MODELING, SIMULATION AND PERFORMANCE ANALYSIS OF AC-DC-AC SVPWM CONVERTERS BASED WIND ENERGY CONVERSION SYSTEM USING LCL FILTER AND FAST SIMULATOR FOR 5MW AND 10 KW DDPMSG

[1]SAMRAAT SHARMA, [2]ANKHI GULATI, [3]MANILA BHATNAGAR

[1,2,3]Department of Electrical Engineering IFTM University, Moradabad

Abstract— The Simulation model of DDPMSG 10 KW and 5MW grid Connected are developed using MATLAB 2013(a) and FAST Simulator. In addition to it SVPWM technique has been applied for 10 KW and 5MW grid connected model. Space vector pulse width modulation has been used for obtaining the output voltage with less distortion. The result so obtained show that there is a degree of freedom of space vector placement in a switching cycle. The fully controlled converter has been used to provide separate control for active and reactive powers. The simulation results in MATLAB SIMULINK 2013a showing the model have good dynamic and static performance.

Keywords—Direct drive permanent magnet synchronous generator, Space vector pulse width modulation, Fully controlled converters.

I. INTRODUCTION

The aim of this research is to model an autonomous control wind turbine driven permanent magnetic synchronous generator.(PMSG) which feeds alternating current (AC) power to the utility grid. Furthermore, this research also demonstrates the effects and the efficiency of PMSG wind turbine which is integrated by autonomous controllers. In order for well autonomous control, two voltage source inverters are used to control wind turbine connecting with the grid. The generator-side inverter is used to adjust the Synchronous generator as well as separating the generator from the grid when necessary. The grid-side inverter controls the power flow between the direct current (DC) bus and the AC side. Both of them are oriented control by space vector pulse width modulation (SVPWM) with back-to-back frequency inverter. Moreover, the proportional-integral (PI) controller is enhanced to control both of the of the converters and the pitch angle of the wind turbine.

II. INVERTERS AND THE PITCH ANGLE OF THE WIND TURBINE

According to the continuous development of wind power technology, the efficiency of inverter device is facing some tough issues and plays a vital role in the improvement of wind power generation system performance. They need to be enhanced by controller to improve the efficiency and the reliability. Inside them, MPPT integrating with the back to back space vector Pulse width modulation is the advantage of controller, which is used to measure the rotor speed and compare with the calculated optimal rotor speed. On the other hand, not only does the inverter take an advantage in efficiency control but also the pitch angle controller takes another important part of wind turbine. It is integrated to adjust the aerodynamic torque of the wind turbine when this study rates wind speed.

III. MODEL OF PMSG

Structure of PMSG Wind Turbine. The basic of PMSG wind turbine structure shown on Figure 1 is defined as. The wind turbine generates torque from wind power. The torque is transferred through the generator shaft to the rotor of the generator. The generator produces an electrical torque, and the difference between the mechanical torque from the wind turbine and the electrical torque from the generator determines whether the mechanical system accelerates, decelerates, or remains at constant speed. The generator is connected to a three-phase inverter which rectifies the current from the generator to charge a DC-link Vdc capacitor. The DC-link Vdc feeds a second three-phase inverter which is connected to the grid through a transformer. Through the control system, the information of wind speed, pitch angel, rotor RPM, and inverter output is accepted to compare with the grid-side data. Therefore, this information is solved by using a digital signal processing. The LCL filter is connected between inverter and Grid to remove the harmonic content in the voltage output. The dc link capacitor is placed between the rectifier and the inverter. The purpose of dc link capacitor is remove the ripples in the dc link voltage and size of the capacitor have to trade of between ripples and response time.

D-Q AXIS VOLTAGES EQUATIONS AFTER PARKS TRANSFORM

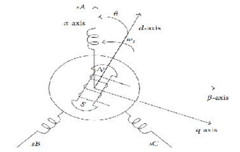

Figure1 DQ axis frame of PMSG

ω_e the frequency of the generator's emf and p is the number of generator pole pairs.voltage equatoin of the PMSG in dq reference frame.

