Improvement of Voltage Profile in A Radial Distribution System with Variable Speed Wind Turbines

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Abstract— This paper presents the Power generation with renewable energy sources is essential in now a days to control the atmospheric pollution and global warming. But interconnection of these sources to the power system brings problem of voltage fluctuation and harmonic distortion. The wind energy conversion system is designed and it is synchronized with a 14-Bus radial distribution system through the diode rectifier and inverter (IGBT). The control of firing pulses to the inverter is done by PI controller. The wind energy conversion system is to maintain the good voltage profile in radial distribution system and its effectiveness is observed. For analyzing the performance of the wind energy conversion system, case study on a 14-Bus radial distribution is considered. This case study shows that the voltage fluctuation and harmonic distortion can be minimized with proposed power electronic and control system interface and results were simulated in the MATLAB-SIMULINK Version 7.6. It has been found that the voltage profile in the system is improved and the harmonic distortion is reduced to acceptable levels.

***Index terms*—Harmonic minimization, maximum power capture, reactive power control, voltage regulation, wind power.**

I. INTRODUCTION

Grid connection of renewable energy sources is essential if they are to be effectively exploited, but grid connection brings problems of voltage fluctuation and harmonic distortion [1]. A design for a high power density 10kW inverter circuit is presented for conversion of energy from DC fuel cells to AC power to be used mainly for domestic utility applications. The configuration is achieved using a high frequency dc-dc push-pull converter at the input side followed by a full-bridge PWM inverter and a low-pass filter at the output side [2]. Radial-field multi pole permanent magnet, synchronous machines may be used as direct-coupled generators for large grid connected wind turbines. Power rating from below 100kw to more than 1mw and pole numbers of 100 to 300 may be required. Modular construction reduces the detail design effort, and the number of drawings and tools needed. Module designs are presented which can be used for a wide range of machine designs[3]. The variable speed operation of a high pole-number, modular, PM, generator is discussed and the benefits of the modular arrangement for variable-speed wind turbine generators are demonstrated [4]. The many forms of DC/AC converter which may be applied to permanent magnet generators, examine their potential to meet the wave form, power factor , cost and efficiency requirements and consider their features in relation to the special environment of a wind turbine system. A simulation and digital computer modeling effort is described in which a wind turbine-generator system is adapted for stability evaluation using a large scale transient stability computer pro-gram. A capacitor failure at a wind energy electric generation facility is investigated. The probable cause of the capacitor failure is identified to be over voltage resulting from self excitation of the induction generators. Static power converters can be analyzed by means widely available circuit simulation software packages such as PSPICE [5-8]. Two of the most promising types of power converter applicable to the task of interfacing variable-voltage dc energy sources to the grid are compared [9]. A Wind Generator System that employs a boost chopper and a permanent magnet synchronous generator is studied. By replacing the main circuit of generator and boost chopper with the equivalent circuit, the power and DC output voltage are obtained as a function of duty ratio of the boost chopper and generator rotational frequency [10].

II. SYSTEM DESCRIPTION

The wind power conversion system studied has the configuration shown in the following Fig. 1, below. The system consists of a wind turbine, a high pole number modular PM generator [1],a modular rectifier system [3] and a controllable power electronics inverter [2], [4].The modelling and simulation of these elements are discussed below.

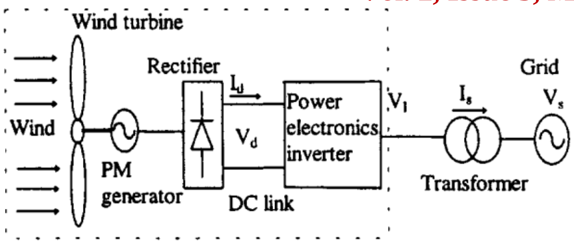


Fig. 1. Schematic wind energy conversion system.

