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# PMSG Wind Power System Connected To Grid Using Z-Source Inverter

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## Abstract

*This paper presents analysis of a control system to a PMSG wind power system using Z-source inverter. Z-source inverter has advantage that it can provide any desired AC output voltage regardless of DC input with regulation in shoot-through time. In this control system Z-source capacitor voltage can be kept stable with variations in the shoot-through time, maximum power from the wind turbine to be delivered to the grid can be extracted by the regulation of d-q axis current. The proposed system has greater efficiency and lower cost.*

## 1. Introduction.

The renewable energy sources gained special importance over the years because of depletion of conventional energy sources. Wind energy is a very important renewable energy source and lots of technologies has been introduced to fetch power from wind energy. PMSG wind power system using z-source inverter is an efficient way of harnessing power.

Permanent magnet synchronous generator has numerous advantages like high power factor, high efficiency, low cost, gearless operations. PMSG system includes diode rectifier, boost dc-dc converter and three phase inverter. Control of inverter provides extracted power to the utility grid and boost converter is controlled for maximum power point tracking (MPPT). this system becomes complex expensive because of extra active devices and controls.

Z-source inverter overcomes voltage limitations of traditional inverter .voltage is boosted with single stage converter, both switches in same inverter must turn ON in same time that is shoot-through state, due to this shoot-through state short circuit across any phase leg is allowed therefore reliability of system greatly improved.

Based on the advantages of z-source inverter this paper presents application of z-source inverter connected to wind power system which uses PMSG and generated power deliver to grid.

## 2. State space model of z-source inverter.

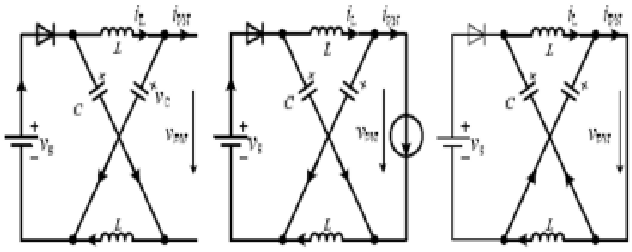

Figure 1. Equivalent circuit of Z-source network in (a) open state (b) active state (c) shoot-through state

The Z-source network can operate in six possible states, in which three states are desired while the other three are undesirable. And the undesirable states can be avoided by choosing appropriate values of the inductors and capacitors of the impedance network. It is supposed that only the three

desired states are considered in the following analysis. The desired open state, active state and shoot-through state are illustrated in Figure 1.(a), (b) and (c), respectively. Assuming that the Z-source network is symmetrical, that is

$L_1 = L_2 = L$, $C_1 = C_2 = C$, $i_{L1} = i_{L2} = i_L$ and $v_{C1} = v_{C2} = v_C$.

The state variables are chosen as $i_L$ and $v_C$ the input variables are $v_S$ and $i_{PN}$, and the output variables are denoted by $v_{PN}$ and is Then from Figure 1. (a), the state equations and output equations during the open state can be written as

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} v_S \\ i_{PN} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} v_{PN} \\ i_S \end{bmatrix} = \begin{bmatrix} 0 & 2 \\ 2 & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} -1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} v_S \\ i_{PN} \end{bmatrix}$$

From figure 1.(b) The state and active equations during the active state are

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & -\frac{1}{C} \end{bmatrix} \begin{bmatrix} v_S \\ i_{PN} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} v_{PN} \\ i_S \end{bmatrix} = \begin{bmatrix} 0 & 2 \\ 2 & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} v_S \\ i_{PN} \end{bmatrix}$$

From figure 1(c) the state equations and output equations during the shoot-through state can be expressed as

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{L} \\ -\frac{1}{C} & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} v_S \\ i_{PN} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} v_{PN} \\ i_S \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} v_S \\ i_{PN} \end{bmatrix}$$

Then the state-space averaging model of the Z-source network can be derived by performing state-space averaging method on (1), (2) and (3), and expressed as

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dv_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{2D_4 - 1}{L} \\ \frac{1-2D_4}{C} & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} \frac{1-D_4}{L} & 0 \\ 0 & \frac{D_4 - 1}{C} \end{bmatrix} \begin{bmatrix} v_S \\ i_{PN} \end{bmatrix} \quad (4$$

$$\begin{bmatrix} \overline{v_{PN}} \\ \overline{i_S} \end{bmatrix} = \begin{bmatrix} 0 & 2(1-D_4) \\ 2(1-D_4) & 0 \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} D_4 - 1 & 0 \\ 0 & (D_4 - D_1) \end{bmatrix} \begin{bmatrix} v_S \\ i_{PN} \end{bmatrix}$$

Where $v_{PN}$ and $i_S$ are the average output variables.