$$V_d = Ri_d - \omega_e L_q i_q + L_d \frac{di_d}{dt} \quad (1)$$

$$V_q = Ri_q - \omega_e (L_d i_d + \psi) + L_q \frac{di_q}{dt} \quad (2)$$

The electrical and mechanical angle relation given below. shows the dq-coordinates frame of the PMSG with θ being the angle between d-axis and the main stator axis. V_d , V_q and id ,iq are voltages and current of direct and quadrature axis.Ld and Lq are generator inductance

$$\theta_{\text{electrical}} = p\,\theta r \quad (3)$$

$\omega_e = p\omega_r$

ωe is the basic electrical angular frequency of the generator.The direct and quadrature axis Voltage by parks transform

$$V_d = Ri_d - p\omega_r L_q i_q + L_d \frac{di_d}{dt} \quad (4)$$

The electrical torque is given by

$$\tau_e = \frac{3}{2} p \left(i_d i_q (L_d - L_q) + \psi i_q\right) \quad (5)$$

The machine is non salient therefore $L_d = L_q = L_s$ applying in above equation we get.

$$V_q = Ri_q - p\omega_r (L_d i_d + \psi) + L_q \frac{di_q}{dt} \quad (6)$$

$$V_d = Ri_d - L_s \left(\frac{di_d}{dt} - p\omega_r i_q\right) \quad (7)$$

$$\tau_e = \frac{3}{2} p\, \psi i_q \quad (8)$$

This are equation of non salient rotor of PMSG.

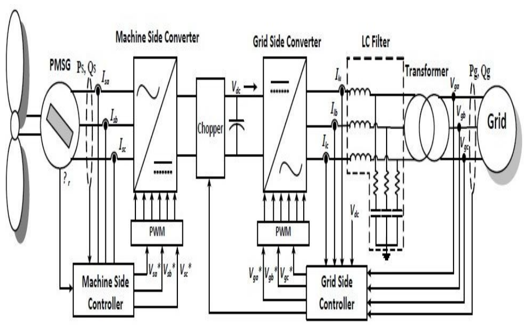

Figure 2 PMSG Complete Control System

It is made of three power electronics equipments
(a) Rectifier (AC/DC converter),
(b) Chopper (DC/DC converter)
(c) Inverter (DC /AC converter)

IV Space vector pulse width modulation

Three phase voltages

$$v_{AO}(t) + v_{BO}(t) + v_{CO}(t) = 0 \quad (9)$$

Two phase voltages Clarke Tranform(α,β)

$$\begin{bmatrix} v_\alpha(t) \\ v_\beta(t) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos 0 & \cos\frac{2\pi}{3} & \cos\frac{4\pi}{3} \\ \sin 0 & \sin\frac{2\pi}{3} & \sin\frac{4\pi}{3} \end{bmatrix} \begin{bmatrix} v_{AO}(t) \\ v_{BO}(t) \\ v_{CO}(t) \end{bmatrix} \quad (10)$$

Space Vector Representation

$$\vec{V}(t) = v_\alpha(t) + j v_\beta(t) \quad (11)$$

$$\vec{V}(t) = \frac{2}{3}\left[v_{AO}(t)e^{j0} + v_{BO}(t)e^{j2\pi/3} + v_{CO}(t)e^{j4\pi/3}\right] \quad (12)$$

Where

$$e^{jx} = \cos x + j \sin x \quad (13)$$

$$v_{AO}(t) = \frac{2}{3}V_d,\ v_{BO}(t) = -\frac{1}{3}V_d \text{ and } v_{CO}(t) = -\frac{1}{3}V_d \quad (14)$$

$$\vec{V}_1 = \frac{2}{3} V_d e^{j0} \quad (15)$$

$$\vec{V}_k = \frac{2}{3} V_d e^{j(k-1)\frac{\pi}{3}} \quad (16)$$

K=1,2,6

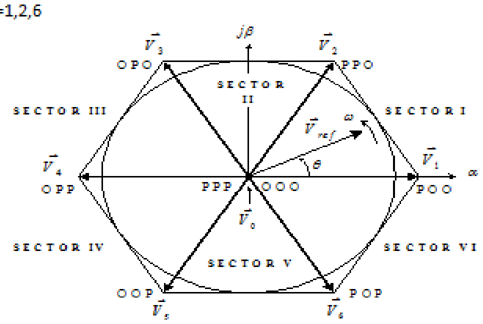

Figure3 Space Vector Modulation

Reference vector V_{ref} Definition

$$\vec{V}_{ref} = V_{ref}\, e^{j\theta} \quad (17)$$

Rotating in space at ω

$$\omega = 2\pi f \quad (18)$$

$$\theta(t) = \int_0^t \omega\, dt \quad (19)$$

Dwell time calculation (20)

$$\begin{cases} \vec{V}_{ref} T_s = \vec{V}_1 T_a + \vec{V}_2 T_b + \vec{V}_0 T_0 \\ T_s = T_a + T_b + T_0 \end{cases}$$

