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DEVELOPMENT OF VARIABLE SPEED WIND TURBINES FOR OPTIMUM UTILIZATION OF WIND POWER AND IMPROVING THE POWER QUALITY

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Abstract — *This paper aims in presenting an improvement technique for the electrical part of a wind power generation system with a Permanent Magnet Synchronous Generator (PMSG) which aims in optimizing the utilization of wind power which is injected into the weak grids. An uncontrolled rectifier, digitally controlled inverter system is proposed in this paper in order to realize this goal. The proposed system is simpler. It is advantageous due to the use of fewer controlled switches which lead to less control complexity. It further provides full control over active and reactive power injected into the grid by using a Voltage Source Inverter (VSI) as a dynamic Volt Ampere Reactive (VAR) compensator. In order to control the energy to be injected into the grid, a Voltage Oriented Control (VOC) scheme is proposed. An LC filter is inserted between VOC, VSI and the grid, in an attempt to minimize the harmonics in the inverter current and voltage and also to avoid poor power quality of the wind energy conversion system (WECS). Maximum Power Point Tracking (MPPT) controllers are being used for extracting maximum possible power in WECS. MATLAB/Simulink is used to carry out the simulation.*

Keywords- *Permanent magnet synchronous generator (PMSG), voltage source inverter (VSI), dynamic volt ampere reactive (VAR) compensator, voltage oriented control (VOC), wind energy conversion systems (WECS), maximum power point tracking (MPPT).*

I. INTRODUCTION

The WIND energy system, one of the most promising renewable energy resources which is rapidly developing and being implemented all over the world. The penetration of wind power generation system is very essential in order to solve major problems such as global warming and the exhaustion of fossil fuel. Many kinds of power conversion systems to connect between the generator and the grid line have been proposed and utilized, in order to optimize the wind turbine system [1].

Harmonic currents are being injected into the ac system by nonlinear devices, such as power electronic converters, and increase the overall reactive power demanded by the equivalent load. Also, there is increase in the number of sensitive loads that require ideal sinusoidal supply voltages for their proper operation [2].

We do believe that there is still room for improving the power quality, for grid-connected wind energy conversion systems (WECS) to obtain more economical systems. It is necessary to include compensation, in order to keep power quality under limits proposed by standards.

A three-phase ac-to-dc resonant converter which operates in high input power factor mode is introduced in [1]. High power factor and low THD operation are the features and advantages of this design. However, the overall efficiency will be reduced due to high switching losses for high frequency operation.

A power electronic converter with a simple open-loop feed forward control technique designed for small-scale wind energy systems is proposed in reference [1]. This proposed technique has improved the system efficiency at low wind speeds which expands the operating range of the wind turbine. As an interface part between wind turbine and dc-load, an uncontrolled diode rectifier and dc–dc converter are employed.

An efficient wind generator control technique is developed using -current control loops. Achieving maximum power from the generation side was the main objective.

The voltage oriented control (VOC) technique, that guarantees high dynamics and static performance via internal current control loops, has become very popular today and it is constantly being developed and improved. This method uses conventional proportional and integral (PI) compensators in the rotating reference frame in order to produce its control input commands. However, the response of conventional controllers are somewhat slower for very fast transients, which is its inherent drawback and their control range is limited because of the fixed gains but it can be still improved using the good design for its gain parameters.

In this paper, a permanent magnet synchronous generator (PMSG)-based WECS with VOC strategy for a three-phase voltage-source PWM inverter is being proposed as a dynamic volt ampere reactive (VAR) compensator system for weak grids. A second-order software phase-locked loop (SPLL) in order to detect the phase angle of the grid voltage in synchronous reference frame is proposed. An analytical model for the voltage source inverter (VSI) connected to the grid with LC filter is proposed and the operating principle of the proposed vector controllers is introduced.