A. Wind Modelling

Wind is an intermittent and variable source of energy. Wind speed varies with many factors and is random in magnitude and direction. For this study, the wind is simulated with four components, namely base component, ramp component, gust component and noisy component [5] as:

$v_{wind} = v_{base} + v_{ramp} + v_{gust} + v_{noise}$ (m/s)

B. Wind Turbine Characteristics

The power in the wind is proportional to the cube of the wind speed. However, only part of the wind power is extractable. Although a complete aerodynamic model of the wind turbine could simulate the interaction between the wind and the turbine blades in detail, the simple expression of (2), which is quite often used to describe the mechanical power transmitted to the hub shaft, is sufficient for this study.

$p_{turbine} = 0.5\ell A c_p v^3{}_{wind}$ (w)

The circuit configuration of sets of stator and rectifier module in a modular PM generator system is shown in Fig. 3. The multi-phase rectifier system can be seen as an extension of a three phase parallel bridge rectifier circuit reported in 1970s [7]. A stator coil is represented by an internal resistor (RS), an inductor (LS) and an electromotive force which is induced by the flux produced by multi-pole set of permanent magnets on the rotor. An ac capacitor is connected in parallel with the ac input terminals of each rectifier module to enhance the power output for matching the wind power characteristic [3]. The above circuit model can be simulated in detail, but a modular PM machine at MW level may have more than a hundred stator modules and associated bridge rectifier units, consequently, the simulation of a circuit model would be very time consuming. A full simulation would only be used when the internal behaviour is of interest. With such a large number of phases, the generator rectifier system produces a smooth dc link voltage and current, therefore, in the steady state, the electrical characteristics as viewed from the dc side may be described by an equivalent DC machine as shown in Fig. 4. The dc system characteristics within the normal operating region are shown in Fig. 5. The dc link voltage and current are related by (3)

$v_d = E_{eq} - R_{eq} I_d$

The parameters ( ) of the equivalent DC machine can be expressed as functions of frequency and dc current. These functions can be established by fitting a suitable analytic curve to data obtained by test or numerical simulation [8].

F. Controllable Power Electronics

Below rated wind speed, the control objective is to track wind speed, to capture and transfer the maximum power to the grid. The generator and rectifier system is uncontrolled and so control has to be implemented by the power electronics converters. Several types of power electronics interface have been investigated [2], [4]. One of the options, using a DC/DC converter is shown in Fig. 8. In a wind farm, there may be dozens of turbines of the type as shown in Fig. 8. These units may be connected in parallel at the dc side to supply power to a common dc bus and current controlled voltage source inverters can then be used to convert the dc power into ac for connection to the grid. Such an arrangements is shown in Fig. 9.

DC/DC Converter Control: DC/DC converters regulate the dc voltages of generator-rectifier units by varying the switching ratio, so that the optimum dc voltage profile, as shown in Fig. 7,is presented at the rectifier terminal for maximum power capture operation. Meanwhile an appropriate dc voltage is maintained at the dc bus to enable the voltage source inverters to perform the optimal real power transfer and reactive power regulation. It may be observed that the optimum – characteristic in Fig. 7 can be represented by a variable resistor connected to the PM generator and rectifier terminal. For the purpose of simulating the generator/rectifier therefore, the DC/DC converter and its loading can be represented by an adjustable load resistance. The load resistance value is a function of wind speed as shown in Fig. 10. In practice, the regulation would be implemented by means of a varying PWM switching ratio.

Current-Controlled VSI Control: CC-VSIs can generate an ac current which follows a desired reference waveform and so can transfer the captured real power along with controllable reactive power and with minimal harmonic pollution. The phasor diagram of relevant variables is shown in Fig. 11. The real and reactive power supplied to the grid is:

$P_S = P_I = V_S I_{S1} \cos \Phi 1$ (PU)

$Q_S = V_S I_{S1} \sin \Phi 1$ (PU)

III. POWER SYSTEM MODELING

A. *System Modelling for Voltage Fluctuation Studies.*

The voltage fluctuation problem is closer to a steady state problem such as load varying, which is well defined by the real and reactive power distribution. The harmonics effects may be ignored with PWM switching inverters and appropriately designed filters. Therefore, the conventional power flow equations are sufficient for voltage fluctuation study. The node voltage and node injected power are related by

$P_k = \sum_{m \neq k} V_k \; V_m (G_{km} \cos \theta km + B_{km} \sin \theta km)$

$Q_k = \sum_{m \neq k} V_k \, V_m (G_{km} \; \sin \theta km \; - B_{km} \; \cos \theta km)$

$\theta_{km} \; = \theta_k - \theta_m$

k = 1,2,3………..n.