## 3. PMSG wind power system.

The PMSG wind power system with Z-source inverter based grid connected is shown in figure 2.This configuration includes a PMSG is connected to three phase diode rectifier with the input capacitors ($C_a$, $C_b$ and $C_c$), a Z-source network, and inverter system connected to grid. The purpose of the input capacitors is to serve as the dc source feeding the Z-source network. The voltage of the generator fed to the Z-source inverter varies according to the generator speed.

It is assumed that the DC voltage fed to the Z-source inverter where $V_{LL}$ is the line to line voltage of the generator.

$$V_{dc} = \frac{3\sqrt{2}}{\pi} V_{LL} \qquad (1)$$

In boost operating mode that is in shoot through state, the peak DC link voltage across the inverter bridge is expressed as

$$V_i = 2V_c - V_{dc} = X.V_{dc} \qquad (2)$$

where $V_{dc}$ is the source voltage and X is the boost factor that is determined by

$$X = \frac{T}{T - 2T_0} \geq 1 \qquad (3)$$

where To is the shoot-through time interval over a switching cycle T.

The average dc-link voltage across the inverter bridge can be found as follows

$$V_i = \frac{T - T_0}{T}(2V_c - V_{dc}) = V_c \qquad (4)$$

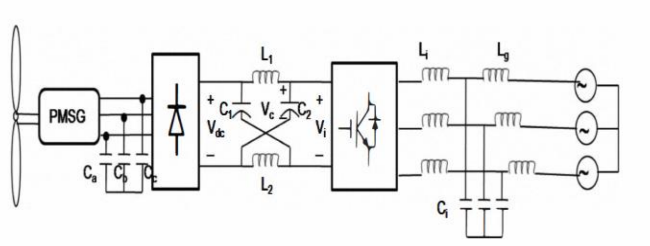

Figure 2. PMSG wind power system with Z-source inverter based grid connected.

The capacitors voltage can be expressed as

$$V_c = \frac{(T-T_0)}{(T-2T_0)} V_{dc} \geq V_{dc} \qquad (5)$$

From (5), the capacitor voltage can be boosted by adjusting the shoot-through time.

The output peak phase voltage can be expressed as

$$V_{ac} = Y.X \frac{V_{dc}}{2} \qquad (6)$$

the peak output phase voltage can be controlled both by adjusting the modulation index or shoot-though time.

## 4. PWM signal with shoot-through state.

PWM signals are pulse trains with fixed frequency and magnitude and variable pulse width. There is one pulse of fixed magnitude in every PWM period. However, the width of the pulses changes from period to period according to a modulating signal.

The PWM signal with shoot-through state is shown in figure 3. In shoot-through state two extra straight lines as shoot-through signals, Vsc and -Vsc. When the carrier signal is greater than V sc or it is smaller than -V sc, a shoot-through vector is created by inverter.

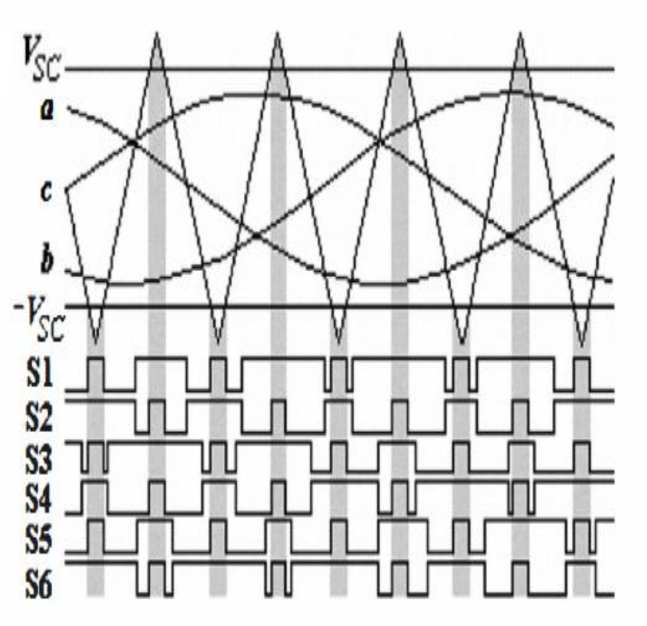

Figure 3. PWM signal with shoot-through state.

