Wind Energy Conversion based on Cascaded H-Bridge Inverter using Single DC source

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ABSTRACT
A wind energy conversion system run by a variable speed wind turbine having pitch mechanism and two mass direct driven permanent magnet synchronous generator is implemented in this paper. Multilevel inverter is an emerging power technology recently for high-medium application. Out of different topologies, cascaded H bridge multilevel inverter is implemented with WECS as it requires fewer components as compared to other multilevel inverter. One of the major limitations is the use of separate dc source for each H Bridge in cascaded multilevel inverter which can be overcome by inserting isolation transformer. For generation of seven level controlled output voltages, a phase- multi-carrier pulse width modulation is used. The proposed WECS having seven-level inverter having isolation transformers is simulated in MATLAB/SIMULINK. The simulated waveform of the output obtained from PMSG, DC link voltage, Pitch angle and three phase CHB MLI voltages are shown.

Keywords
Cascaded H-Bridge multilevel inverter topology , Permanent-magnet synchronous generator (PMSG), Pulse Width Modulation, Isolation Transformer, Wind energy conversion system (WECS).

1. INTRODUCTION
Wind Power is one of the inexhaustible power generation technologies with increasing demand day to day. Wind energy technology is developing rapidly in every part of the world. For harnessing electric power, wind turbine plays the major role. Nowadays by increasing the diameter of wind turbine and using of sophisticated power electronics devices makes it more attractive and reasonable. The major benefit of using variable speed wind turbine are increased Annual Energy Production (AEP), reduced output power variations, high-energy conversion efficiency, improved power quality and reduced mechanical stress and noise [1].

Recently PMSG based two mass direct driven variable speed WECS is popular due to elimination of gear box, no copper loss on rotor, high active/reactive power controllability [2][4][12]. In order to avoid damage to the turbine at high wind speed of approximately 15 to 25 m/s, aerodynamic power control of turbine is required. Out of different ways to control aerodynamic forces on the turbine blades, the most commonly used method being pitch control [3]. The elimination of bulky transformers can be done by using multilevel inverter. The most attractive features of multilevel inverter are high voltage capability, operate with lower switching frequency, lower electro-magnetic interference (EMI). The significant advantage is the reduction of harmonics in the output waveform with an increase in the level of inverter [5].

Out of different topologies of multi-level inverter, cascaded H-bridge inverter is used as it require least numbers of components and flexible as compared to others. For which a new topology is proposed employing single DC source with isolation transformer [6][7][8].For control of multilevel inverter, phase shifted multi-carrier modulation has been used for generation of seven level output voltage [9]-[11].

2. WIND ENERGY SYSTEM
The block diagram of the proposed system is shown in fig. 1. The system comprises of wind turbine, two mass direct driven PMSG, an uncontrolled diode bridge rectifier, a seven level cascaded H-bridge inverter with PWM control and a three phase load.

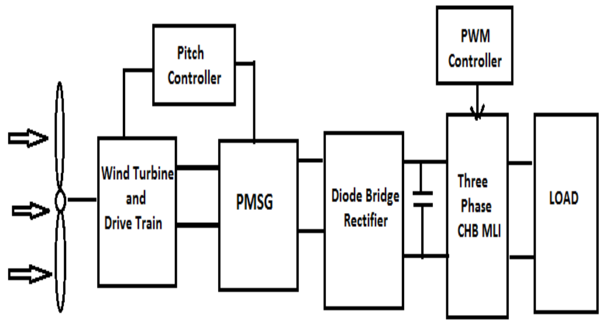

Fig 1: Block diagram of variable speed PMSG based WECS

2.1 Wind Turbine Modeling
Wind turbine plays a major role in a wind energy conversion system. Wind turbines produce electricity by using the power of the wind and drive the generator connected to it. The conversion kinetic energy contained in the wind that passes over the blade to rotational mechanical energy is done by wind turbine.

The power in the air flow is given by

$$P_{air} = \frac{1}{2} \rho \text{ A } \upsilon^3 \tag{1.1}$$

Where ρ is the air density (1.25 kg/m^3), A is the swept area of rotor in (m^2) and υ is speed of the wind in (m/s).