Where

n is the node number of the power network v_i is the voltage at bus i

θi is the voltage phase angle with respect to the reference bus

P_k and Q_k are the real and reactive power injected at bus k

G_{km} and B_{km} are respectively the real and imaginary of the bus admittance

B. *System Modelling for Harmonics Studies*

The power delivered by the generator at a given speed is determined by the dc link voltage which thus acts as the principal control parameter for the generator speed. Control is effected by the grid-connected inverter. The power extracted from the dc link and delivered into the grid can be controlled by adjusting the phase angle between the grid voltage and the fundamental component of the inverter output voltage as shown in Fig.4. This resembles the phasor diagram for a grid connected synchronous generator.

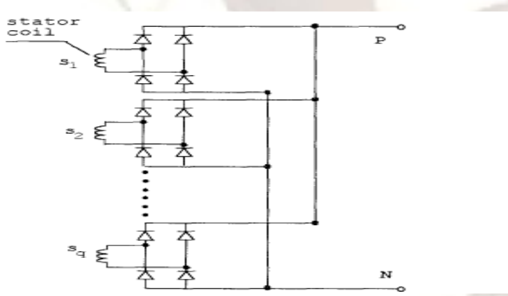


Fig2. Modular electrical arrangement

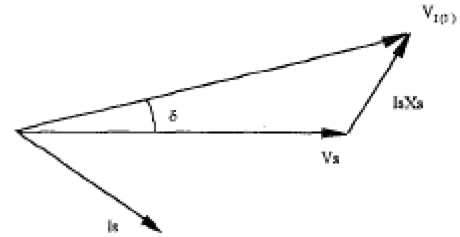


Fig 3. Phasor difference between the grid voltage and fundamental component of the inverter output voltage.

This system requires a force-commutated inverter to create a defined output voltage. Six-step quasi-square switching leads to low switching loss and can be achieved with a wide choice of devices such as GTOs making high power rating possible but causes high levels of harmonic pollution. Harmonic pollution can be virtually eliminated by using a sinusoidal PWh4. inverter with a high switching frequency or lower frequency **PWM** with a harmonic elimination switching strategy. However, **PWM** inverters do not make full use of component ratings when required to operate from a variable voltage dc link and are thus very expensive

A 6-pulse, line-commutated, thyristor inverter would provide control of the dc link voltage at much lower cost but the harmonic current pollution of the grid would be unacceptable and the inverter would absorb a variable amount of reactive power, making power factor correction difficult. Grid-side filtering or using an inverter with 12 or more pulses would reduce the harmonic pollution. The harmonics in the system can be eliminated by using the second order damped filter shown in the figure below. v,Cp

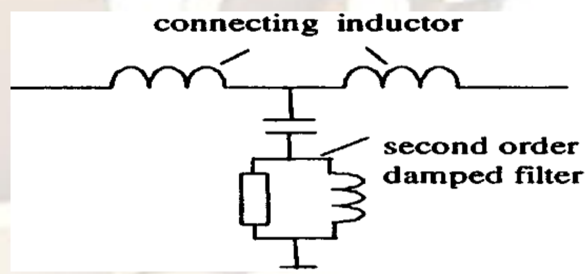


Fig 4. second order damped harmonic filter

iv CASE STUDY

A. *Power Network Configuration*

A radial distribution system [11] has been chosen for the study. Fig. 14 shows the network configuration. The slack bus keeps a voltage of 1.053 pu. An equivalent CC-VSI (which, in practice, would be a number of CC-VSIs) at bus 13 connects the wind farm to bus 8 of the grid. It is assumed that the loading at each node is kept nstant during the analysis and the multi-machine wind farm has a total capacity of 32% system loading.