II. POWER CHARACTERISTICS OF A WIND TURBINE

Wind turbine is a non-linear system. Velocity of the wind, dimensions of the wind turbine and tip speed ratio are some of the parameters on which the output of the wind turbine is dependent. The output of the wind turbine is determined by the following equation

$$P = \frac{1}{2} C_p \rho A v^3 \quad (1)$$

Where, C_p – power co-efficient, ρ – air density, A – swept area of the wind turbine, V – wind speed.
The value of ideal power is limited by what is known as Betz coefficient with a value of $C_P = 0.59$ as the highest possible conversion efficiency[3]. In practice, most of the wind turbines have efficiencies well below 0.5 depending on type, design and operational conditions.
Cp is the wind power coefficient (denotes power extraction efficiency which is a function of β and λ, β being the pitch angle and λ being the tip speed ratio – TSR given by $R\,\Omega / v$ where R is turbine radius, Ω is turbine shaft speed*)*. Thus, power captured by the wind turbine is heavily dependent upon TSR when β is unchanged. The power conversion efficiency has a well determined maximum *Cp,max* for a specific tip speed ratio λ. The optimal control of active power in a variable-speed fixed-pitch WECS can therefore be easily achieved, if λ is controlled for attaining the *Cp,max* corresponding to a given wind velocity. From equation (1), it follows that

$$Pwt = 0.5\, Cp(\lambda, \beta)\, \rho\, \pi\, R2\, v3$$

$$= 0.5\, \{Cp(\lambda) / \lambda 3\}\, \rho\, \pi\, R5\, \Omega 3 \quad (2)$$

Thus the torque produced by the turbine is computed as

$$Twt = Pwt / \Omega \quad (3)$$

Hence the torque produced by the turbine will be proportional to Ω2 and power is proportional to Ω3. So, from the above equations it can be inferred that for a particular TSR, the power extracted by the turbine is maximum for a given wind velocity. This is equivalent to maintaining the tip speed ratio at its optimal value λopt and can be achieved by operating the turbine at a variable speed, corresponding to the wind speed. Fig. 1 represents the power curves of a typical wind turbine of wind energy conversion system (WECS) [2].

