International Journal of Pure and Applied Mathematics
Volume 118 No. 24 2018
ISSN: 1314-3395 (on-line version)
url: http://www.acadpubl.eu/hub/
Special Issue
http://www.acadpubl.eu/hub/

VOLTAGE STABILITY ENHANCEMENT OF WIND ENERGY CONVERSION SYSTEM USING SVPWM CONTROLLER

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May 9, 2018

Abstract

The world at present is striving towards an increase in the utilization of renewable energy for sustainability and to replace the current dependence on the exhaustible resources. However the increase in the penetration of the renewable power is limited as it is currently not highly reliable. In this paper we study the enhancement of voltage stability of a permanent magnet synchronous generator (PMSG) based wind energy system using the Space Vector Pulse Width Modulation (SVPWM) controller on the grid side converter of the wind energy conversion system by reducing the voltage distortions caused by the harmonics. Park transformation technique was used in the SVPWM controller and the proposed system has been simulated using the MATLAB/SIMULINK software.

***Index Terms*:**Distribution feeder; permanent magnet synchronous generator; Space Vector Pulse Width Modulation; voltage regulation; wind energy.

1 INTRODUCTION

Depleting reserves of fossil fuels and coal added with the adversities caused due to pollution has pushed the world to strive towards a pollution free and renewable source of energy. This has led to a surge in the demand for the exploitation of renewable resources available for us, especially wind and solar energy resources. Wind energy is exploited by converting the kinetic energy of the wind into mechanical energy caused due to the rotation of the rotor blades which then is transmitted to a turbine shaft connected to an electrical generator. The rotation of the shaft thereby turns the generator and electricity is generated. The wind turbine model proposed in this paper includes a wind turbine , a permanent magnet synchronous generator which then is connected to the Machine Side Converter (MSC), converting the variable distorted alternate current into a direct current. This then is filtered and fed to the Grid Side Converter (GSC). The Grid Side Converter acts as the inverter and is controlled by the Space Vector Pulse Width Modulation (SVPWM) controller. Thus the energy generated is hence transmitted to the grid using AC-DC-AC converters. These converters aid in maximizing the power extraction and transmission. In this article we will be focusing on the Voltage Source Inverter (VSI) used in the Grid Side Converter although it can also be used as a Current Source

Inverter (CSI). The VSI is more often preferred over the CSI because of its ease in operation and low switching losses.

The grid side conversion's significance is realized upon the need to have a constant frequency, continuous sinusoidal waveform with minimum distortions. Methods such as Hysteresis Current Control (HCC), Sinusoidal Pulse Width Modulation are the commonly used techniques for the control of grid side converter voltage source inverter. The Space Vector Pulse Width Modulation however is preferred due to low harmonic content, constant switching frequency, reduced switching losses. A three phase LC circuit is used to further filter the variable three phase alternate current generated from the grid side inverter to produce a distortion free, constant frequency voltage to the grid or the load. The paper aims to simulate the proposed model in MATLAB/SIMULINK software and analyze the outputs.

The paper is divided into five sections. Section II depicts the integral components and their descriptions. In section III the working and control of the proposed system. Section IV represents the analysis of the simulations and section V is the conclusion inferred from the study.

2 MODELING OF THE SYSTEM

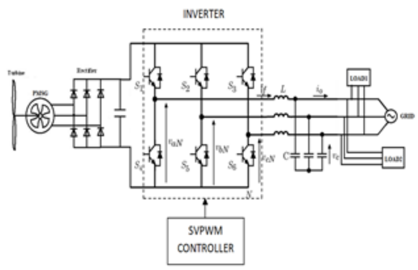

Fig1. Circuit Diagram of the proposed system

the inverter is the Grid Side Converter (GSC). The three IGBT legs are linked with DC capacitor. Each leg is hence connected to L-C filter for achieving the output AC wave form.