Ta, Tb , Tc are dwell times for V1 ,V2,Vo Ts is sampling period

$$\vec{V}_{ref} = V_{ref} e^{j\theta},\ \vec{V}_1 = \frac{2}{3} V_d,\ \vec{V}_2 = \frac{2}{3} V_d e^{j\frac{\pi}{3}} \vec{V}_0 = 0 \quad (21)$$

$$\begin{cases} \textbf{Re}: & V_{ref}(\cos\theta) T_s = \frac{2}{3} V_d T_a + \frac{1}{3} V_d T_b \\ \textbf{Im}: & V_{ref}(\sin\theta) T_s = \frac{1}{\sqrt{3}} V_d T_b \end{cases} \quad (22)$$

$$\begin{cases} T_a = \frac{\sqrt{3}\, T_s V_{ref}}{V_d} \sin\left(\frac{\pi}{3} - \theta\right) \\ T_b = \frac{\sqrt{3}\, T_s V_{ref}}{V_d} \sin\theta \\ T_0 = T_s - T_a - T_b \end{cases} \quad (23)$$

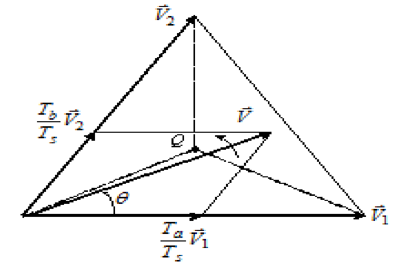

Figure 4 Relationship Between V_{ref} and V_{AB}

Vref location	θ =0	0<θ<π/6	θ = π/6	π/6 < θ < π/3	θ = π/3
Dwell times	Ta>0 Tb=0	Ta>Tb	Ta= Tb	Ta<Tb	Ta=0 Tb>0

V_{ref} is approximated by two active and a zero vectors V_{ref} rotates one revolution, V_{AB} completes one cycle .Length of V_{ref} corresponds to magnitude of V_{AB}.

$$\begin{cases} T_a = T_s m_a \sin\left(\frac{\pi}{3} - \theta\right) \\ T_b = T_s m_a \sin \theta \\ T_0 = T_s - T_b - T_c \end{cases} \quad (24)$$

modulation index (25)

$$m_a = \frac{\sqrt{3}\, V_{ref}}{V_d}$$

(26)

$$V_{ref,max} = \frac{2}{3}V_d \times \frac{\sqrt{3}}{2} = \frac{V_d}{\sqrt{3}}$$

$m_{a,max} = 1 \rightarrow$
Modulation range: $0 \le m_a \le 1$

Minimize the number of switching's per sampling period Ts. Transition from one switching state to the next involves only two switches in the same inverter leg.

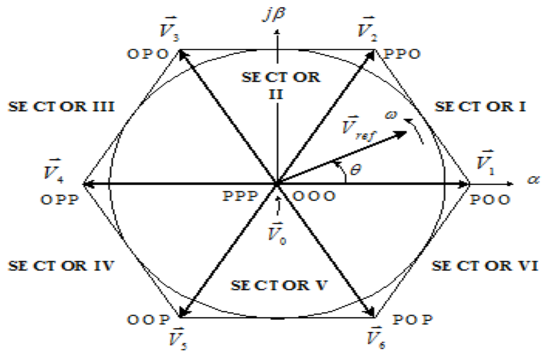

Figure5 Space Vector Modulation with Sector.

Figure5 Space Vector Modulation with Sector.

Selected vectors: V_0, V_1 and V_2 Dwell times:
$T_s = T_0 + T_a + T_b$

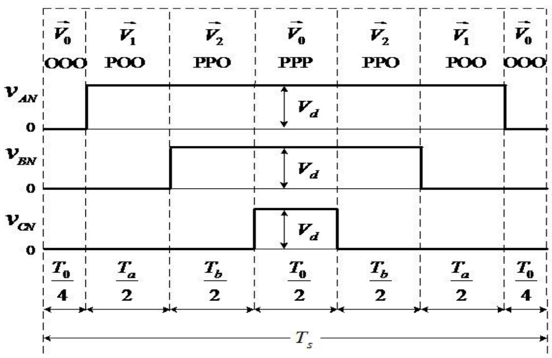

Figure6 Seven-segment Switching Sequence

Selected vectors: V_0, V_1 and V_2 Dwell times $T_s = T_0 + T_a + T_b$

Generator-Side Inverter Controller.