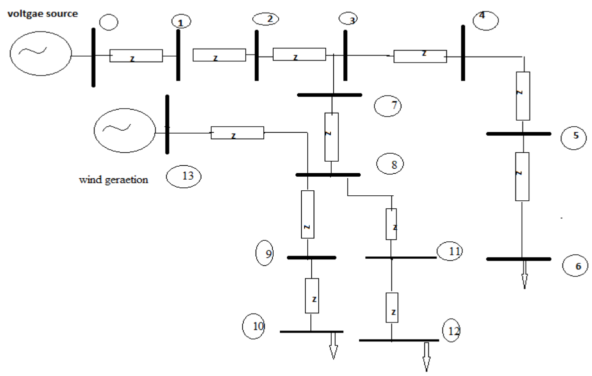


Fig 5. 14 Bus Radial Distribution System

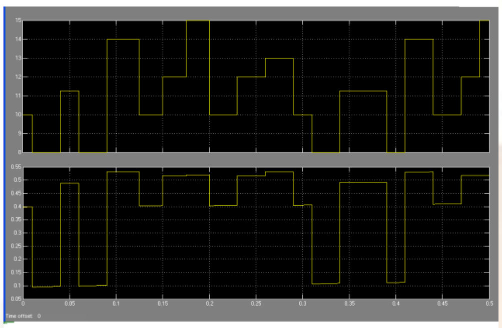


Fig 6. Wind speed(varying between 7-15m/s) and power coefficient traces

P,q

Time in sec

Fig 7. Generated active and reactive power.

Time in sec

V

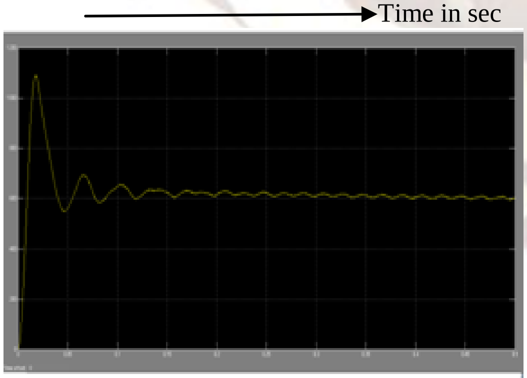


Fig 8. D.C bus voltage Time in sec

V,i

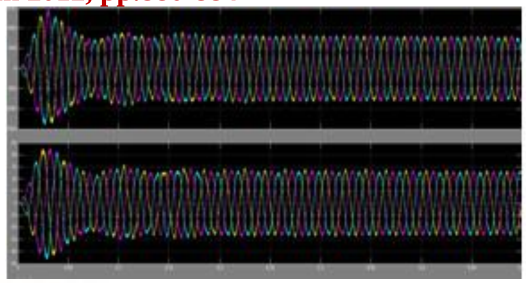


Fig 9. Inverter output voltage and current

Time in sec

V

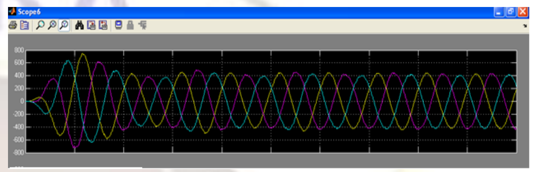
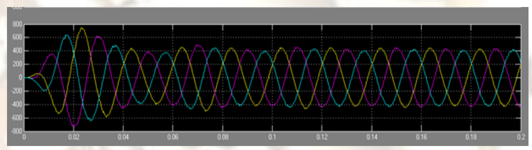


