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Research Paper

ANALYSIS OF PMSG IN WIND INTEGRATION USING T SOURCE INVERTER WITH SIMPLE BOOST CONTROL TECHNIQUE

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This paper deals with the Analysis of PMSG in wind integration using T-source Inverter with Simple Boost Control technique for improving voltage gain. The Permanent Magnet Synchronous Generator (PMSG) offers better performance than other generators because of its higher efficiency and of less maintenance since they don't have rotor current and can be used without a gearbox, which also implies a reduction of the weight of the nacelle and a reduction of costs. T-Source inverter has high frequency, low leakage inductance transformer and one capacitance, this is the main difference from Z-source inverter. It has low reactive components in compare with conventional ZSI. The T source network has an ability to perform dc to ac power conversion and it provides buck boost operation in a single stage but the traditional inverter cannot provide such feature. All the components of the wind turbine and the grid-side converter are developed and implemented in MATLAB/Simulink.

Keywords: Wind Turbine, PMSG, Inverter, Simple Boost Control, T-Source inverter, Voltage gain

INTRODUCTION

Since the early 1990s, installed wind power capacity has increased significantly. The total installed wind power world capacity reached 194.5 GW at the end of 2010, with an increasing wind energy penetration into the grid (Venkata, 2014). Power system operators have given response to this new scenario by gradually updating their Grid Connection Requirements (GCR) to ensure the reliability and efficiency of the utility.

The wind turbines indicate a trend toward higher power levels. Over the past decade, the

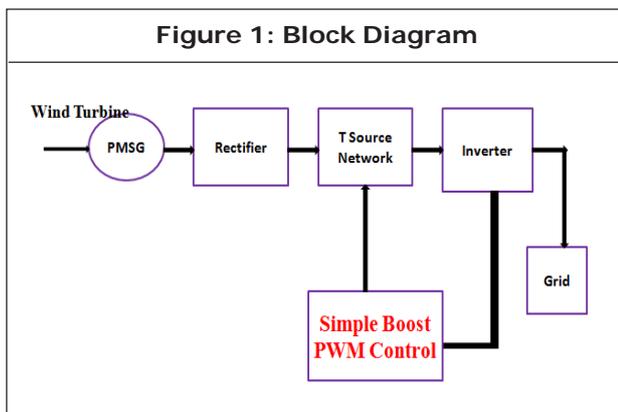
size of wind turbines has steadily increased and currently reaches a level of 7.5 MW/unit (Marco, 2011; Paulson, 2011). This is mainly propelled by: 1) enhanced energy harvest capability due to higher tower height and greater blade diameter; 2) reduced initial installation cost; and 3) reduced maintenance cost per unit (Bin, 2011). Future models of turbines are anticipated to be in the range of 10–15 MW (Shahjith, 2011).

The current trend of megawatt level turbines also indicate the use of: 1) variable speed technology using full scale power converters to

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increase the wind energy conversion efficiency; 2) Permanent Magnet Synchronous Generators (PMSGs) to achieve higher power density and efficiency; 3) gearless drive to reduce the maintenance cost especially; 4) medium voltage on the grid-side to improve the power quality, increase efficiency, reduce step-up voltage requirement, reduce cable costs, and minimize both the nacelle space and the weight



requirement.

For the PMSG wind turbines, the passive front-end configuration offers a low cost and reliable solution compared with the active front-end (Salvador, 2013). The system combines the advantages of the low-cost passive front-end and efficient grid-side multilevel operation.

Variable-speed wind energy systems are currently preferred than fixed-speed wind turbines due to their superior wind power extraction and better efficiency. The Doubly-Fed Induction Generator (DFIG) is the most used implementation for variable-speed wind systems, because of the reduced power rating of the converter. Another common variable-speed wind system configuration is based on a Permanent-Magnet Synchronous Generator (PMSG) with a full power converter (Salvador, 2013). In comparison with the DFIG, this provides extended

speed operating range, and full decoupling between the generator and the grid. Results in higher power capture at different wind speeds and enhanced capability to fulfill the LVRT requirement.