The generator-side inverter is controlled to catch maximum power from available wind power. According to (5), in order to control the electromagnetic torque Te, this study just controls the q-axis current isq with the assumption that the d-axis current id is equal to zero. Furthermore, show that, in order to catch maximum power, the optimum value of the rotation speed is adjusted. The tip speed ratio λ is taken into account due to

$$\lambda_{opt} = (\omega_{ref} R)/v$$

with $Es = p\omega_r \cdot \psi$ being the permanent flux linkages. The generator-side inverter control schematic is illustrated in Figure 6. Through the MPPT in , the error of ωref is produced. Therefore, the error of ωref and ωs is rescued to PI controller to produce q-axis current component iq ref which put into space vector pulse width modulation (SVPWM).The d-axis current id ref is set to zero because the d-axis current control is adopted. Consequently, through the SVPWM containing voltage feed-forward compensation, the power factors of the generator are calculated and controlled well.

$$V_d = Ri_d - L_s\left(\frac{di_d}{dt} - p\omega_r i_q\right)$$

$$V_q = Ri_q - L_s\left(\frac{di_d}{dt} + p\omega_r i_d\right) + p\omega_r \psi$$

There,ref is the blades angular velocity reference and λopt is the tip speed ratio optimum.

Grid-Side Inverter Controller

The goal of the grid-side inverter is keeping the stability of the DC-line voltage as well as controlling the active and reactive power Here, Vd is the d-axis output voltage of the grid, respectively, ω is the angular frequency in electrical degree of grid, R is the resistance, L is the inductance, respectively, and id and iq are the currents of d-axis and q-axis. By ( ), it is easy to figure out that the current of d-axis and q-axis can be controlled to moderate the active and reactive power. The inner current loop is controlled through PI controller similar to generator side inverter controller. The output voltage loop produces PI controller for calculating the error between Vdc and Vdc ref to produce id ref. Therefore, q-axis current is set to be zero to decoupling control of the active power P and reactive power Q by moderating the d-axis current id and the q-axis current iq.

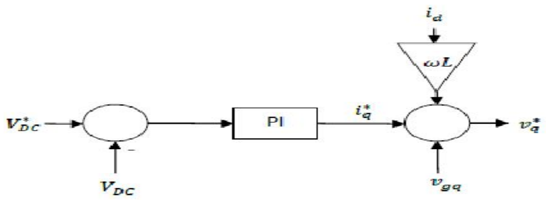

Figure 7. DC Link Voltage Control Block diagram.

Pitch Angle Controller.

Pitch angle controller is based on the principle which is changing the blades angle at the revolutions over the maximal generator speed as well as protecting the generator before overloading at high wind speeds. The optimal angle for the wind speed below the nominal value is approximately zero and then it increases with the wind speed. The speed of the generator is compared with its reference value through PI controller to have the output value of the pitch angle of the blades, which changes the performance coefficient of the turbine.

Maximum Power Point Tracking

In the generator-side inverter, MPPT produces the ωref for the comparative PI controller. the wind turbine coefficient achieves the maximum for the tip speed, when the pitch angle $\beta = 0$. In terms of every wind speed, there exists a specific point to get the maximum output. Hence, in order to control the maximum power in every wind speed, the MPPT tracks the continuous line and optimal line. The tip speed ratio is kept at constant value for all maximum power points, while the relationship between the wind speed and the wind turbine generator speed is explained as follows:

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

Ω is the optimal rotation wind turbine generator At wind speed V. The MPPT control strategy is based on monitoring the wind turbine generator output power using measurements of the wind turbine generator output voltage and current as well as directly modeling the dc/dc converter duty cycle, which is followed by the comparison of among output power values.

Table 1: Transformer Properties

S. No.	Symbol	10 Kw	5 MW
1.	V (primary)	90.13 V	650 V
2.	V (secondary)	208 V	34.5 kV
3.	Nominal power	20 KVA	6 MVA
4.	Series resistance (primary)	0.0043264 Ω	211.25 μΩ
5.	Series resistance (secondary)	8.124*10-4 Ω	0.198375 Ω
6.	Series inductance (primary)	0.574 mH	54.168 μH
7.	Series inductance (secondary)	86.198 μH	526.21 μH
8.	Magnetizing resistance	1086.6 Ω	99188 Ω
9.	Switching frequency	2.869 H	263.1 H

Table 2: Electrical Model Parameters Parameter.