A. Wind Turbine model The mechanical power transferred from the kinetic wind energy to the rotor is as :

$$P_T = \frac{1}{2}\pi R^2 \rho V^3 C_p(\lambda, \beta)$$

R = radius of turbine in m, ρ = density of air [kg/m3], V= wind speed in m/s

Power coefficient in terms of λ and β components are :

$$C_p(\lambda, \beta) = C_1(\frac{c_2}{\lambda_1} - c_3\beta - c_4)e^{\frac{-c_5}{\lambda_i}} + c_6\lambda$$

with $c_1 = 0.5176, c_2 = 116, c_3 = 0.4, c_4 = 5, c_5 = 21, c_6 = 0.0068$.

where λ_i is

$$\frac{1}{\lambda_i} = (\frac{1}{\lambda + 0.008\beta} - \frac{0.035}{\beta^3 + 1})$$

Ω is the rotor speed , therefore the tip speed ratio is

$$\lambda = \frac{\Omega.R}{V}$$

With constant wind speed V and λ varying with rotor speed we have the torque output as :

$$T_m = \frac{P_T}{\Omega} = \frac{1}{2}\frac{C_p(\lambda,\beta)\rho\pi R^2 V^3}{\Omega}$$

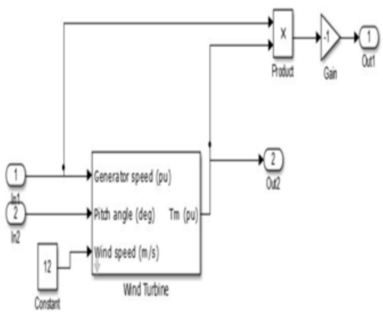

Fig 2. Simulink of wind Turbine

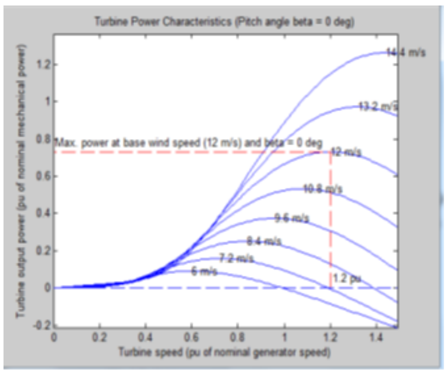

Fig 3. Characteristics of Wind Turbine

B. Pitch Angle Control

Blade pitch refers to the angle of attack of the blades of a propeller into or out of the wind regulate the production or absorption of wind power. The pitch angle control helps to adjust the rotation speed and generate power. It plays a significant role on the power of coefficient C_p. If the speed of the turbine is greater than the defined or rated speed then the controller adjusts the pitch angle to maintain the rated speed.

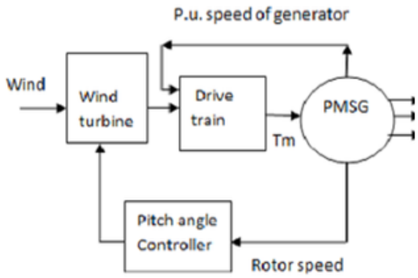

Fig 4. Block diagram for pitch control

The mechanical torque is nonlinear with the pitch angle and wind speed. To obtain a liberalized model we can use Taylor formulae:

$$T_e - T_m = J\frac{d\Omega_r}{dt}$$

T_e = Electromagnetic Torque
T_m= Mechanical Torque
J = Inertia of generator
C. PMSG MODEL

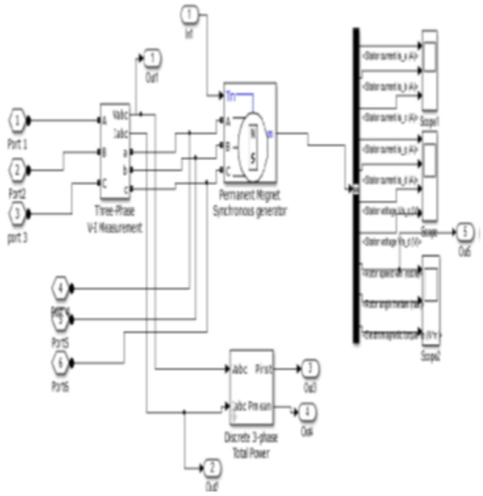

Fig 5. Simulink model of PMSG

Permanent Magnet Synchronous Generator is used in wind energy conversion systems as it is more efficient, reliable and requires less maintenance as compared to other options.

