Power Quality Improvement in Wind Energy Conversion System of Grid Interfacing Inverter using Hysteresis Band Current Controller

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Abstract: - Recently renewable energy resources especially wind power integration has been extensively increased in the electric power distribution system. To exploit renewable energy sources more effectively, grid connection of renewable energy sources is done through power electronics interfaces. But it causes problem of voltage fluctuation and harmonic distortion. In this paper, an appropriate model of wind energy conversion system is presented and simulation techniques are discussed for studying power quality problems due to the voltage fluctuation and harmonic distortion in the system. A hysteresis band current control strategy of grid side power converter is presented for grid synchronisation. The proposed power electronics interface and control technique calculates compensating signal and injects it at point of common coupling (PCC). Generation of gate signal of voltage source inverter (VSI) is done through hysteresis band current controller (HBCC). Matlab/simulink is used to simulate wind energy conversion system and control strategy implemented using HBCC to ensure high quality of the injected power and grid synchronization.

Keywords: Hysteresis band current controller, phase locked loop (PLL), point of common coupling, power quality, wind energy conversion system (WECS).

1 Introduction

Regulating the frequency and the voltage in the grid become more significant due to increasing penetration of wind power. To insert power electronics [1, 2] as an interface between the wind turbine and the grid improves behaving of wind power. Power electronics is shifting the basic trait of the wind turbine and converting it as an active power source for the grid. A special attention has been paid on the grid integration of wind turbines in last two decade. The grid connection conditions need to be redefined by the system operator (SO) in different countries, so that integration of wind power on grid does not unfavourably affect the power system operation with respect to security of supply, reliability and power quality [3, 4].

Essential grid code requirements related to frequency, voltage and wind turbine behaviour in case of grid faults need to be considered. The harmonic distortion in system voltage or current must be kept below the limit specified by IEEE 519 standards or IEC 61000-3-6 [5].

Permanent magnet synchronous generator and doubly fed induction generator are mainly employed to generate electric power in variable speed wind energy conversion system. Now-a-days application of PMSG based wind turbine has been increased because of several advantages associated with it. PMSG eliminates the use of gearbox hence results in increased reliability and less maintenance. PMSG are energy efficient and reliable as well as do not require field excitation separately so a diode bridge rectifier can simply be used in conjunction with it. In early days, PMSG was restricted from large size operation for its uneconomic permanent magnet material cost. In the literature various combinations of PMSG and power electronic converters are available, which invariably use rectifier on the generator side, while choice of grid side converter depends upon the application and control strategy.

Vector control method is frequently used in variable speed PMSG for control of active and reactive power separately on the grid-side inverter which is a current regulated voltage source inverter. This is how, the power converter maintains the DC-link voltage constant and the power factor of the system also gets improved [6]. Different control strategies are used to control the grid side converter. They all are focused on the same topics: the control of the DC-link voltage, active and reactive power delivered to the grid, grid synchronization and to make sure high quality of the injected power [7].

This paper is arranged as follows. Brief introduction about WECS and control strategy is given in section 1. In section 2, a model of the wind energy conversion system is presented with an illustration on different components of WECS. The PMSG is connected to power system using power electronics interfaces i.e. a three phase rectifier, an inverter and a DC-link in between them. Hysteresis band current control method based on the vector control strategy applied to control DC-link voltage, active and reactive power at grid discussed in section 3. In this control method synchronization to the grid is done using PLL monitoring the instantaneous grid angle and amplitude. To validate control method, simulation of entire system has been done using Matbal/Simulink software. Simulation results are shown in section 4. Lastly, some conclusions are drawn in section 5.

2 Wind Energy Conversion System

The wind energy conversion system is shown in Fig. 1. The basic component of WECS connected to grid includes variable speed wind turbine, aerodynamic converter, an electric generator, power electronic interface and grid. Modelling of all components of WECS is done in Matlab and Simulink with appropriate control scheme to study steady state performance of wind energy conversion system.