Fig 10. Voltage at bus number 8 without wind farm

Time in sec

V



Time in sec

Fig 11. Voltage at bus number 13 without wind farm

V

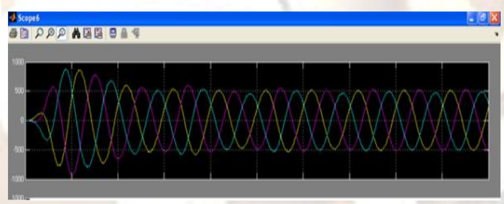


Fig12. Voltage at bus number 8 with wind farm

Time in sec

V

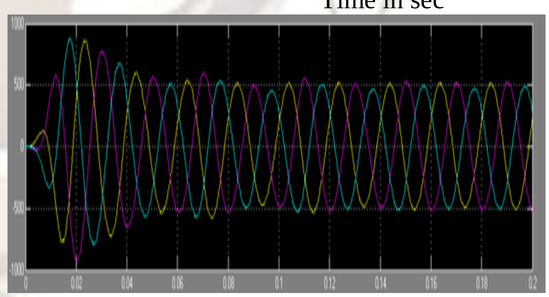


Fig 13. Voltage at bus num 13 with wind farm

Time in sec

B Grid Current Harmonic Distortion

The time domain harmonic analysis has been performed with the operating points obtained by power flow analysis. The switching frequency of the grid interface inverter is 3.15 kHz. It is assumed that the system operates in a balanced condition. The voltage waveform and harmonic spectra of VSI wind power (bus 13) and bus 8 are shown in Figs. 20 and 21. Fig. 22 shows the total voltage harmonic distortion at each bus. These results correspond to the operating condition of as shown in Fig. 17.It can be seen clearly that the harmonic distortion can be reduced sufficiently to meet modern standards for the discussed type of distribution systems.

IV DISCUSSIONS

In the proposed variable speed wind energy conversion system, the generator and the grid are de-coupled by the power electronic frequency converter. The effects of the energy conversion system on the network, such as voltage regulation, reactive power control and power quality will mainly depend on the type of grid connected inverter chosen. Decoupling these parameters from the generator itself gives more freedom to the modular PM generator designer bringing cost and performance benefits

VI. CONCLUSION

The wind energy conversion system has been designed and the performance has been tested by simulation taking the case that the wind energy conversion system is connected to a 14-Bus radial distribution system. The voltage fluctuation and harmonic distortion has been studied and the closed loop control scheme enabled the wind energy conversion system to inject a voltage of desired magnitude in order to maintain a good voltage profile in a radial distribution system. The output voltage waveforms show that 6-pulse inverter generates three phase sinusoidal output voltage with minimal harmonic contents together with a relatively low cost harmonic filters. The simulation results clearly shows that there is an improvement in the voltage profile of the radial distribution system with minimal harmonic contents.

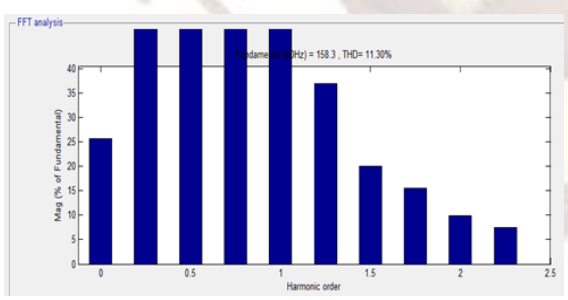


Fig 13. Frequency of the system without power conditioning system

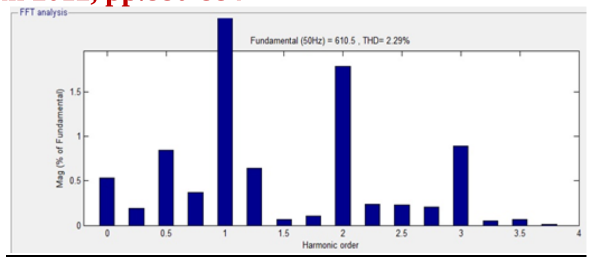


Fig 14. Frequency of the system without power conditioning system

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