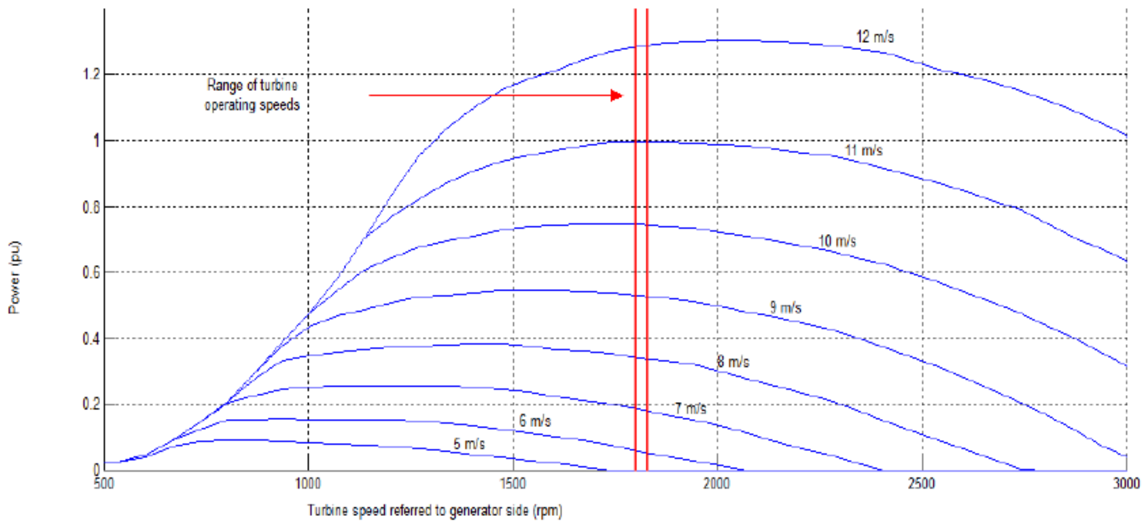

Figure 1. Power curves of a typical wind turbine

III. METHODOOLOGY

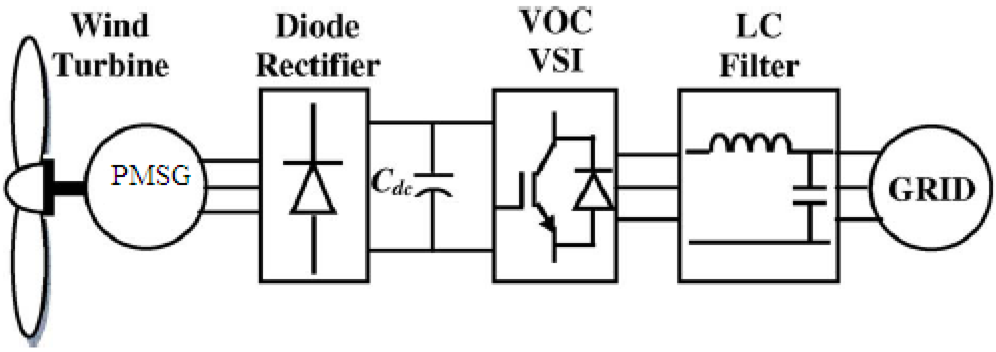

Figure 2. Proposed PMSG-based WECS with VOC VSI

The proposed topology is as shown in Fig. 2. The advantages of the system proposed in this paper over the previous traditional systems are:

- The circuit is simpler
- Due to the absence of switches in the rectifier stage, it is more efficient
- The proposed system is capable of full active and reactive power control. Hence the system is more reliable
- Higher injected power quality is achieved as LC filter between the inverter and the grid is employed
- Better dynamic performance under different possible conditions can be achieved, by using decoupled VOC control scheme

IV. SYSTEM PERFORMANCE

4.1. Rectifier

A rectifier is an electronic device that converts alternating current [AC], which periodically reverses its direction, to direct current [DC] and which flows in only one direction. The rectifier used in this paper is Un-controlled rectifier [3]. The output of the rectifier is given to DC link capacitor.

4.2. DC Link capacitor

A DC link connects a rectifier and an inverter. The DC link usually involves a capacitor known as the DC link capacitor. This DC link capacitor is connected in parallel between the positive and negative conductors. These capacitors help in preventing the transients appearing from the load side from going back to the distribution side. It also smoothens the pulses in the rectified DC.

4.3. Voltage source inverter

The inverter is the power electronic circuit which converts DC voltage into AC voltage. The DC source is normally a battery or output of the controlled rectifier. Voltage source inverters (VSI) are commonly used to transfer real power source to an AC load.

Until recently, most wind power plant and utility have utilized capacitor banks to correct power factor to near unity. The capacitors are switched in and out by means of mechanical contactors [4]. Unfortunately, because these contactors are relatively slow, they are unable to react to sudden momentary dips in voltage commonly seen in weak grid and can add greater stress to the utility grid. VOC VSI is proposed here as a dynamic VAR compensator system.

Dynamic VAR systems detect and instantaneously compensate for voltage disturbances by injecting leading or lagging reactive power at key points on power transmission grids. Through the VAR control system, reactive power is supplied to the grid in a fraction of a second, regulating the system voltage and stabilizing the weak grid.

4.3. Grid with LC filter

To mitigate the harmonics present in the output of the inverter an LC filter is inserted between the voltage source inverter and the grid. By removing the distortions present in the output, quality of the output power can be improved.