During operation, the dynamic model of Permanent Magnet Synchronous Generator is obtained from two-phase synchronous reference frame of which the q axis leads d axis by 90 degrees on rotation. It is represented in the Park's system as follows :

$$V_d = R_s i_d + L_d \frac{di_d}{dt} - \omega_r L_q i_q$$

$$V_q = R_s i_q + L_q \frac{di_{sq}}{dt} - \omega_r L_d i_d + \omega_r \Phi$$

here i_{sq} and i_{sd} are the currents and the V_{sq} and V_{sd} are stator voltages . The stator resistance is represented by Rs. Electromagnetic Torque is given by the expression:

$$T_{em} = \frac{3p}{2}[\Phi_r - (L_q - L_d)i_d]i_q$$

$$\Omega_r = p\omega_r$$

p = number of pole pair,

λ_m = magnetic flux,

L_q = inductance in quadrature,

ω = Electrical angular frequency.

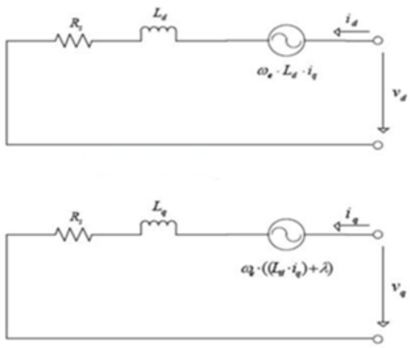

Fig 6. PMSG Equivalent Circuit in d-q state reference

The voltage equations are as follows :

$$\frac{d}{dt}i_d = \frac{1}{L_d}V_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}\rho w_r i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}V_q - \frac{R}{L_q}i_q + \frac{L_d}{L_q}\rho w_r i_d - \frac{\lambda \rho w_r}{L_q}$$

L_d = Inductance in d axis
L_q = Inductance in q axis
V_d = Voltage across d axis
V_q = Volatge across q axis
W_r = Angular velocity of rotor
R = Resistance of stator winding

3 CONTROL OF THE SYSTEM

A. Grid Side Control

The grid side inverter converts the DC power into AC power. The grid side converter helps in regulating DC bus voltage and also helps to control the active and reactive power fed into the grid. In this study we are employing the Space Vector Pulse Width Modulation (SPVWM) technique in the grid side inverter. The active and reactive power flowing into the grid can be determined by using these formulas:

$$P_g = \frac{3}{2}(V_{dg}i_{dg} + V_{qg}i_{qg})$$

$$Q_g = \frac{3}{2}(V_{qg}i_{dg} - Vi_{qg})$$

i_{dg} and i_{qg} are grid currents whereasV_{dg} and $V_{qg}$are the grid voltages with respect to d-q axes reference frame.

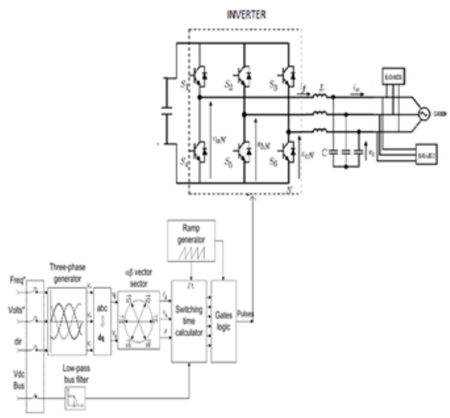

Fig 7. Control block for grid side voltage control.