S. No.	Symbol	10 Kw	5 MW
1.	Nominal grid voltage	208 V 3	34.5 kV
2.	Nominal grid frequency	60 Hz	60 Hz
3.	Nominal PMSG voltage	260 V	690 V
4.	C_{DC}	600 μF	2000 μF
5.	IGBT forward voltage drop	2.0 V	2.0 V
6.	Diode forward voltage drop	1.0 V	1.0 V
7.	IGBT conducting resistance	55 mΩ	7 mΩ
8.	IGBT fall time	70 ns	200 ns
9.	Switching frequency	7 kHz	4 kHz
10.	Transformer turns ratio	1:2.3077 1	1: 53.0769

TABLE 3 Aeroelastic Model Summary

Parameter	10 kW Turbine	5 MW Turbine
Rotor diameter	7 m	123 m
Nacelle mass	260.5 kg	240,000 kg
Nacelle inertia	39.81 kg m²	2,6078,9000 kg m²
Generator inertia	0.5 kg m²	534.116 kg m²
Hub inertia	7.71 kg m²	115,926 kg m²
Blade nodes for BEM	15	17
Blade mass	21.7724 kg	17,740 kg

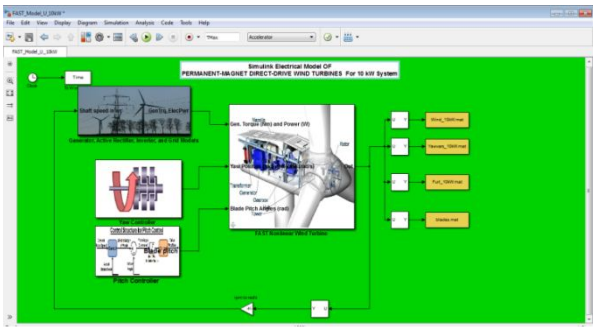

Figure8 Simulation Model of 10 KW of PMDD Wind Turbine.

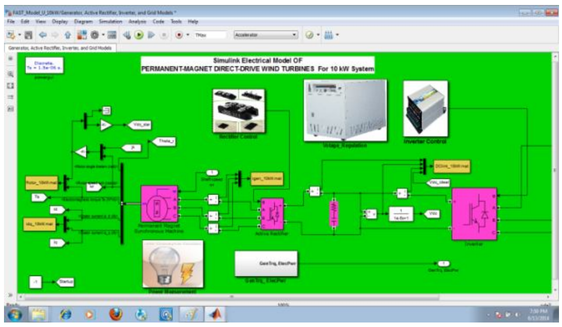

Figure9 Electrical Model For 10KW PMSG Grid Connected

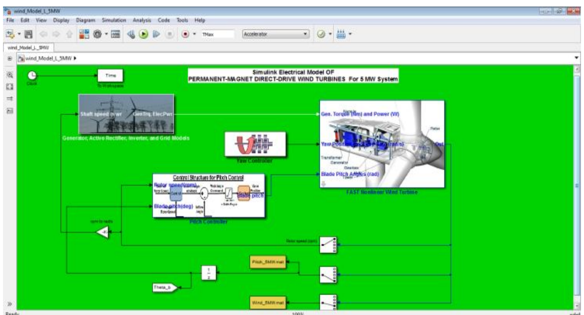

Figure10 Simulation Model of 5MW of PMDD Wind Turbine.

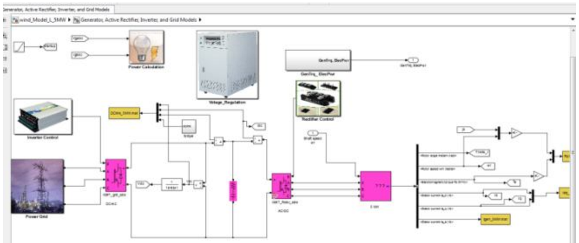

Figure 11 Electrical Model 5MW PMDD wind Turbine

The electrical model consist of several block

- PMSG block of 5 MW and 10KW
- Universal bride(Consist of IGBT both generator and inverter side)
- Rectifier control block
- Inverter control block
- Power grid block
- Voltage regulation block
- LCL filter and dc link
- Power calculation
- Power GUI block

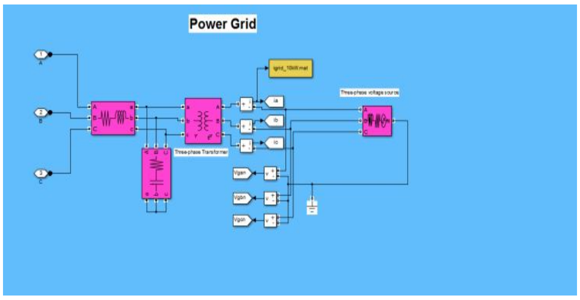

Figure12 Power Grid Block.