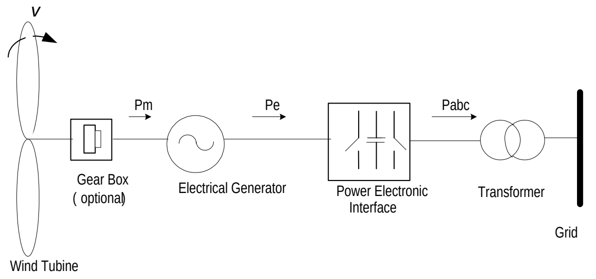

Fig. 1 Wind Energy Conversion System

2.1 Wind Turbine

Calculation of the power in the wind can be done by

$$P_w = \frac{1}{2} * \rho * A * V^3 \text{ Watts} \qquad (1)$$

In eqn. (1)

- A is Area (in m^2) of rotor blade being swept by the wind
- V (in m/s) is the wind speed
- ρ (in kg/m^3) is air density which varies with altitude

The equation (1), gives us the power in the wind but actual power that can be extracted from the wind is less than this. According to Betz limit any wind turbine can only extract a maximum of 59.3% of the power from the wind [1]. The mechanical power which is produced by the wind is given by:

$$P_m = \frac{1}{2} * Cp * \rho * A * V^3 \text{ Watts} \qquad (2)$$

Here Cp is the coefficient of performance of the wind turbine and function of pitch angle β and tip speed ratio λ [8].The ratio between the blade tip speed and the wind speed V is called tip speed ratio and is given by

$$\lambda = \omega R/V \qquad (3)$$

Here ω is turbine rotational speed.

2.2 **Permanent Magnet Synchronous Generator (PMSG)**

The PMSG model is developed in the d-q reference frame to eliminate the time varying inductances assuming a sinusoidal distribution of the permanent magnet flux in the stator and surface mounted round rotor [9]. The state equation to model stator currents is given by

$$\frac{di_d}{dt} = \frac{1}{L_d}\left[V_d + p\omega_g L_q i_q - R_d i_d\right] \qquad (4)$$

$$\frac{di_q}{dt} = \frac{1}{L_q}\left[V_q - p\omega_g (L_d i_d + M i_f) - R_q i_q\right] \qquad (5)$$

Here i_d, i_q – d and q axis stator currents

L_d, L_q – d and q axis inductances

, – d and q axis stator voltages

ω_g – electrical angular velocity

M – mutual inductance
i_f – equivalent rotor current

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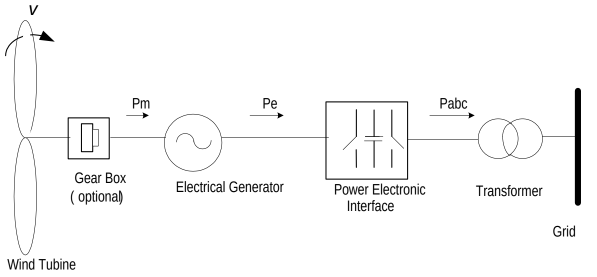

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To avoid demagnetisation of permanent magnet of synchronous generator, a stator current of direct axis is set to zero [10]. The generator torque T_e is given by eqn. (6):

$$T_e = \frac{3}{2} P\varphi i_q + \frac{3}{2} p((L_d - L_q)\, i_d i_q \quad (6)$$

Here P is the no. of pole pairs and φ is the magnetic flux. When the generator is equipped with cylindrical rotor, d-axis and q-axis inductance L_d

and L_q will be equal and generator torque will be given by eqn. (7)

$$T_e = \frac{3}{2} P\varphi i_q \tag{7}$$

2.3 Power electronic Interface

Power electronic devices play key role in generator grid interface. Rectifier-Inverter interface is commonly used in WECS due to simplicity in implementation. A DC-link element used into rectifier inverter interface is for decoupling. Voltage Source Inverter (VSI) use capacitor and Current Source Inverter (CSI) uses inductor as DC link element. Rectifier – Inverter topology is widely applicable because of no need of external excitation. For secondary stage conversion and control the chopper can be used in intermediate DC/DC stage. Rectifier - Inverter topology is as shown in Fig. 2.