## 5. Simulation for PWM signal

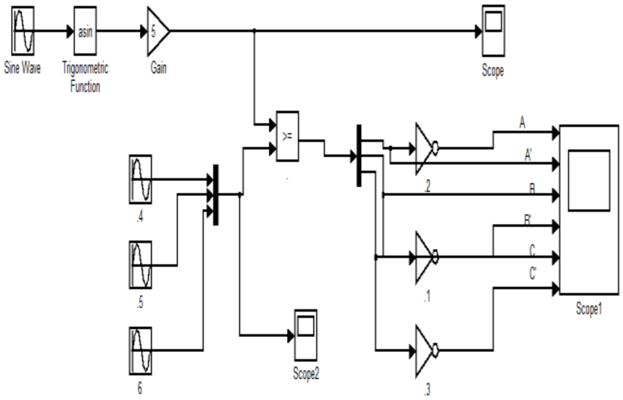

Figure 6. Simulation for PWM signal.

The modulating signal and modulated signal are shown below.

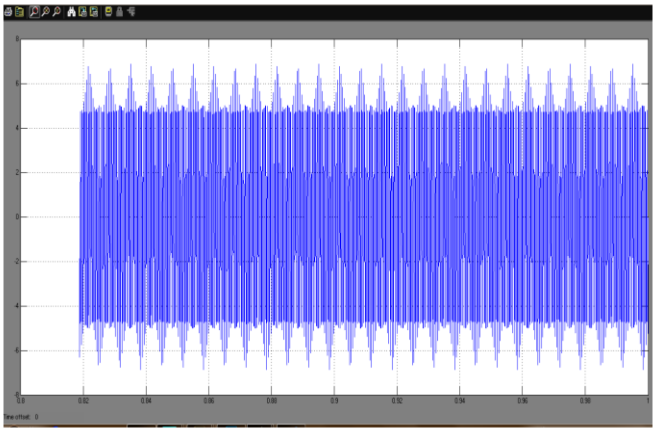

Figure 7. Modulating signal .

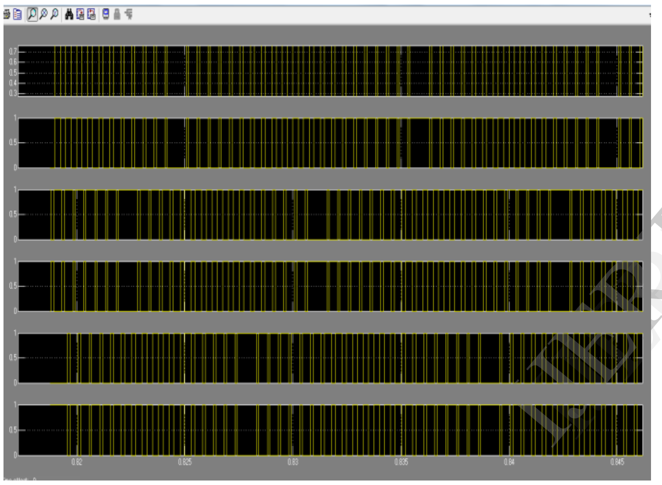

Figure 8. Modulated signal.

## 6. Simulation for control mechanism used in proposed system.

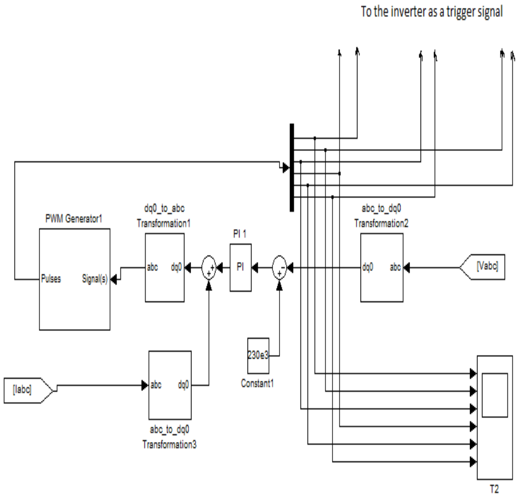

Figure 9. Simulation for control mechanism using proportional integral controller.

The standard PI controllers are used to regulate the grid current in dq synchronous frame. The output of the current controllers sets the voltage reference for a PWM.

