Voltage Regulated Five Level Inverter Fed Wind Energy Conversion System using PMSG

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***Abstract*— This paper deals with simulation of a wind energy conversion (WEC) system with vector controlled Three level inverter. Mechanical to electrical energy conversion is done by using a permanent magnet synchronous generator. Presence of five level inverter reduces the Total Harmonic Distortion component and increases the efficiency of the system. The main requirement for a grid connected system is grid interaction. The voltage regulator provided in the system is for meeting the grid requirement.**

***Keywords*— Permanent Magnet synchronous generator, Wind turbine, Voltage control, Three level inverter.**

I. INTRODUCTION

Meeting the energy demand in the present world is not a simple or easy task. So alternative energy resources to be provided to meet the crisis. This has lead to an interest to capture energy from natural resources such as wind, water and sunlight. Wind energy conversion system can be considered as an effective way to provide continuous power to the electrical load.

The wind energy available can be transformed to electrical energy by using a wind turbine and a generator. The function of an electrical generator is to provide a mean for energy conversion. The commonly used AC generators for modern wind turbine systems are [1] ,

- Squirrel cage induction generator(SCIG)
- Wound Rotor induction generator(WRIG)
- Doubly fed induction generator(DFIG)
- Permanent magnet synchronous generator(PMSG)

The main AC generators can again classify in to two types. Fixed speed wind turbine generators and variable speed wind turbine generators. The fixed speed wind turbine systems always operate in a fixed speed. Which is independent of the wind speed. Such wind turbine systems uses squirrel cage induction generators and wound rotor induction generator. Since the system is a constant speed one as the wind speed varies there will be a large tension at the point of inter connection. So there must be a regular maintenance for the system. The fixed speed generators needs to consume reactive power for excitation.For this reason, the generator normally requires compensation for reactive power by connecting it to a capacitor bank [2].

The limitations of fixed speed wind turbine systems make the manufactures to choose variable speed wind turbine system. The generators used for variable speed turbine systems are Doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG). The advantages like higher reliability, power density /volume ratio and smaller size make PMSG as an attractive solution for wind energy conversion system [3]. If the available wind characteristic is a steady and high speed one, fixed speed turbines are generally uses.So that the converter requirement can be reduced. But the available wind speeds are very low in most countries. The turbines used in such places are variable speed wind turbine systems. Variable speed direct drive synchronous generators raise great interest because of their higher efficiency and reliability due to the absence of the gearbox, which is to be regularly maintained [4].

If wind conditions are favorable the wind systems can provide electricity at lowest cost. The available wind does not always produce the required amount of power as the load demands. So there must be a power electronic converter to match the power requirement of the load. Such converters are generally known as frequency converter. A frequency converter generally has two parts, a machine side converter and a grid side converter. Conventional systems are either with a two level back to back converter or a three level inverter. Using multi level inverters it is possible to utilize the dc voltage maximum and to produce required amount of ac voltage without any large transformers.

In this thesis a voltage regulator algorithm for wind energy conversion systems using PMSG are studied and simulated. To mitigate the problem of harmonics and to utilize maximum DC link voltage, a five level inverter is also incorporated with the system. Pitch control used along with wind turbine technology primarily as a means of power regulation. It also works as MPPT in mechanical aspects. The wind turbine connected with PMSG is having a two mass drive train between the wind turbine and PMSG in order to overcome the torque vibrations [4,5].

The paper is organized as follows. Section II provides the description about over all system. Section III describes basic features about five level inverters. Section IV describes the voltage regulator method. Section V explains the simulation results obtained.

II. PROPOSED SYSTEM

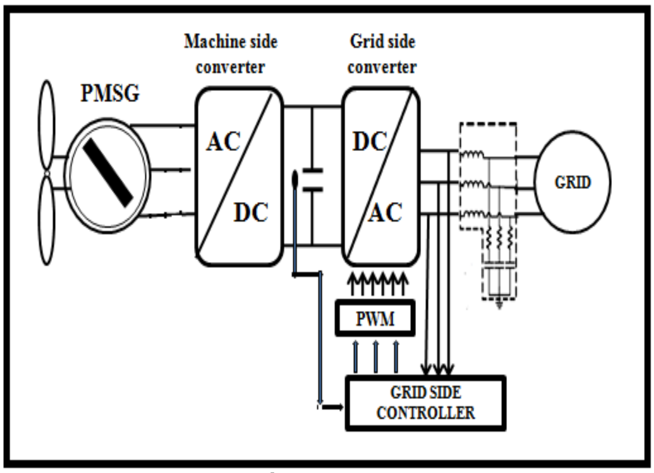

Fig. 1. Wind Energy Conversion System

The power flow in a wind energy conversion system is unidirectional. The rectifier and PWM based VSI takes a major part in converting the wind power to grid. The overall configuration of a wind energy conversion system using PMSG is shown in Fig.1. Here the AC-DC converter shown is an uncontrolled rectifier. Means the control algorithms are used only in the grid side converter.