Figure 13 Shaft Speed(5MW)

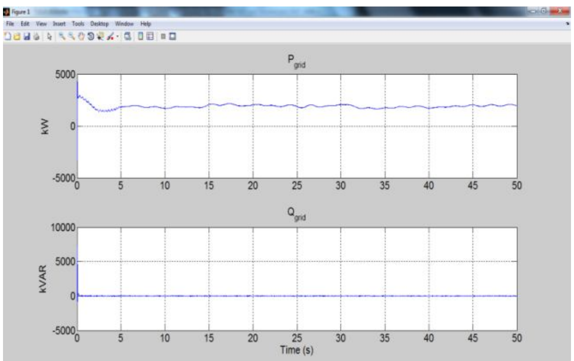

Figure 14 active and reactive power (5MW)

The Figure 13 shows shaft speed between 8.5 to 10.5 Rpm. Figure 14 show active and reactive power. Figure 15 constitute DC voltage and current and inverter current generator and grid current. Figure 18,19 show shaft speed and electromagnetic torque Figure 20, 21 show rectifier and inverter dc output whereas Figure 22 and 24 show active and reactive power. Figure 23 and 25 shows stator current at PMSG and Generator and Grid current respectively.

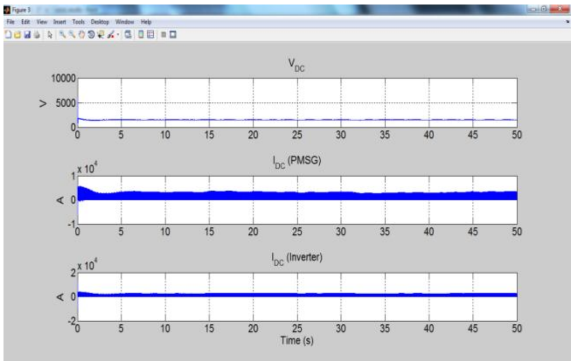

Figure15 DC Voltage, generator current and inverter current (5MW)

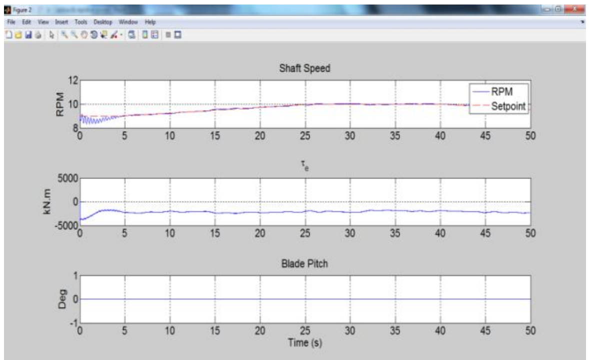

Figure16 blade pitch angle , shaft speed and electrical torque (5MW)

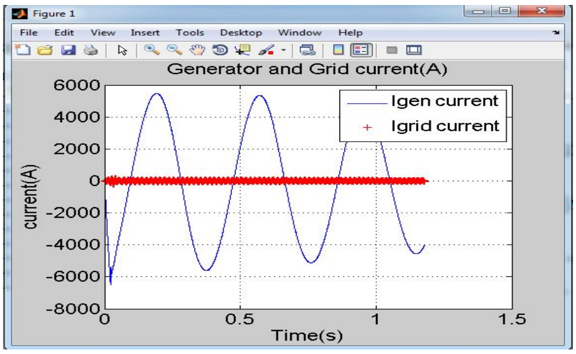

Figure17 Generator and grid current (5MW)

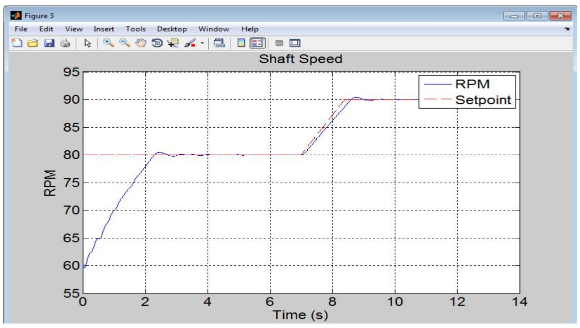

Figure 18 Shaft Speed(10KW)