## 7. Simulation of complete PMSM wind power system using z-source.

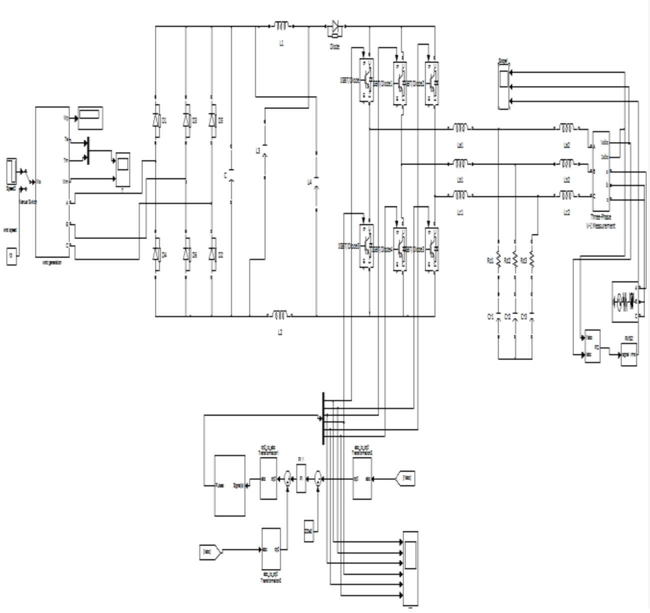

Figure 10. Simulation of complete proposed system.

## 8. Simulation results.

A. The simulation results for current.

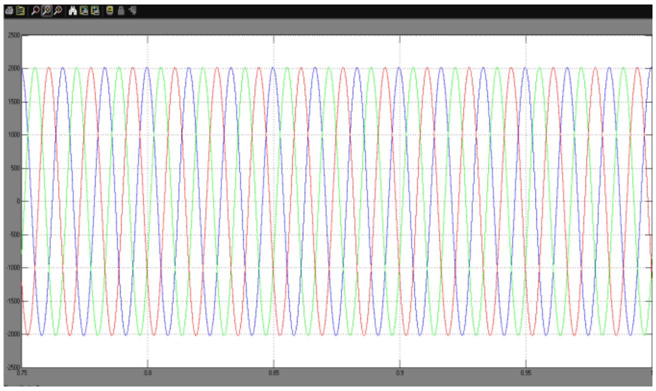

Figure 11. Output current curve.

B. The simulation results for voltage.

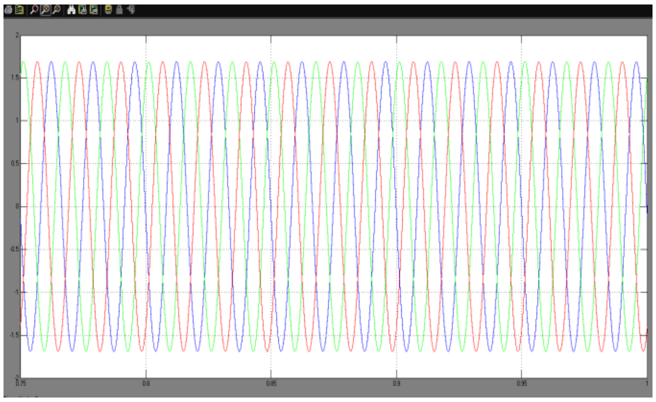

Figure 12. The output voltage curve.

C. The simulation results for active and reactive power.

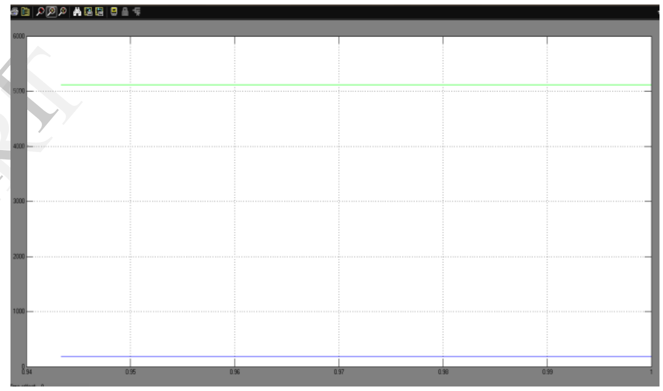

Figure 13. The output active and reactive power curves.

## 9. Conclusion.

In this paper, the PMSG wind power system connected to grid using Z-source inverter is proposed. The proposed system worked effectively with the input DC voltage lower than the grid level voltage. The control system extracted the power from wind turbine and delivered high quality current into the grid. The proposed Z-source inverter is efficient, cost effective and have high performance.

## 10. References.

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