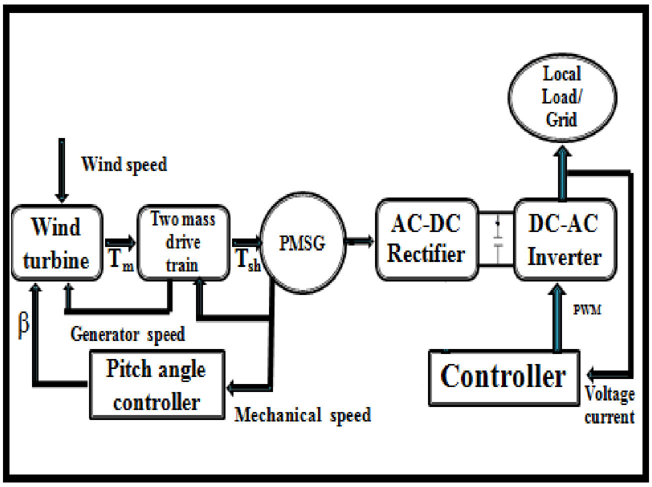

Fig. 2 Proposed WEC system

As seen in this Fig. 2, this system is composed of a wind turbine along with pitch angle control and two mass drive train, PMSG, an uncontrolled rectifier, and an inverter. The wind turbine transforms the kinetic energy present in wind to mechanical power. PMSG converts the mechanical power from the wind into the electrical power. The diode rectifier present will convert the AC power into DC power. where there is no control for the conversion. The controllable inverter helps in converting the DC power to an AC power with grid frequency and magnitude. Using the voltage oriented control algorithm, the inverter is able to control the voltage and frequency of the power, injected into the grid.

III. FIVE LEVEL INVERTER

Two level inverter systems are not smooth like multi level inverters. In order to reduce the THD components, in grid level multi level inverters are used. Multi level converters properly connected can generate a multiple step voltage waveform with variable or controllable frequency, phase and amplitude. Advantages of this multilevel approach include good power quality, and low switching losses. The main disadvantages of this technique are that a larger number of switching semiconductors are required for lower-voltage systems The number of converter level is defined as the number of steps generated by the converter between the output and the neutral point [6].

A five level neutral point clamped inverter circuit is shown in Fig.3. The neutral point clamped inverter is otherwise known as diode clamped inverter. For this type of inverters if the number of levels is 'm', then capacitors required are 'm-1' and power electronic devices per phase are 2(m-1) [7].

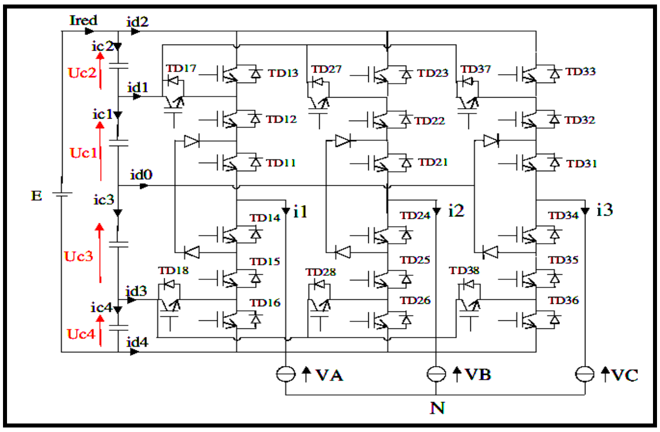

Fig. 3Five level neutral clamped inverter topology

The switching states of a five level inverter is shown in Table I.

TABLE I. SWITCHING STATES OF FIVE LEVEL INVERTER

Terminal Voltage Switching State								
	S_{A1}	S_{A2}	S_{A3}	S_{A4}	S_{A5}	S_{A6}	S_{A7}	S_{A8}
$2V_{DC}$	On	On	On	On	Off	Off	Off	Off
V_{DC}	Off	On	On	On	On	Off	Off	Off
0	Off	Off	On	On	On	On	Off	Off
$-V_{DC}$	Off	Off	Off	On	On	On	On	Off
$-2V_{DC}$	Off	Off	Off	Off	On	On	On	On

The voltage across each capacitor is $V_{dc}/3$. As the number of level increases the performance of inverter as well as the THD component improves.