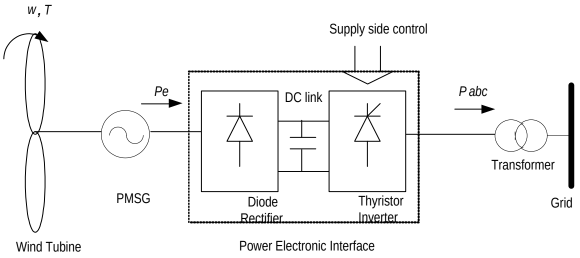

Fig. 2 WECS with Rectifier Inverter Interface

The grid side converter must comply with the grid codes and must provide reliable connection and good power quality to consumers. An appropriate control strategy is required to control active power P and reactive power Q even when wind speed changes. The frequency and voltage amplitude on the grid side should be within tolerance limit under normal operation, and the total harmonic distortion (THD) of the current must be maintained at a low level [11, 12]. The control scheme includes two nested

3 Control Strategy for Grid Interfacing Inverter

Voltage oriented control (VOC) is mostly used for grid converters. In VOC coordinate transformation between the stationary and the synchronous reference frames is done to control grid side converter. A phase locked loop (PLL) is used for coordinate transformation. This control strategy guaranteed fast transient response and high static performance due to internal control loops. Grid currents is converted in two orthogonal axes currents to provide separate control for active and reactive power and an high power factor and sinusoidal grid currents can be obtained [13].

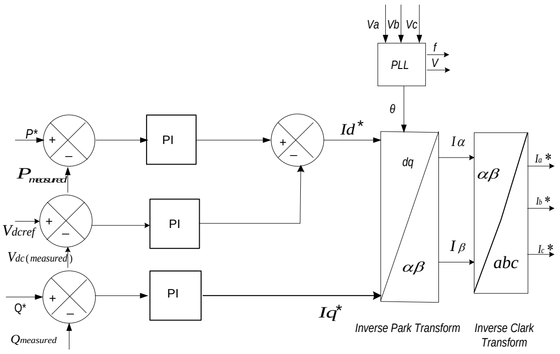

Fig.3.A Control strategy for Grid Side Converter

The d-axis PI controller controls active power, and q-axis PI controller controls reactive power. The d-axis reference is usually obtained from DC-link voltage controller. In order to operate under synchronization with grid, the system uses three PI controllers. The q-axis reference can be set to zero to get unity power factor. In proposed system hysteresis band current controller (HBCC) modulation techniques is used as shown in Fig. 3.B to provide switching pulses to inverter because of fine dynamic response.

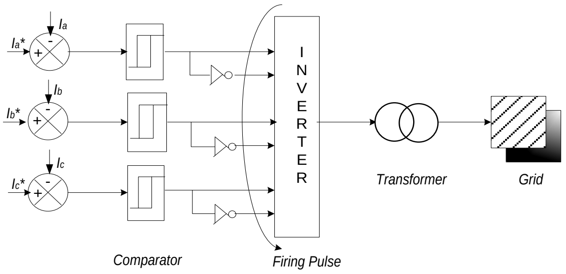

Fig. 3.B Hysteresis band current controller

Phase Locked Loop shown in Fig. 3.C mainly use for detection of phase. PLL is a feedback control system that shifts the phase of a logical generated signal to go with the phase of an input signal. PLL necessitates two orthogonal voltages. The Clarke transformation transforms inverter output currents in a rotating reference frame dq. To get grid power factor close to unity, the PLL match the inverter current angle with the grid voltage angle.

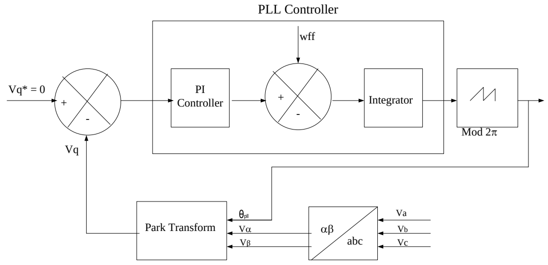

Fig. 3.C Phase Locked Loop

Grid angle θ is use to calculate the reference current that is compared to the actual output current of the inverter. In this control topology synchronization to the grid is done using PLL monitoring the instantaneous grid angle and amplitude. Use of PLL is optional. But with PLL stability under grid faults conditions can be improved. The PLL guaranteed more consistent results and smoother angle. The PLL keeps source parameters unaffected from grid harmonics, phase shifts or voltage sags [14].