In the figure 7, The control scheme of the Grid Side Converter is given. The three-phase generator (PMSG) produces three sine waves with variable frequency and amplitude and are out of phase with each other by 120 degrees. The inverter-requested frequency and voltage are two of the block inputs. The low-pass bus filter removes fast transients from the DC bus voltage measurement. This filtered voltage is used for computing the voltage vector. The d-q transformation is used in converting the three-phase system variables (ABC) to the two-phase d-q system. The d-q vector sector is used to determine the sector of the d-q plane in which the voltage vector is found. The d-q plane is disintegrated into six unique sectors of each spaced by 60 degrees. The ramp generator produces a unitary ramp at the PWM switching frequency. This ramp acts as a time base for the switching sequence. The switching time calculator then calculates the timings of the voltage vectors. The voltage vector lies in a sector called the block input. The gates logic gets the timing sequence from the switching-time calculator and the ramp from the ramp generator. It then evaluates the ramp and the gate timing signals to turn on and off the inverter switches as required .When an average value inverter is used the gates logic block is deactivated and switching time calculator issues inverter leg PWM duty cycles. In this mode, the Space Vector Modulator block outputs the duty cycles of the various pulses but not the pulses themselves. These duty cycle signals are expected by the average-value Inverter block when used in space vector modulation mode.

B.SPACE VECTOR PULSE WIDTH MODULATION (SPVWM)

Space Vector Modulation is used for controlling the pulse width modulation. It facilitates in the generation of a variable alternating 3 phase voltage from DC. It significantly reduces the Total Harmonic Distortion (THD). It converts AC power into DC power by using 6 IGBT power switches (S1,S2,S3,S4,S5,S6) controlled by a, b and c. a, b and c are the switching variables present in the each phase leg. The switches in the same leg should not be ever in the same state that is when one switch turned ON in one of the legs the other should be in OFF state. From the table 1, it can be found that there are eight possible combinations for switching vectors. There are six active switches and two zero vectors. V1-V6are active vectors. V0 and V7 are the zero vectors.

Voltage Vector	Switching State			Phase-to-Neutral Voltage		
	a	b	c	V_a	V_b	V_c
V_1	1	0	0	2/3	-1/3	-1/3
V_2	1	1	0	1/3	1/3	-2/3
V_3	0	1	0	-1/3	2/3	-1/3
V_4	0	1	1	-2/3	1/3	1/3
V_5	0	0	1	-1/3	-1/3	2/3
V_6	1	0	1	1/3	-2/3	1/3
V_7	1	1	1	0	0	0
V_0	0	0	0	0	0	0

Table 1. Switching state and phase to neutral voltage.

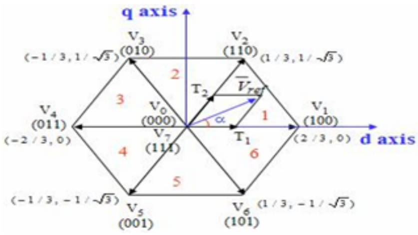

Fig 8. Switching sectors and vectors (zero and active)

Space vector modulation can be used to determine the switching pattern based on the depiction of switching vectors in the$\alpha - \beta$ plane.

The ABC to DQ transformation equations for Park transformation is as follows:

$$\begin{bmatrix} d \\ q \\ 0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}.$$

The voltage phases of the three phase sinusoidal waveforms of a the Voltage Source Inverter (VSI) is obtained as follows:

$$V_{an} = V_m \sin(\omega t)$$
$$V_{bn} = V_m \sin\left(\omega t - \frac{2\pi}{3}\right)$$
$$V_{cn} = V_m \sin\left(\omega t + \frac{2\pi}{3}\right)$$

Here Vm is the peak magnitude of the phase voltages. is angular frequency. IV SIMULATION RESULTS

The proposed system was simulated in MATLAB/Simulink and the following observations were made.