IV. VOLTAGE REGULATOR CONTOL

The voltage regulator control used here is mainly used for grid interfacing. To interface the system with grid the voltage, frequency and phase of system generated power has to be match with grid power. For that purpose a vector control algorithm is used. Which will always maintain a constant voltage with fixed frequency that we require. The vector control algorithm will indirectly control the torque and power by controlling the d-q axis vectors[8,9].

The control algorithm also helps in interfacing the variable power produced from the PMSG driven wind energy conversion system to a grid supply. The control method used here is to produce a reference signal for pulse production which is meant to control the voltage and frequency [10].

Here fluctuations will be present in the dc link voltage due to variations in wind speed. The variations in PMSG voltage will reflect on the DC link voltage, because the rectifier used is uncontrolled one. But the variations in DC link voltage can be overcome using this voltage regulator [11].

The most widely used sine triangle PWM method is used here. To produce pulse, a reference signal produced using this control method. And in this PWM for Five level inverter the reference wave is to be compared with (5-1) number of level shifted carriers to produce pulse for various switches.

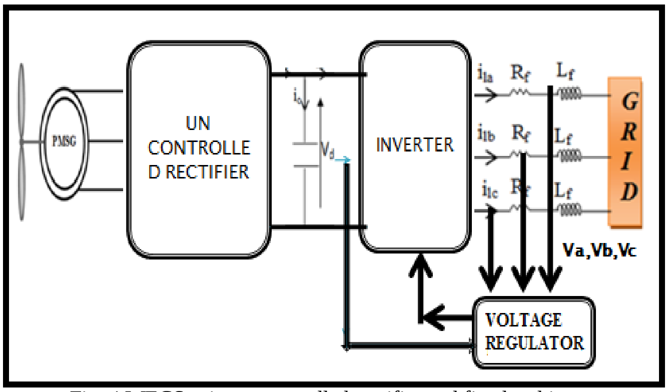

Fig. 4 WECS using uncontrolled rectifier and five level inverter

The WECS using uncontrolled rectifier and controlled five level inverter is shown in Fig. 4. Here the uncontrolled rectifier will introduces a large amount of harmonic content in the switching system and there will not be any control over the DC link voltage. So the PMSG system may have vibrations and this vibration affects the dc link voltage and obviously in the inverter output also. Since we are using a voltage control in the inverter side, the control will maintain a constant grid voltage and frequency

V. Results and Discussions

Simulation has been carried out considering a low generator with 4 pole pairs; wind turbine that is coupled to the generator shaft trough a drive train system. Pitch angle control presents in the system provides a zero pitch angle. The parameter details for the wind turbine connected PMSG system is shown in table II.

TABLE II. System Parameters

Parameters of turbine		Parameters of machine	
parameter	value	parameter	value
Air density	1.08 kg/m^3	Pr, rated power	2.00 KW
A, area swept by blades	31.98 m^2	L_d L_q	0.01 H
V, base wind speed	12 m/s	R_r, rotor resistance R_s, stator resistance	0.425 ohm
C_{pmax}	0.48	Pole pairs	4
Lambda	8.1	Voltage constant	300 Vpp/krpm
Pitch angle , β	0	Torque constant Inertia constant viscous	2.48 Nm/A 0.01197 kgm^2 0.001189 N.m.s

The WECS using uncontrolled rectifier MATLAB model is shown in fig.5.

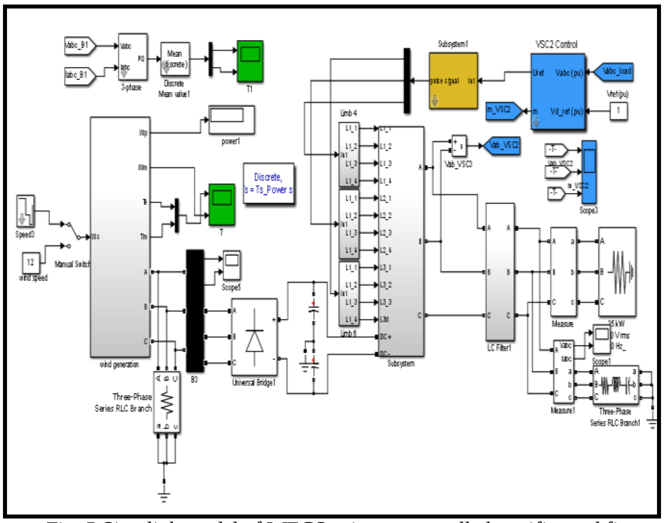

Fig. 5 Simulink model of WECS using uncontrolled rectifier and five level inverter