4. Simulation model

The WECS is built using Matlab and Simulink shown in fig. 4. The parameters of the wind turbine and PMSG are given in table 1 and table 2. In this section, simulation model of WECS connected with grid model is presented.

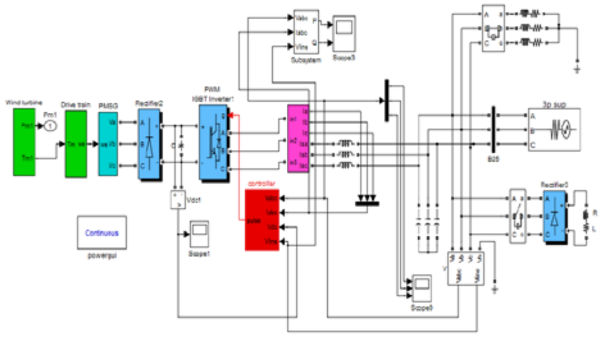

Fig. 4 Simulation model of WECS

Hysteresis band current controller implemented in the model shown in fig. 5 provides gate pulse to grid side inverter. The performance of inverter primarily depends on the control strategy implemented to generate the gate pulses. The dynamic responses of the system are controlled by the current controllers. Hysteresis control is the trendy control techniques out of many current control techniques used for voltage source inverter.

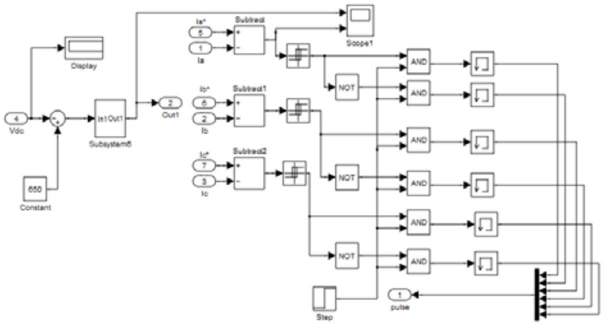

Fig. 5 Simulink model of HBCC

5. Results and Discussions

Figure 6-10 shows the waveforms of wind power generation system.

5.1 Grid Angle

The success of PLL depends on extraction of phase angle θ. The simulation results of grid angle can be observed in Fig. 6 which is used for synchronization. From the figure it is observed that grid angle θ extracted using phase locked loop which further used to convert the feedback variables into the synchronous reference frame dq. Subsequently, output of inverter phase and grid phase angle synchronization is obtained by locking PLL for the duration between 0 to 2π.

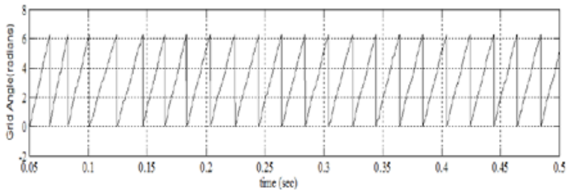

Fig. 6 Plot of Grid angle θ

5.2 Active and reactive power

Reactive power flowing into the grid is almost zero ensuring unity power factor operation at grid. Small variation in active power can be notice in fig.7.

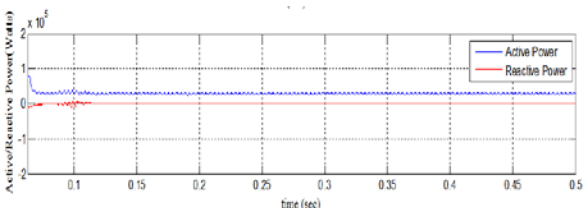

Fig.7 Waveform Active ad reactive power

5.3 DC-Link voltage

The active power transmitted to the grid from PMSG through the grid side inverter causes fluctuating dc-link voltage. Fig.8 shows the simulation result of DC link voltage that remains a constant value at 630 volts in vector control current strategy. The grid-side converter (GSC) is used to keep DC-link voltage constant by controlling active and reactive power injected into grid. Reference of reactive power is set to zero during simulation.