The power transferred to the rotor depends upon power coefficient C_P given by

$$C_P = \frac{P_{Mech}}{P_{air}} \quad (1.2)$$

The mechanical torque in (N-m) is given by

$$T_M = \frac{P_{Mech}}{\omega_M} \quad (1.3)$$

Where P_{Mech} is the output mechanical power in (watts) and ω_M is the mechanical speed of the wind turbine in (radian/sec).

The proposed model uses a PI based control design scheme for the control of blade pitch angle in a variable speed wind turbine. The purpose of control design are (1) optimizing the power output when wind speed is less than rated wind speed (2) when the wind speed is above rated wind speed it keep the output power at rated value by turning the blades out of wind direction [3].

2.2 Permanent Magnet Synchronous Generator

In the PMSG, the rotor magnetic flux is generated by permanent magnets instead of electromagnets and therefore brushless .Because of the absence of the rotor windings, a high power density can be achieved, reducing the size and weight of the generator. In addition, there is no rotor winding losses and reducing thermal stress on the rotor. However, the drawback of this generator lies in the fact that, permanent magnets are more expensive and prone to demagnetization. In direct driven PMSG, the primary advantage is elimination of gearbox which reduces the maintenance cost. In this configuration, a generator is directly coupled to the rotor of a wind turbine known as Two Mass Model [12].

The equation used to develop the dynamic model of permanent magnet synchronous generator are given as

$$V_{ds} = - R_s + \omega_r L_q i_{qs} - L_d \frac{di_{ds}}{dt} \quad (1.4)$$

$$V_{qs} = -R_s i_{qs} - \omega_r L_d i_{ds} + \omega_r \lambda_r - L_q \frac{di_{qs}}{dt} \quad (1.5)$$

The electromagnetic torque of PMSG is given by

$$T_e = \frac{3P}{2}(i_{qs} \lambda_{ds} - i_d \lambda_{qs}) \quad (1.6)$$

Where V_{ds} , V_{qs} are stator voltage in d and q axis, R_s is the stator resistance, i_{ds} , i_{qs} are stator current in d and q axis , ω_r is the rotor mechanical speed, λ_r is rotor flux linkage, L_d, L_q are inductance in d and q axis respectively. The quantities are given in P.U.

2.3 Diode Bridge Rectifier

The universal bridge or three phase diode bridge rectifier converts the AC power generated by PMSG into the DC power in an uncontrolled way. For filtering purpose a DC capacitor is connected across the output terminal of rectifier. The DC voltage can be calculated as

$$V_O = \frac{3\sqrt{2}\, V_{rms}}{\pi} \quad (1.7)$$

Where, V_O is the output DC voltage and V_{rms} is the input AC line voltage.

3. CASCADED H-BRIDGE MULTEVEL INVERTER

Cascaded H-bridge MLI comprises of series of power conversion modules that synthesize a desired ac voltage. Fig. 2 shows the structure of single phase seven level cascaded H bridge inverter having three units of H-bridge power cells connected in series. The output AC voltage is the sum of the voltage generated by each H-bridge module. Each half bridge module consists of four IGBT provide flexible operation.