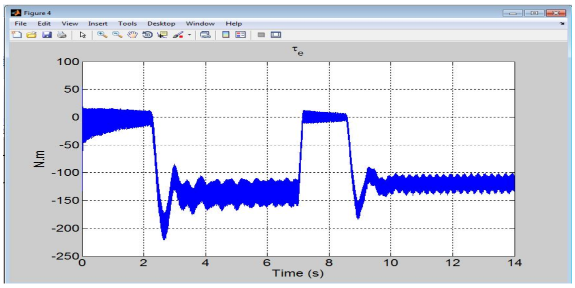

Figure 19 Electrical Torque(10KW)

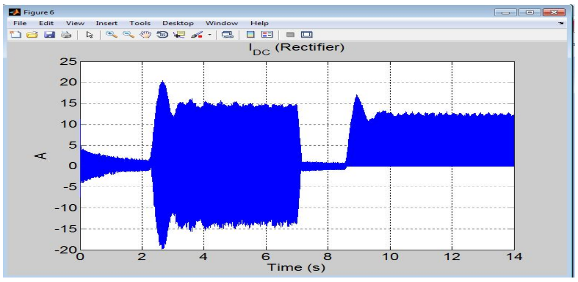

Figure 20 Idc(Rectifier) (10KW)

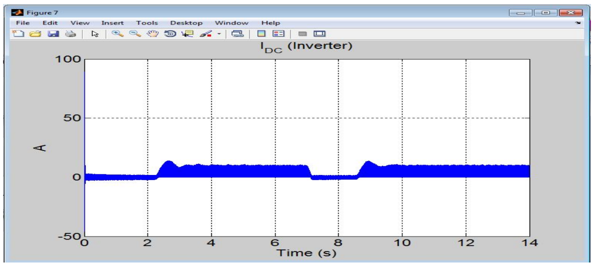

Figure21 Idc(inverter) (10KW)

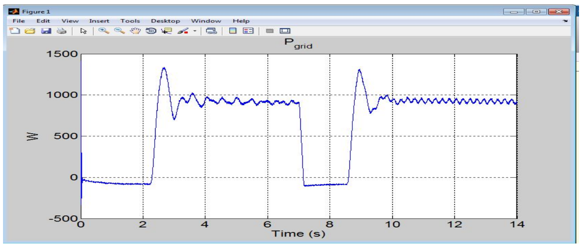

Figure22 ACTIVE_ POWER (grid) (10KW)

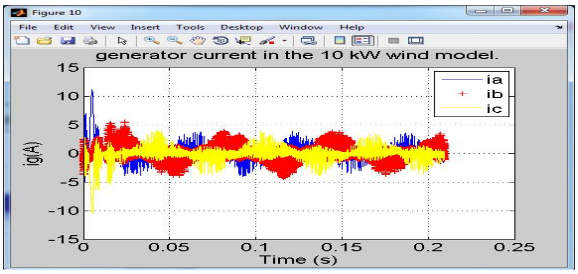

Figure23 I_a,I_b,I_c Stator current from PMSG(10KW)

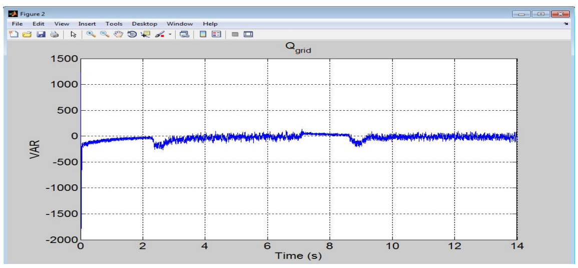

Figure 24 REACTIVE_ POWER (grid) (10KW)

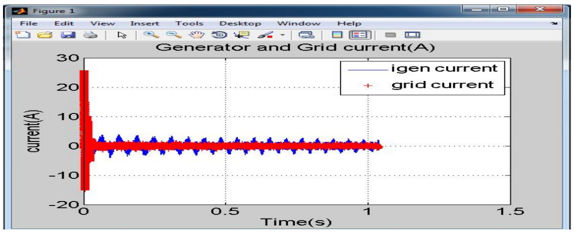

Figure25 Generator and grid current (10KW)

CONCLUSIONS

This study analyzes the control strategies as well as models and designs of 5MW and 10 KW DDPMSG wind turbine and simulates the whole autonomous system of PMSG wind turbine feeding AC power to the utility grid in Matlab Simulink 2013a. The simulation results show that the combination of pitch angle controller, generator-side inverter controller, and grid-side inverter controller has good dynamic and static performance. The maximum power can be obtained using SVPWM modulation technique and the generator wind turbine can be operated in high efficiency. DC-link voltage is kept at stable level for decoupling control of active and reactive power. The DC voltage utilization ratio which may be around 71% of the DC link voltage as compared to the conventional sine-pulse width Modulation which is 61.2 % in the linear modulation range. Space vector PWM generates less harmonic distortion in the output voltage or current waveform in comparison to a Sine PWM and it also decreases the harmonic content in the output waveform. Hence, the output will get the optimum power supply for the grid.

