proposed system is shown below. The main parts of WECS are wind turbine, wind generator, diode bridge rectifier, boost converter and a battery (ideal dc voltage source). A wind turbine is used to convert kinetic energy of wind into mechanical energy. This mechanical energy is converted into electrical energy by means of a generator, here we are using a permanent magnet synchronous generator. The energy from the wind is ac, so in order to convert ac power to dc power, a diode rectifier is used. Boost converter is used to regulate the turbine power by adjusting duty ratio. The aerodynamic power is given by the equation,

$$P_m = 0.5 C_p(\beta, \lambda) \rho A (V_w)^3 \quad (1)$$

Where C_p is Power Co-efficient, A is area of rotor blade, β is pitch angle, λ is tip speed ratio, V_w is wind velocity.

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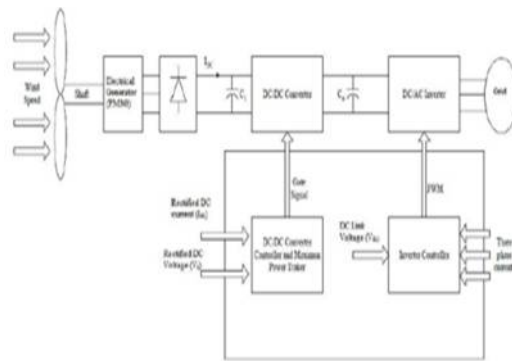


Fig 2: Basic block diagram of system

III. PITCH ANGLE CONTROLLER

Pitch control system is for each blade in a turbine. Each pitch control system is a servo loop which will make the pitch follow a given reference as quickly as possible and with sufficient damping. The pitch controller is a non-linear controller which compensates for the dead band and the limitations in the proportional valve. When the wind velocities are higher than rated, the maximum energy captured must be limited using pitch control by modifying β [11].

IV. TWO MASS DRIVE TRAIN MODEL

This Model shows the combination of wind turbine and shaft side. The differential equations are representing its mechanical dynamics which are given below [12].

$$2H_t \frac{d\omega_t}{dt} = T_m - T_{sh} \quad (2)$$

$$\frac{1}{\omega_{elb}} \frac{d\theta_{tw}}{dt} = \omega_t - \omega_r \quad (3)$$

$$2H_g \frac{d\omega_r}{dt} = T_{sh} - T_g \quad (4)$$

Where H_t = inertia constant of the turbine,

H_g = inertia Constant of the PMSG,

θ_{tw} = shaft twist angle,

ω_t = Angular speed of the wind turbine in p.u.

ω_r = rotor speed of the PMSG in p.u.

ω_{elb} = electrical base speed

V. SIMULINK MODEL AND SIMULATION RESULTS

The figure 3, 4, and 5 shows the simulink model of closed loop control of PMSG connected to wind turbine diode bridge and controller, Simulink model of GI Inverter, Simulink model of control part of GI inverter. Figure 6 shows the Simulation of Wind speed at 12m/s which is constant at that time the results obtained in GI inverter is show in figure 7, 8, 9 which are GI voltage, GI current and inphase voltage and current of GI inverter. Figure 10 shows the Simulation of Wind speed from 7m/s to 11m/s which is varying at that time the results obtained in GI inverter is show in figure 11, 12 which are GI voltage, GI current.