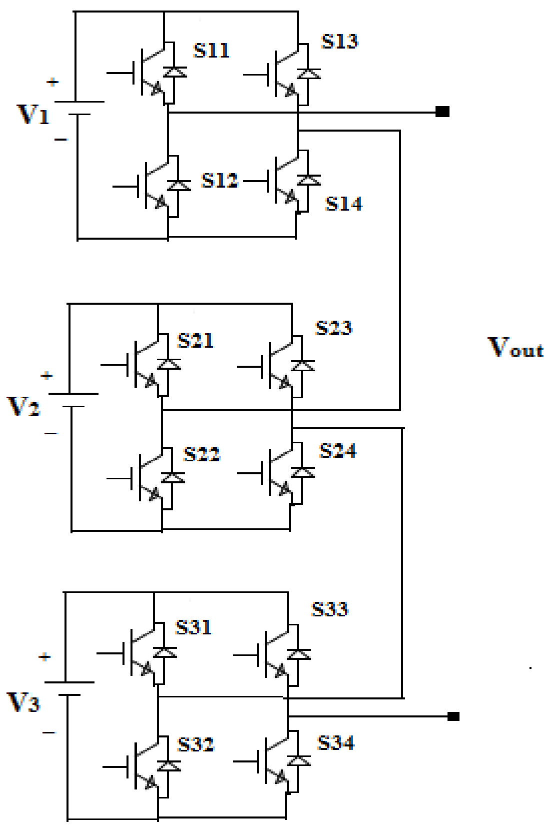

Fig 2: A Single phase cascaded H-bridge MLI

With the increase in the level of multilevel inverter, the output voltage waveform become more sinusoidal and THD (Total harmonic Reduction) value decreases [6]. Three phase system can obtained by connecting three identical single phase cascaded H bridge MLI in star or delta configuration and this configuration provides elimination of triplet harmonics components.

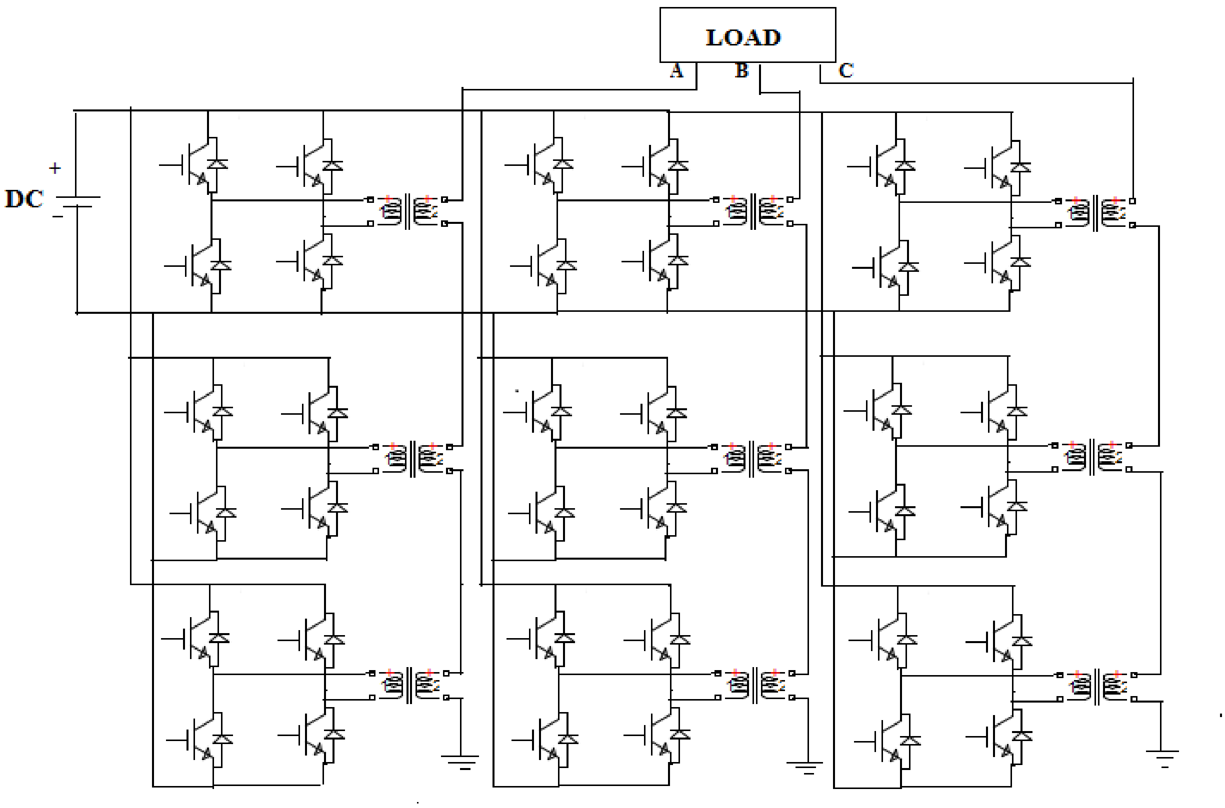

Fig 3: Three Phase Cascaded H bridge MLI with Single DC Source

In this model, the problem of cascaded H-bridge inverter of using of separate DC source for each H-bridge cell can be overcome by taking single DC source with isolation transformer. Fig. 3 shows the circuit of proposed three phase seven level CHB MLI using single DC source. Here, three H-bridge module are connected to same DC source input obtained from wind energy system. Single Phase Isolation transformers are used to isolate each H-bridge from AC output. Primary winding of isolation transformer is connected to the H bridge module whereas secondary of each module connected in series the grounded. But power of the DC source must be bigger than the DC source in the conventional cascade topology.