The wind turbine system modeled is shown in the below fig.6

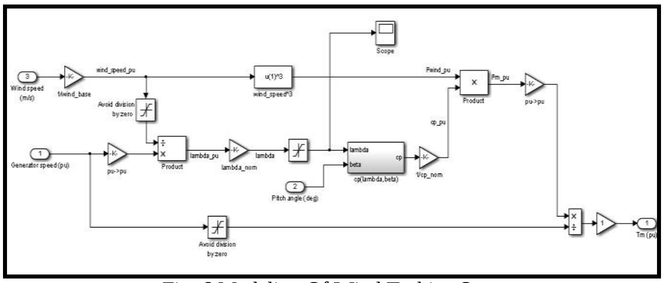

Fig. 6 Modeling Of Wind Turbine System

The PMSG Machine model using mathematical equation is shown in fig. 7

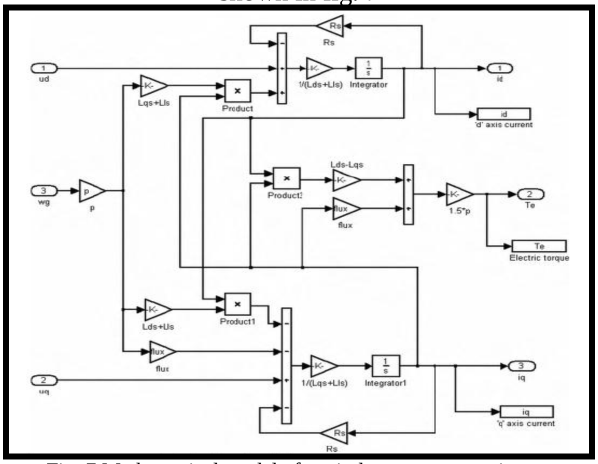

Fig. 7 Mathematical model of a wind energy conversion system

The simulation waveforms for wind velocity, torque produced from wind turbine system (T_m) and torque given to PMSG after two mass drive train (T_{sh}) are shown in below Fig. 8. It is clear that the sudden torque variations in the input side of a PMSG affects its performance. By using a two mass drive train and a rectifier control the torque is maintaining a constant value with fewer vibrations.

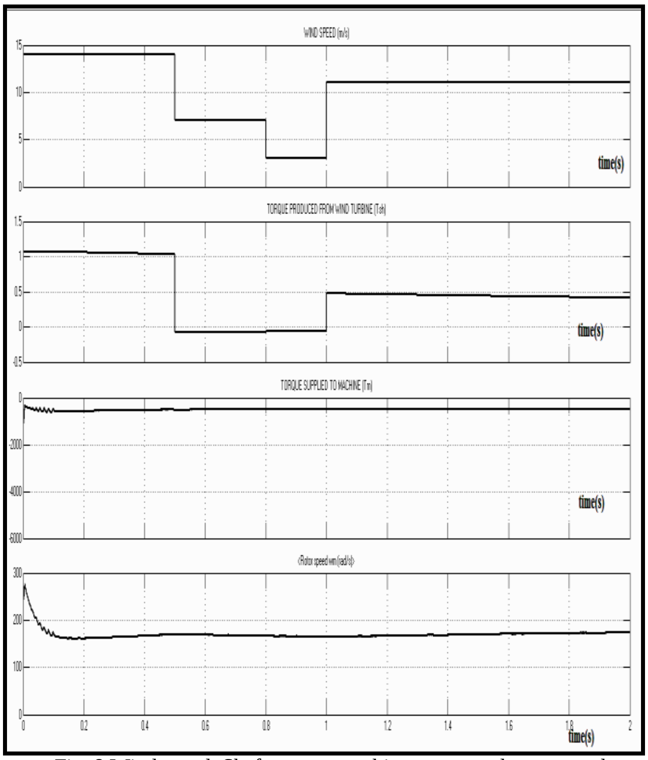

Fig. 8 Wind speed, Shaft torque, machine torque and rotor speed

The generated voltage and current wave forms from PMSG of a WECS using uncontrolled rectifier is shown in Fig. 9. The dc link voltages using an uncontrolled rectifier with variations are shown in Fig. 10.