The paper is organized as follows. In Section II the performance of the system description and model is analyzed, In Section III PMSG Model, In section IV T-Source inverter, In Section V the performance of Simple Boost Control method is analyzed, Section VI outlines the conclusions.

SYSTEM DESCRIPTION AND MODEL

The system considered in this work is shown in Figure 2. In this section, the models for the generator and grid sides are shown.

A. Model of the Generator Side

For the generator side, the electrical equations of the PMSG are shown in Equation (1) and (2), the torque equation in (3) and The mechanical equation in (4). Electrical and torque equations are expressed in the rotative frame (dq), where the q axis is aligned with the rotor flux.

$$v_{sd} = R_s i_{sd} + L_s \frac{d}{dt} i_{sd} - \omega_s L_s i_{sq}$$

$$v_{sq} = R_s i_{sq} + L_s \frac{d}{dt} i_{sq} + \omega_s L_s i_{sd} + \omega_s \psi_r$$

$$T_e = \frac{p}{2} \psi_r i_{sq}$$

$$T_m - T_e = J \frac{d}{dt} \omega_m + b \omega_m$$

B. Model of the Grid Side

The grid-side converter has to deal with the grid dips. Three different methods to deal with asymmetrical grid dips based on the use of

symmetrical components have been detailed (Venkata, 2014). Among these three methods, the vector current controller with feedforward of negative sequence grid voltage (VCCF) has been used in the present work. With this method, the control is implemented on the positive sequence, and there is no need to develop the negative-sequence model for the grid-side converter. The model for the grid-side converter is shown in

$$\frac{d}{dt} i_{dgrid} = \omega i_{qgrid} - \frac{RL}{L} i_{dgrid} + \frac{1}{L} v_{vsl} - \frac{1}{L} v_{gd}$$

$$\frac{d}{dt} i_{qgrid} = -\omega i_{dgrid} - \frac{RL}{L} i_{qgrid} + \frac{1}{L} v_{gq} - \frac{1}{L} v_{gq}$$

C. Dc-Link Voltage Balance

Dc-link neutral point voltage balance is achieved by means of a virtual space vector modulation switching strategy and a tailored voltage balancing control, which is used in both NPC converters in the back-to-back topology. With this approach, there is no need to include in the model some information about the dc-link neutral point (Macro, 2011).

D.Wind Turbine Model

The wind turbine converts the wind energy into the mechanical energy through a suitable wind turbine configuration (Venkata, 2014; Macro, 2011). The wind power (Pm) extracted by the wind turbine can be defined as

$$P_v = 0.5 \rho A V^3$$

$$P_m = 0.5 \rho C_p (\lambda, \beta) A V^3$$

Where,

Pv - power available in the wind turbine

Pm - Power output of the wind turbine

ρ - Air density (Kg/m³), (approximately 1.225 kg/m³)

A - Turbine swept area i.e., $A = \pi r^2$

R - Blade radius (m), (it varies between 40-60 m)

V - wind velocity (m/s) (velocity can be controlled between 3 to 30 m/s)

Cp - Power coefficient which is a function of blade pitch angle θ and tip speed ratio λ.

The power coefficient is calculated from

$$C_p (\lambda, \beta) = C_1 (C_2/\lambda_i - C_3\beta - C_4) e^{-C_5/\lambda_i} + C_6\lambda_i$$