A sinusoidal PWM technique is used for control of multilevel inverter with different carrier signal. In this paper, Phase shifted PWM scheme has been implemented which require (N-1) triangular carrier and phase shift between any two adjacent carrier wave, given by $\Phi = \frac{360}{N-1}$ where N is the level of inverter. The advantage of this method is that the switches in the multi-level converter operate at a fixed switching frequency $f_{carrier}$ while harmonic cancellation is achieved up to 2N $f_{carrier}$ frequency, thus generating better quality of output. In Phase shifted modulation, the switching of the inverter is related to the device switching frequency by

$$f_{sw,inv} = 2n\, f_{sw,dev} = (m-1)\, f_{sw,dev} \qquad (1.8)$$

Where, m is the modulation index. The flexibility of the system is maintained and AC voltage level can be increased by increasing the level of inverter.

4. SIMULATION AND RESULTS

The proposed model shown in Fig 1 with the PS-PSW modulation scheme has been simulated in MATLAB/SIMULINK for variable speeds. Fig 4 represent the simulation model of wind energy system based on cascaded H-bridge inverter using single dc source.

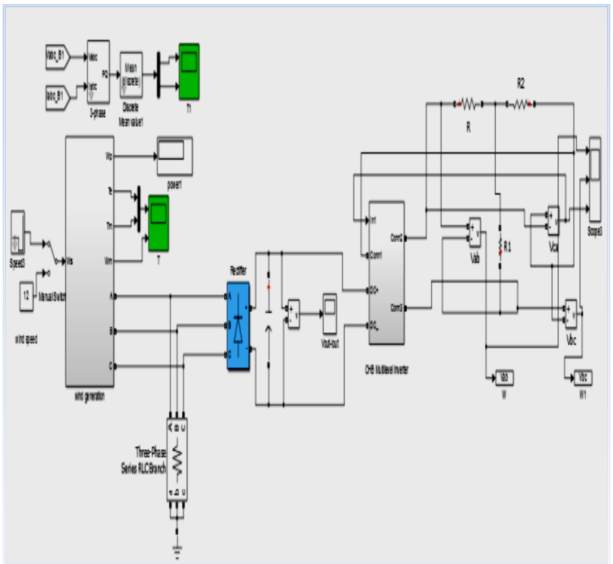

Fig 4: Simulation model of Wind energy Conversion using CHB MLI

Fig 5-9 show the simulated waveform of phase voltage and line current of PMSG, rotor speed of PMSG, Pitch angle, DC link voltage and output voltage of cascaded H-bridge MLI in three phase.

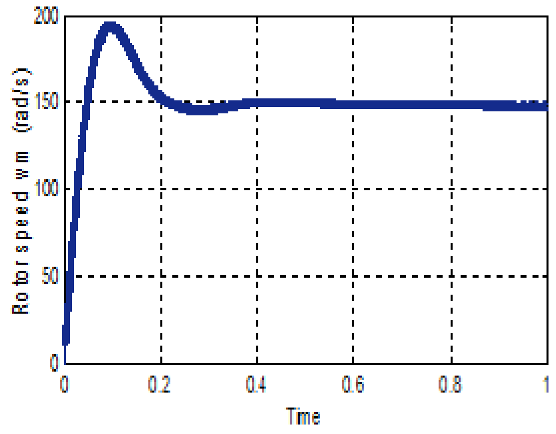

Fig 5: Rotor Speed of PMSG

The above graph shows the rotor speed of permanent magnet synchronous generator.