REFERENCES

[1] E. Mahersi, A. Khedher, M. F. Mimouni, “The Wind energy Conversion System Using PMSG Controlled by Vector Control and SMC Strategies,”published in international journal of renewable energy research Vol.3, No.1, 2013 vol. 3, no. 1, 2013.

[2] Natalia Angela Orlando, Marco Liserre, , Rosa Anna Mastromauro, M and Antonio Dell’Aquila. “A Survey of Control Issues in PMSG-Based Small Wind-Turbine Systems. Proceedings of IEEE transactions on industrial

[3] D. Ahmed and a Ahmad, “An optimal design of coreless direct-drive axial flux permanent magnet generator for wind turbine,” J. Phys. Conf.vol. 439, p. 012039, Jun. 2013.

[4] B. Plangklang, S. Kantawong, and A. Noppakant, “Study of Generator Mode on Permanent Magnet Synchronous Motor (PMSM) for Application on Elevator Energy Regenerative Unit (EERU),” Energy Procedia, vol. 34, pp. 382–389, Jan. 2013.

[5] Y. Xia, K. Ahmed, and B. Williams, “Wind turbine power coefficient analysis of a new maximum power point tracking technique,” IEEE transition on industrial Electronics. vol. 60, no. 3, pp. 1122–1132, 2013.

[6] G. Revel, A. Leon, D. Alonso, and J. Moiola, “Dynamics and Stability Analysis of a Power System With a PMSG-Based Wind Farm Performing Ancillary Services,” IEEE transiction on , pp. 1–12, 2014.

[7] S. Alshibani at el,“Lifetime Cost Assessment of Permanent Magnet Synchronous Generators for MW Level Wind Turbines,”,IEEE transition on industrial electronic. vol. 5, no. 1, pp. 10–17, 2014.

[8] N. Freire and J. Estima, “A Comparative Analysis of PMSG Drives Based on Vector Control and Direct Control Techniques for Wind Turbine Applications,” PRZEGLĄD ELEKTROTECHNICZNY (Electrical Review), ISSN 0033-2097 no. 1, pp. 184–187, 2014.

[9] ION BOLDEA “Variable Speed Generators “The electrical Generator handbook Published in 2006 by CRC Press Taylor & Francis Group.

[10] OLIMPO ANAYA-LARA, NICK JENKINS “Wind Energy Modulation and Control” John Wiley & Sons, Ltd 2009

[11] MUKUND R PATEL “Wind and Solar Power System” CRC Press 2011Edition.

[12] JOSHUA EARNEST & TORE WILZELIUS “Wind Power Plant and Projects Development” PHI learning 2012Edition

[13] L. Trejos-Grisales, C. Guarnizo-Lemus, and S. Serna, “Overall Description of Wind Power Systems.,” Ingeniería yCiencia,enerojunio. 10, no. 19. pp. 99–126, 2014.

[14] G. Revel, A. Leon, D. Alonso, and J. Moiola, “Dynamics and Stability Analysis of a Power System With a PMSG-Based Wind Farm Performing Ancillary Services,” IEEE transiction on , pp. 1–12, 2014.

[15] D. Ochs, R. Miller, and W. White, “Simulation of Electromechanical Interactions of Permanent-Magnet Direct-Drive Wind Turbines Using the FAST Aeroelastic Simulator,” pp. 1–8, 2014.

[16] S. Alshibani at el,“Lifetime Cost Assessment of Permanent Magnet Synchronous Generators for MW Level Wind Turbines,”,IEEE transition on industrial electronic. vol. 5, no. 1, pp. 10–17, 2014.

[17] N. Freire and J. Estima, “A Comparative Analysis of PMSG Drives Based on Vector Control and Direct Control Techniques for Wind Turbine Applications,” PRZEGLĄD ELEKTROTECHNICZNY (Electrical Review), ISSN 0033-2097 no. 1, pp. 184–187, 2014.

★★★