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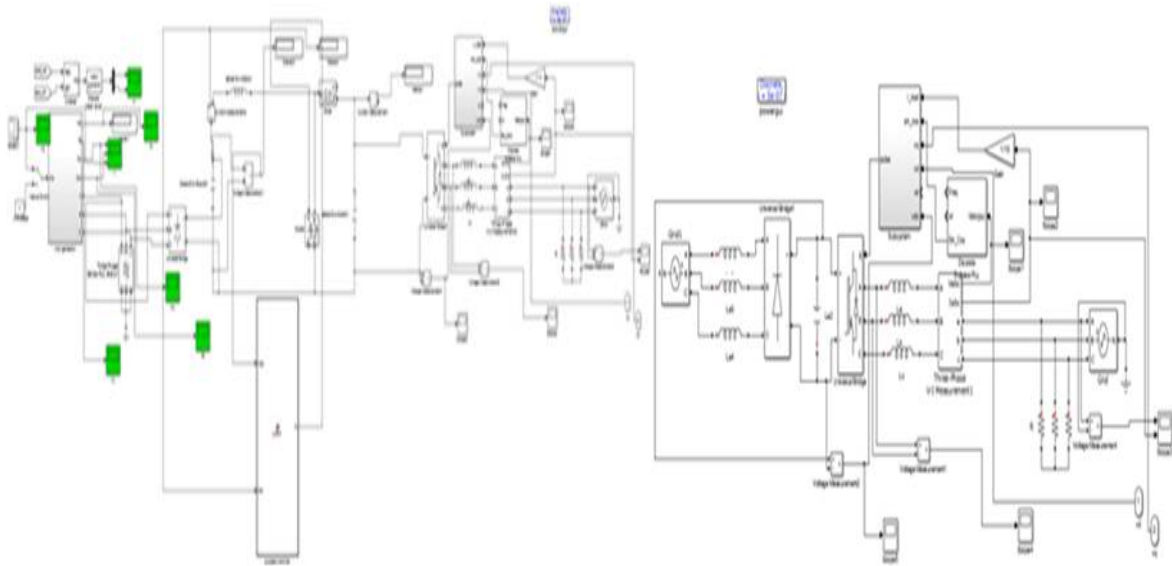


Fig 3: Simulink model of closed loop control of PMSG Fig 4: Simulink model of GI Inverter

connected to wind turbine diode bridge and controller

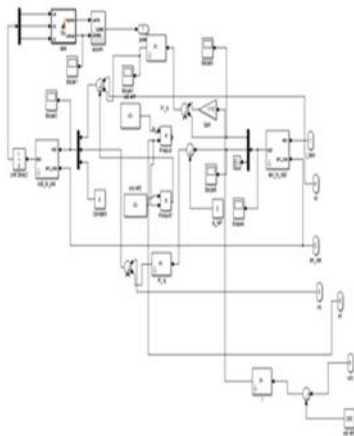


Fig 5: Simulink model of control part of GI inverter

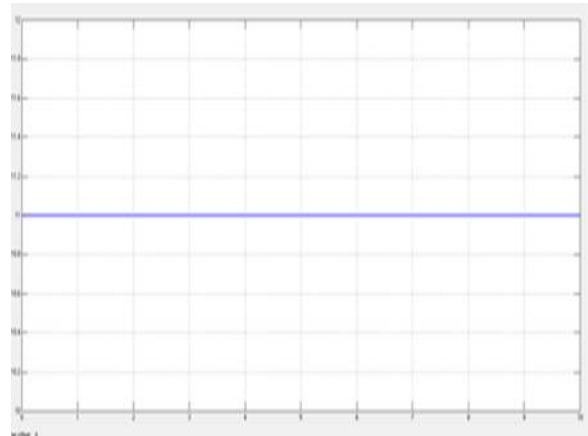


Fig 6 Simulation of Wind speed at 12m/s

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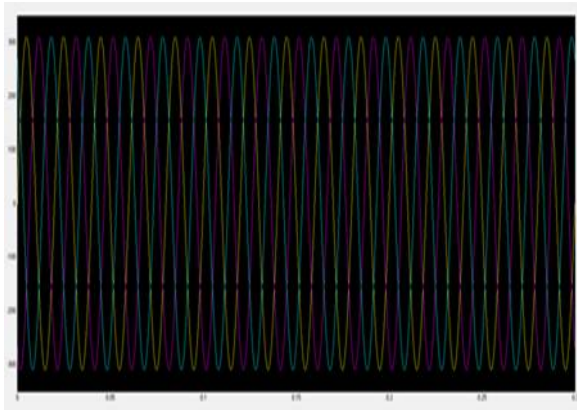