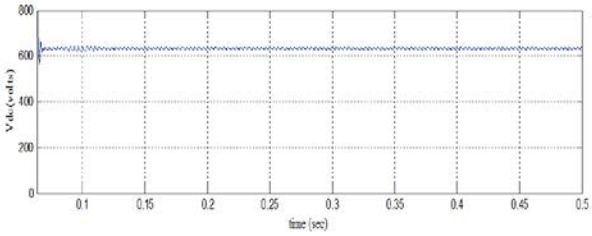

Fig. 8 DC-Link voltage plot

5.4 Grid voltage and grid current

The phase A of the grid voltage and current of same phase is plotted simultaneously to check phase difference between them. It can be notice that the grid voltage and grid current are roughly in phase when reactive power is near to zero.

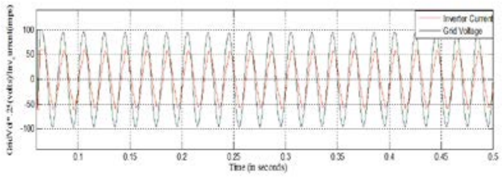

Fig. 9 Waveform of grid voltage and current at PCC

5.5 Grid Voltage

Grid Voltage plot of phase a, b and c is shown in Fig. 10, no disturbance noticed in it.

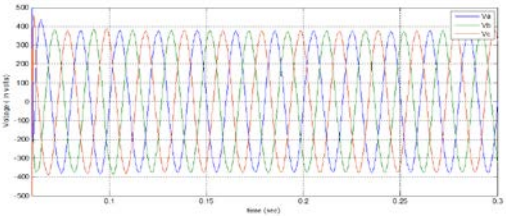

Fig. 10 Voltage waveforms of grid line voltages

5.6 Fast Fourier analysis

Measured THD and its harmonics order shown in fig. 11 and fig. 12 for grid voltage and grid current. It is shown that current and voltage harmonics has been observed under the limits i.e. within 5%.

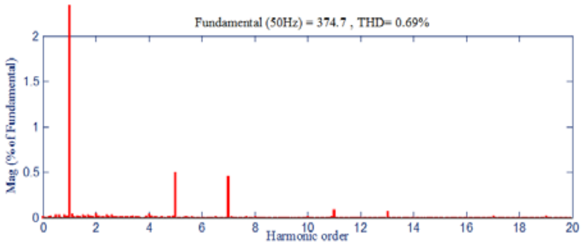

Fig.11 FFT analysis of Grid Voltage

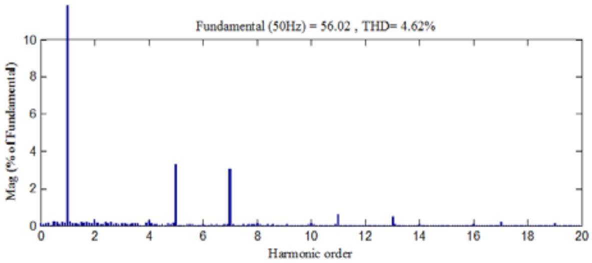

Fig. 12 FFT analysis of Grid Current

6 Conclusion

This paper is intended to demonstrate grid synchronisation and power quality improvement of a variable speed wind energy system based on permanent magnet synchronous generator, which supplies an AC to power grid. The simulation results obtained with the proposed control method system has a stable operation with unity power factor. A hysteresis band current control technique for grid interfacing inverter has been presented in this paper. The hysteresis band current controller has fast response time. The usefulness of the proposed method based on hysteresis band current controller has been showed through the results of the simulation in MATLAB/simulink. Based on the simulation results it can be concluded that hysteresis band current controller keeps THD within specified limit for entire speed range and in better power quality, hence suitable for wind energy conversion system connected with grid.

Appendix

Table 1 Parameters of Wind Turbine

Parameter	**Value**
Blade Radius R	5.2m

Base wind speed V	12 m/s
Air density ρ	1.225kg/m^3
Area swept by blades A	84.94 m^2
Rotor speed	60 rpm

Table 2 Parameters of the PMSG

Parameter	**Value**
Rated Power Pr	25 KVA
RMS line to line Voltage	380 volt
Rated speed N	375 rpm
Stator resistance	0.685 ohm
Stator d-axis inductance	0.025(H)
Stator q-axis inductance	0.01(H)
Pole pairs	8
Permanent Magnet Flux	0.9 (wb)

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