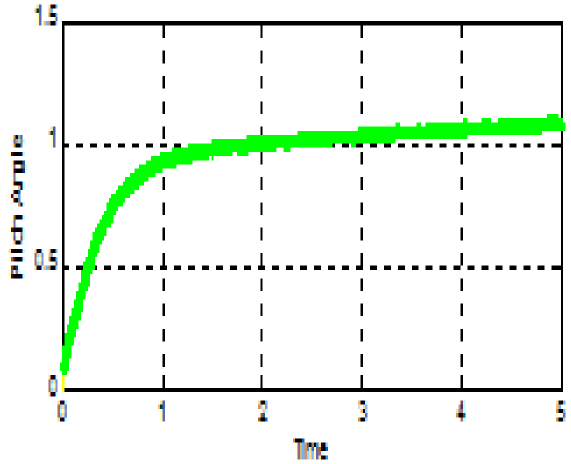

Fig 6

Fig 6 shows the simulation output of pitch angle at wind speed 12 m/s.

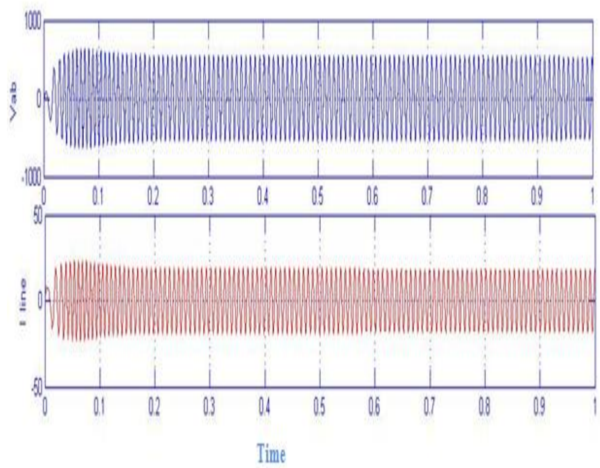

Fig 7: Line voltage and line current of PMSG

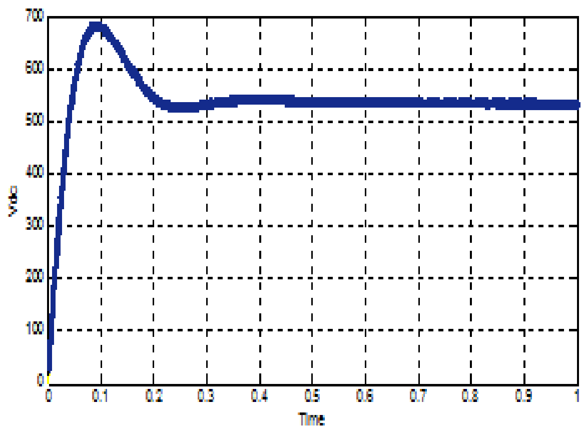

Fig 8: DC link Voltage

The above graph shows the voltage across capacitor which is given to cascaded H-bridge MLI.

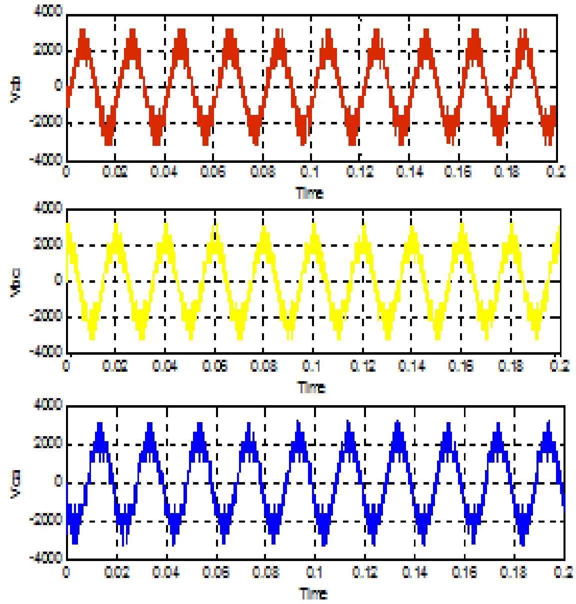

Fig 9: Line voltage of Cascaded H-bridge MLI

5. CONCLUSION

A combination of variable speed wind energy set and cascaded H-bridge multilevel inverter is modeled in MATLAB/SIMULINK. A PI based pitch controller is proposed to limit and regulate the output power at variable wind speed. The seven level cascaded multilevel inverter using single DC source based on isolation transformers is designed to supply power with better output quality. The proposed CHB inverter is controlled by Phase Shifted multicarrier PWM which reduces Total Harmonic Distortion in phase voltage.

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