Fig 7 Simulation results of Grid voltage

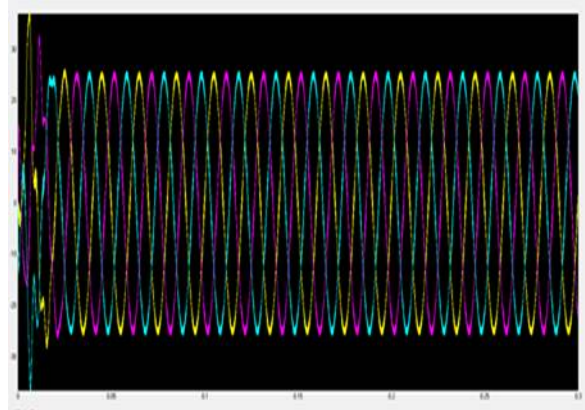


Fig 8: Simulation result for grid current

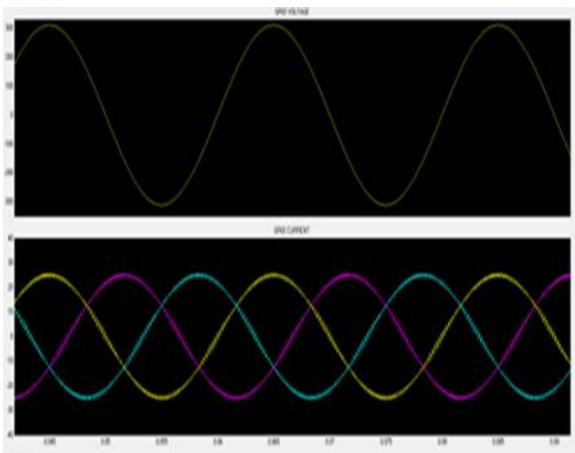


Fig 9 Simulation result of inphase voltage and current of GI inverter

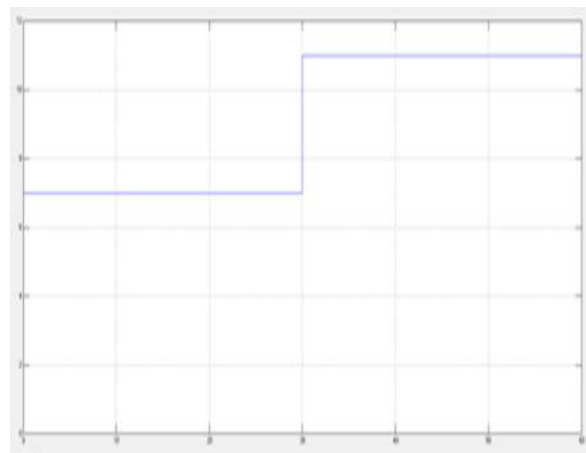


Fig 10: Simulation of change in wind speed from 7m/s and 11m/s

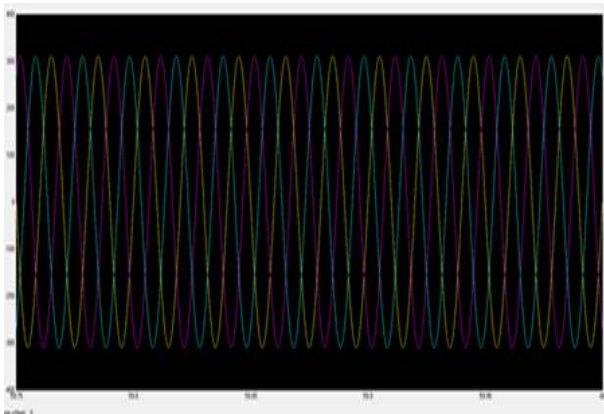


Fig 11: Simulation result of constant grid voltage and 7m/s

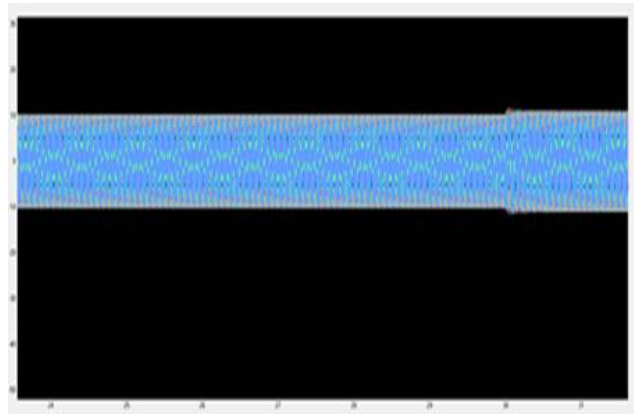


Fig 12: Simulation result for grid current at a variable wind speed of 11m/s

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VI. CONCLUSION

The simulations of PMSG based WECS with unified power controller is presented here and corresponding results are obtained. The unified power controller includes 3 controllers in 3 regions. As a result of this controller low torque and power ripple is achieved.

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