V. SIMULINK MODEL

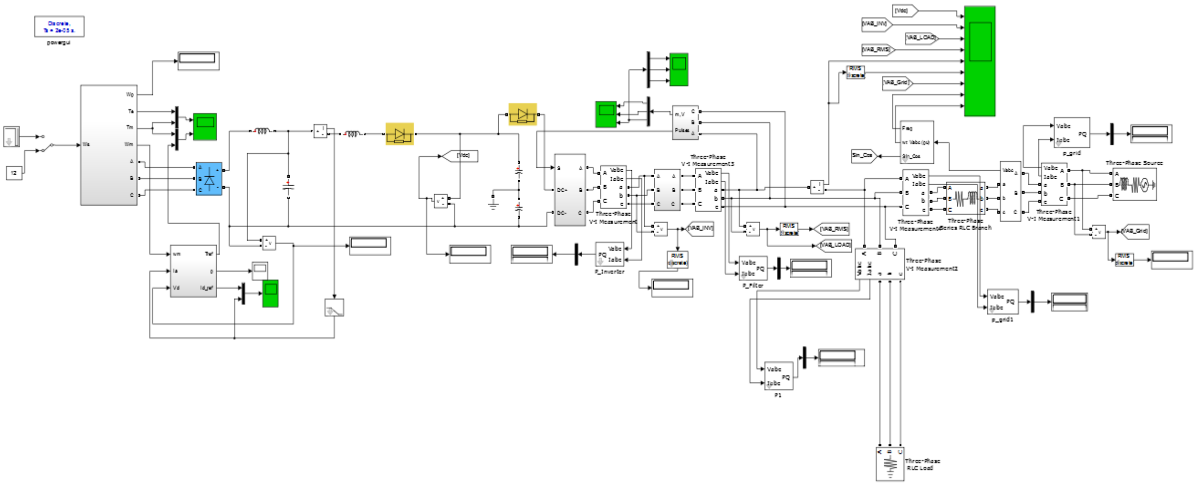

Figure 3. Simulink model of PMSG-based WECS with VOC VSI

VI. RESULTS

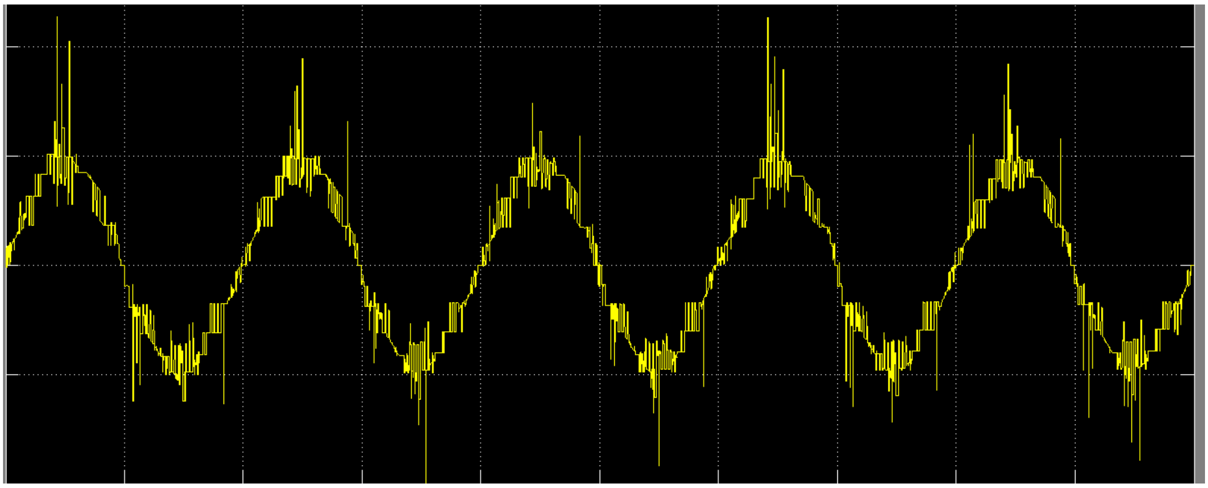

Figure 4. Inverter voltage

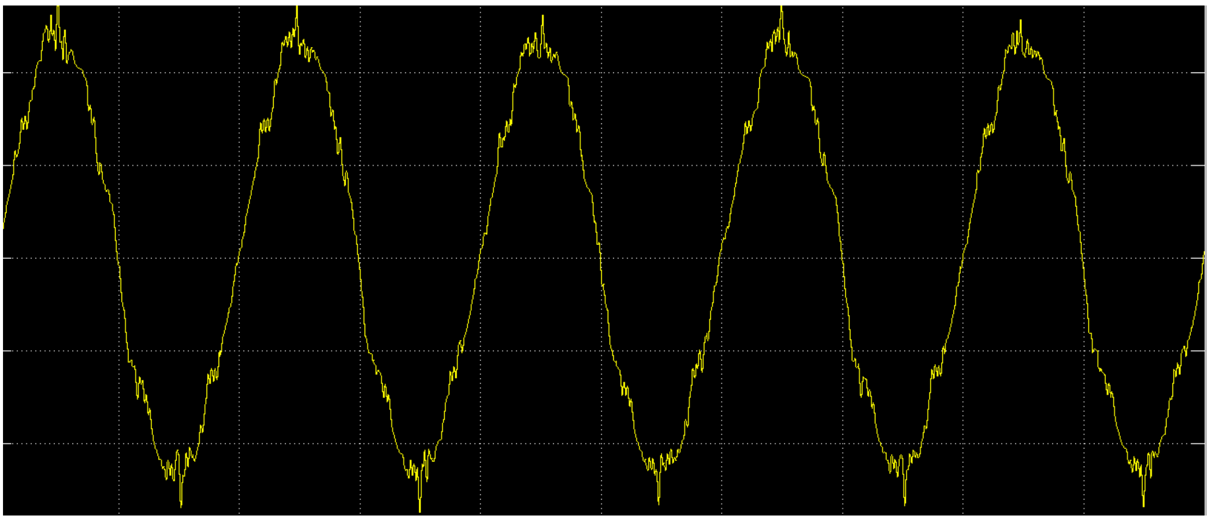

Figure 5. Load voltage

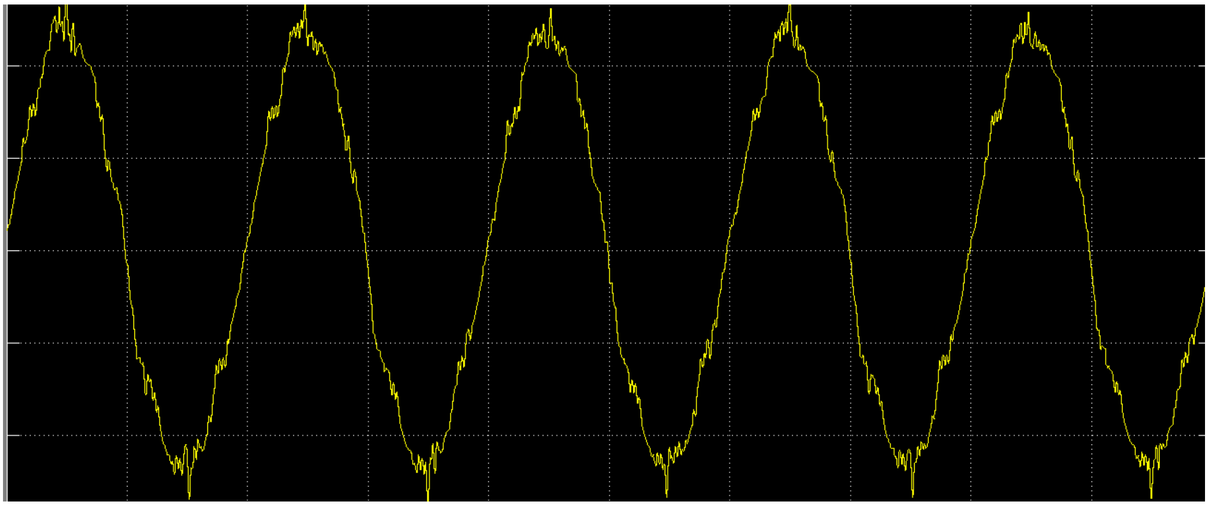

Figure 6. Grid voltage

VII. CONCLUSION

A Permanent Magnet Synchronous Generator (PMSG) is proposed in this paper to optimize the utilization of wind power which is injected into the weak grids. A simpler system is proposed, that involves an uncontrolled rectifier, digitally controlled inverter system in order to realize this goal. In an attempt to minimize the harmonics in the inverter current and voltage, an LC filter is inserted between VOC, VSI and the grid. Using MATLAB/Simulink the simulation is done. The results obtained are a proof for the efficiency and reliability of the proposed paper. This system is sustainable to enhance the power quality of the wind energy conversion system (WECS).

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