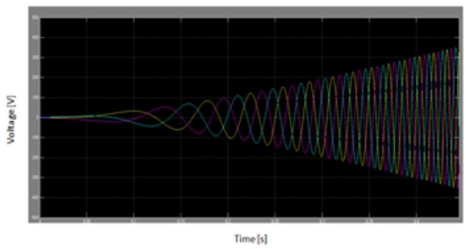

Fig.9. Unregulated wind turbine output

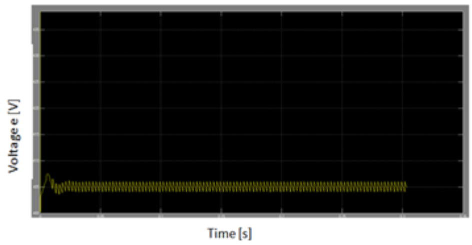

Fig.10. Rippled DC link voltage

Figure 9 shows the unregulated wind turbine AC output, which then is rectified by the main side converter and figure 10 shows the rippled DC link voltage.

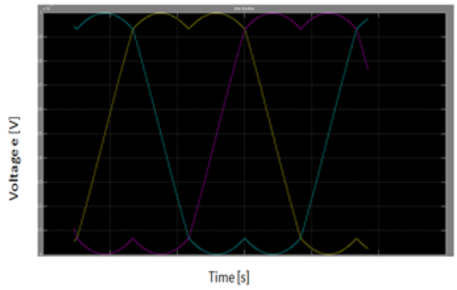

Fig.11. Space Vector Pulse Width modulated wave output

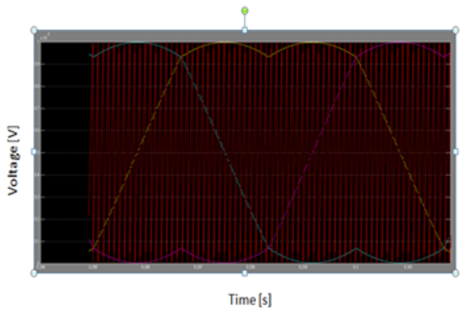

Fig.12. Carrier wave generation

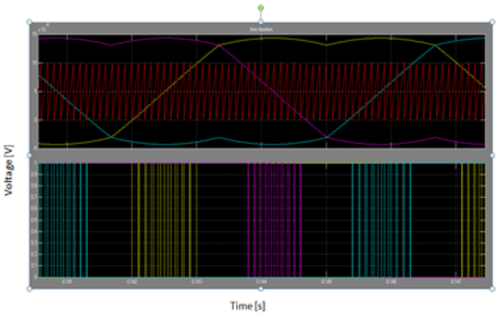

Fig.13. Gate Pulses Formation

As the carrier wave cuts the space vector modulated output gate pulses are triggered. These then controls the grid side inverter to produce a constant voltage with less distortions.

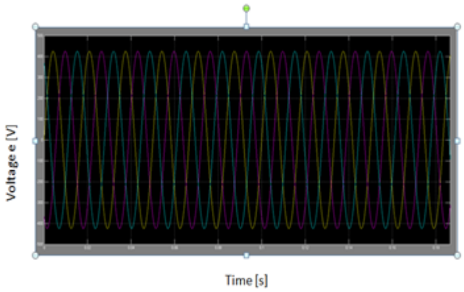

Fig.14. Regulated AC output waveform from Grid.

From fig.14. the voltage obtained from the grid side inverter is found to be more stabilized with almost a constant output of 430V with no distortions.

4 CONCLUSION

The paper has successfully presented the enhancement of the voltage stability of wind energy using Space Vector Pulse Width Modulation for the grid side voltage output. This technique helps in minimizing the total harmonic distortions associated with the voltage produced by the wind energy conversion system. The Space Vector Pulse Width Modulation has found to be the most desirable for processing the dc link voltage.

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