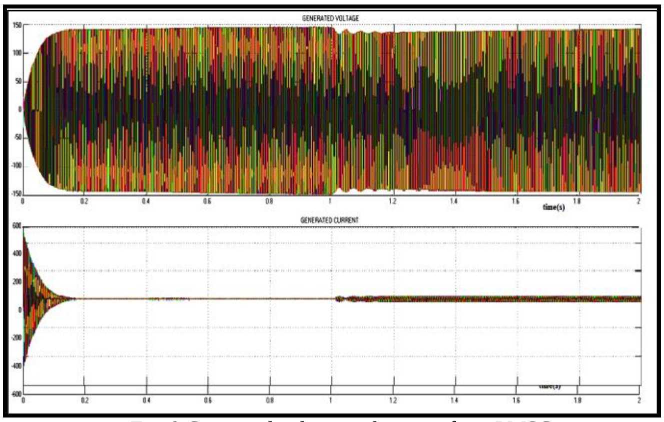

Fig. 9 Generated voltage and current from PMSG

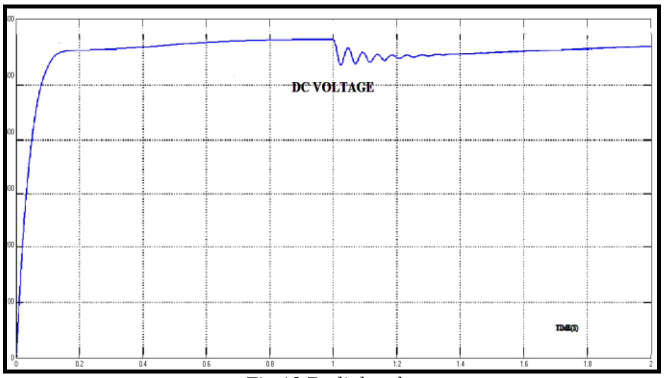

Fig.10 Dc link voltage

The output voltage and current obtained from the five level inverter using voltage regulator algorithm is shown in Fig. 11. Also the THD performance of this waveform is shown in Fig. 11. The wave form shown in Fig. 10 is having a momentarily peak which exist for 0.2 s. And this is a bad effect for a grid connected system. The momentarily peak is overcome by using a voltage regulator algorithm

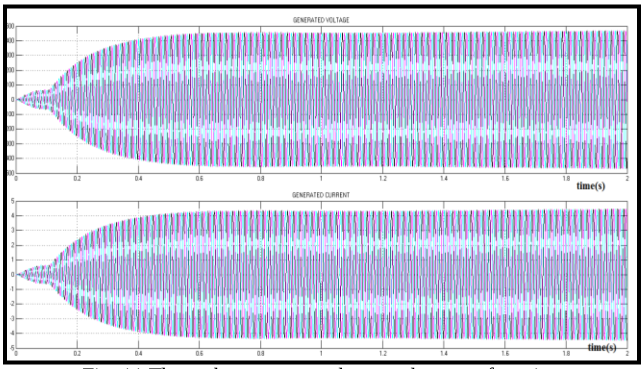

Fig. 11 Three phase output voltage and current from inverter

The THD content of this system is about 2.41%. This is due to the presence of an uncontrolled rectifier in the system.

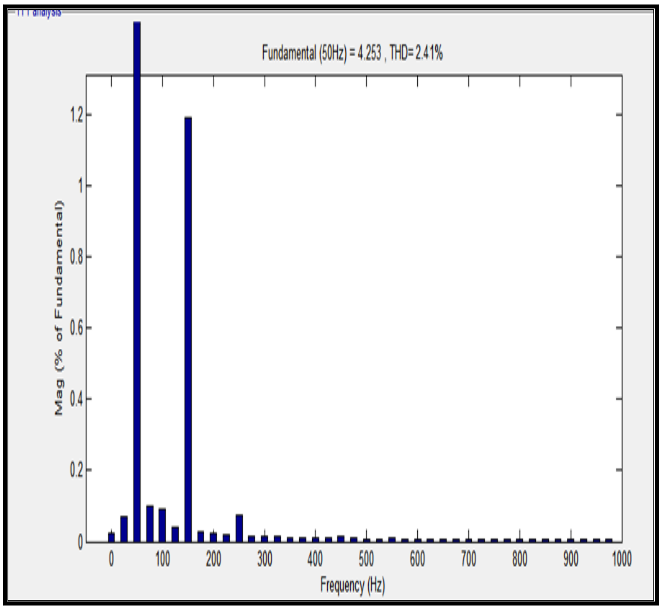

Fig. 12 THD content the system

VI. CONCLUSION

In this paper a wind energy conversion system with five level inverter using uncontrolled rectifier systems has been introduced. Model has been implemented using MATLAB/Simulink software. THD level for a local load was studied for the systems. By using a five level inverter and an uncontrolled rectifier in a WEC system it is noted that the THD values are lower than the IEEE standards. This system provides a smooth grid interacting supply. The grid voltage and frequency can be controlled using the voltage regulator without any control on the machine side.

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