where,

$$\lambda = 2\pi NR / V$$

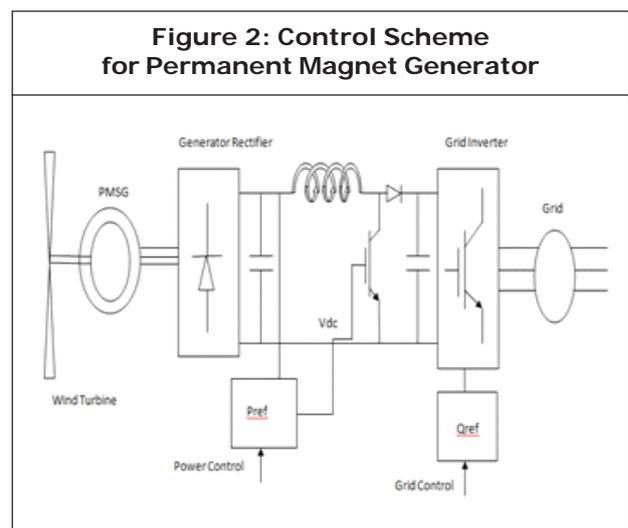
β - Blade pitch angle in degrees

λ - Tip speed ratio

N - Rotational speed in rps

MODELLING OF PMSG

The PMSG has been considered as a system which makes possible to produce electricity from the mechanical energy obtained from the wind. The dynamic model of the PMSG is derived from the two phase synchronous reference frame, which the q-axis is 90° ahead of the d-axis with respect to the direction of rotation. A permanent magnet synchronous generator is a generator



where the excitation field is provided by a permanent magnet instead of a coil (Salvador, 2013). The term synchronous refers here to the fact that the rotor and magnetic field rotates in constant speed, because magnetic field is generated through shaft mounted permanent magnet mechanism and current is induced into the stationary armature. In a permanent magnet generator, the magnetic field of the rotor is produced by permanent magnets. Other types of generator use electromagnets to produce a magnetic field in a rotor winding.

$$\frac{di_d}{dt} = \frac{1}{L_{ds} + L_{ls}} (-R_s i_d + w_e (L_{qs} + L_{ls}) i_q + u_d)$$

$$\frac{di_q}{dt} = \frac{1}{L_{qs} + L_{ls}} (-R_s i_q - w_e [(L_{ds} + L_{ls}) i_d + \psi_f] + u_q)$$

$$\omega_e = p \omega_g$$

p - number of poles pairs of the generator

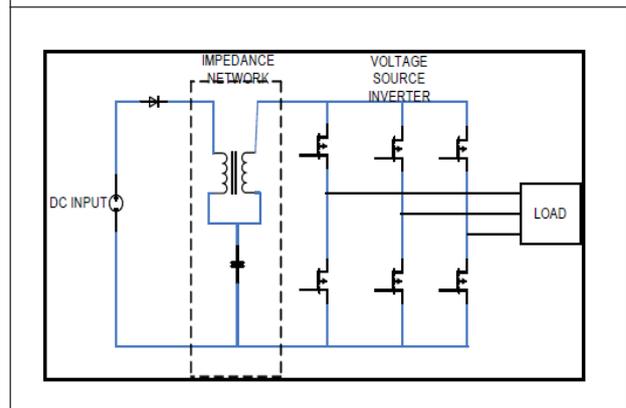
The below equation shows the torque equation of PMSG

$$\xi_e = 1.5((L_{ds} - L_{ls}) i_d i_q + i_q \psi_f)$$

T-SOURCE INVERTER

T-source impedance network is newly introduced to overcome the problems of Z-source inverter. T-Source inverter is similar to Z-Source except the use of high frequency low leakage inductance transformer and one capacitance. It has low reactive components in compare with conventional ZSI (Eswari, 2014). Due to this, the efficiency appreciably increase. The TSI topology requires a very low leakage inductance transformer which should be made with high precision. In such a way, the number of passive elements is reduced because only the transformer and the capacitor are needed. As with

Figure 3: T-Source Inverter Structure



qZ-source inverters, the TSI topology features a common dc rail between the source and inverter, which is unlike traditional ZSI circuits. Moreover, use of a transformer with other than a 1:1 transformer ratio allows for a change of output voltage Z-source converters, as contrasted with the voltage resulting from the shoot-through index or the modulation index (Mahendran, 2011).

The features of T – Source inverter are Low reactive components in comparison to conventional Z-source inverter, Use of a common voltage source of the passive arrangement, Minimize the number of switching devices, No needs of dead time and Inductor decreases the inrush current and harmonics in the inrush current. All PWM methods can be used to control T-source inverter. The utilization of shoot-through switching state is enhanced in T-Source inverter which helps in the unique usage of buck-boost feature to the inverter (Vithya, 2014). It is recommended that to maintain the constant voltage in the input side to get the appropriate voltage in the output side

The new impedance network called T-source network invented to overcome the drawbacks of the Z-source inverter. Normally Z-source inverter requires two inductance and two capacitance but

T-source inverter requires a very low leakage inductance transformer which should be made with high precision. In such a way, the number of passive elements is reduced because only the transformer and the capacitor are needed so that total volume of the system can be minimized (Wei, 2014). Thus, the overall cost of the system is reduced.

TSI can handle shoot through states when both switches in the same phase leg are turned on. The T-network is used instead of the LC-network for boosting the output voltage by inserting shoot through states in the PWM. T – Source Inverter operating principle same as that of conventional ZSI (Sheeja, 2012).

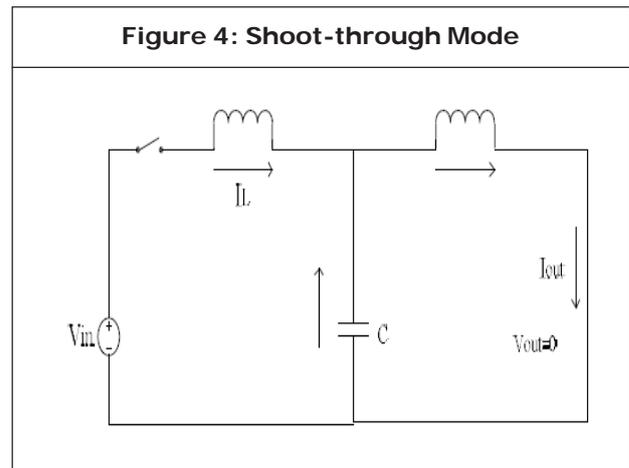
All PWM Methods is used to control the T-source inverter. Here, Simple Boost Control Method is used to control the T source inverter. TSI operate in Shoot through mode and Non shoot through mode. In shoot-through mode of operation, the output voltage is boosted (Eswari, 2014; Mahendran, 2011). The shoot through state of T source inverter helps to get the desired output voltage of the inverter when the wind blow is not sufficient. The non shoot through state of z source inverter maintains the output voltage at the same level when the wind blow is high.

PRINCIPLE OF OPERATION

As with a conventional ZSI, the TSI can handle shoot through states when both switches in the same phase leg are turned on. The T-Source network is used instead of the LC-network for boosting the output voltage by inserting shoot through states in the PWM. T – Source Inverter operating principle same as that of conventional ZSI (Katedra, 2009; Eswari, 2014)]. TSI operate in two modes :i) Shoot through ii) Non shoot through mode

(i) Shoot Through Mode

Figure 4 shows the equivalent circuit of T – Source Inverter in Shoot through mode operation. This shoot through zero state prohibited in traditional voltage source inverter. It can be obtained in three different ways such as shoot through via any one phase leg or combination of two phase leg. During this mode, Diode is reverse biased, separating DC link from the AC line. A



desired voltage can be maintained at the output by controlling the interval of shoot through state. Thus the T – Source inverter highly improves the reliability of the inverter since short circuit across any phase leg is allowed and it cannot destroy the switches in the inverter[8][9].

(ii) Non – Shoot Through Mode

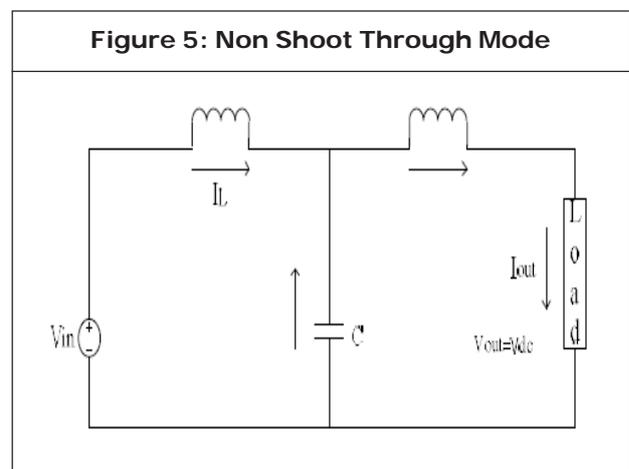


Figure 5 shows the equivalent circuit of TSI in Non – shoot through mode operation. In this mode, the inverter bridge operate in one of traditional active states, thus acting as a current source when viewed from T – source circuit. During active state, the voltage impressed across load. The diode conduct and carry current difference between the inductor current and input DC current. Note that both the inductors have an identical current because of coupled inductors (Wei, 2014; Sheeja, 2012).

PULSE WIDTH MODULATION

A. Types of PWM Techniques

There are two types of PWM Techniques are available namely,

- Sinusoidal Pulse Width Modulation (SPWM) Technique
- Modified Space Vector Modulation (MSVPWM) Technique

The various PWM control algorithms[13][17] are

- Simple Boost Control (SBC)
- Maximum Boost Control (MBC)
- Maximum Constant Boost Control (MCBC)
- Traditional Space Vector Modulation (TSVPWM)
- Modified Space Vector Modulation (MSVPWM)

B. Simple Boost Control Method

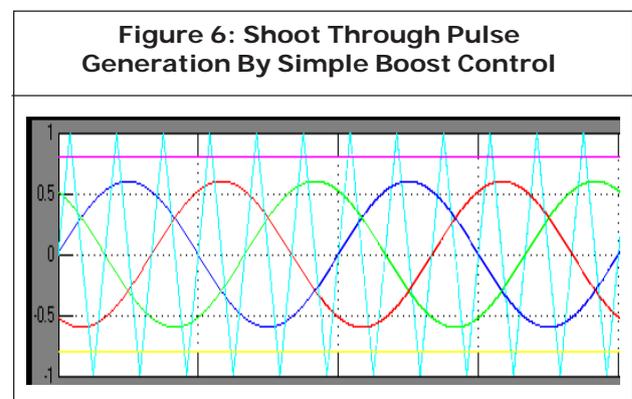
Simple Boost control strategy inserts shoot through in all the PWM traditional zero states during one switching period, which maintains the six active states unchanged as in the traditional carrier based PWM. To control the shoot through states, Simple boost control method utilises two straight lines as shown in Figure 6. When the triangular carrier waveform is greater than the

positive straight line or lowers than the negative straight line the circuit turns into shoot-through state (Budi, 2013). Otherwise it operates just as traditional carrier-based PWM. The shoot - through switching pulses are added with the other PWM pulses with the help of OR gate. Through isolation and gate driver circuits, the switching pulses are given to the power switching devices. This control method provides high switching stress across the switching devices and also ripple current in inductor is high. In order to produce an output voltage that requires a high voltage gain, a small modulation index (*ma*) has to be used (Suresh kumar, 2013; Mary, 2013). However, greater voltage stress on the devices is due to small modulation indices. As the modulation index is raises, the switching frequency of the inverter also raises and hence the switching losses (Budi, 2013).

$$G = \frac{M}{2M - 1}$$

$$B = \frac{1}{1 - 2 \left(\frac{T_{sh}}{T} \right)}$$

$$V_{out} = M \frac{BV_o}{2}$$



BV_o should be the dc input voltage of the traditional voltage source inverter, which in the case of T source inverter is the dc voltage applied to inverter's bridge.

$$BV_o = V_{inv}$$

The voltage stress across the devices is,

$$V_{sv} = (2G-1)V_o = \frac{1}{2M-1}V_o$$

CONCLUSION

The wind turbine model with a permanent magnet synchronous generator has been analyzed. The performance of T-source inverter using Simple Boost Control technique has been analyzed. The T-source impedance network produces output voltage larger than the input voltage by proper maintaining the shoot-through duty ratio, which cannot be achieved by the voltage-source inverter and current-source inverter. The T-source inverter has less passive components in compare with ZSI. All PWM methods can be used to control T-source inverter (Penchalababu, 2012).

The model consists of the wind generator model, PMSG an uncontrolled rectifier, T-Source inverter and the inverter control using Simple Boost Control technique. The model has been implemented in MATLAB/Simulink in order to validate it. The main aim of any modulation technique is to obtain variable output having maximum fundamental component with minimum harmonics. The objective of Simple Boost Control technique is to enhance the fundamental output voltage and the reduction of harmonic content in three phase voltage source inverter. The overall system efficiency is increased.

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