International Journal of Pure and Applied Mathematics
Volume 120 No. 6 2018, 11017-11036
ISSN: 1314-3395 (on-line version)
url: http://www.acadpubl.eu/hub/
Special Issue
http://www.acadpubl.eu/hub/

Design of SVM technique for Matrix converter in a PMSG based Wind Energy Conversion System

K.Jayanthi[1], Dr.N.Senthil Kumar[2]
[1]Assistant Professor, [2]Senior Professor
[1,2]Department of Electrical and Electronics Engineering.
[1,2]MepcoSchlenk Engineering College,
Sivakasi ,Tamil Nadu, India
[1]jayanthi.kathiresan@gmail.com
[2]nsk_vnr@mepcoeng.ac.in

August 5, 2018

Abstract

This paper presents the modeling of variable speed Wind Energy Conversion System (WECS) with a Permanent Magnet Synchronous Generator (PMSG) and a Matrix Converter. The objective of this paper is to convert the variable frequency output voltage from wind energy conversion system into constant frequency output voltage. Space Vector Modulation strategy is adopted to produce the constant frequency output in the load side. Simulation results are obtained based on the modeling of wind generators for different wind speed to demonstrate the performance of the proposed system.

Keywords:WECS, PMSG, matrix converter, space vector modulation

1

1 Introduction

Wind energy is considered as one of the most promising solutions for electric power generation since it is a clean and easily available form of energy [1]. Variable speed wind turbines are gaining more attention because of their capability to capture more power from the wind by using maximum power point tracking algorithm and improved efficiency [2]. Doubly Fed Induction Generators (DFIG) is often used generator in variable speed wind turbine system. The DFIG based wind turbine systems have to use the gearbox to match the turbine and rotor speed; it is consider as major drawback [3]. Now a days PMSG has received more attention owing to its self excitation capability and has improved reliability of the wind turbine system [4]. PMSG is also gaining more interest from the manufactures of small scale wind turbine to large MW applications [5-7]. Recently many power converter topologies are coming up to connect the wind generators with the load or to the grid [8-9]. For grid integration, the output of the PMSG is connected to the diode bridge rectifier in the generator side and a Voltage Source Inverter (VSI) is placed on the grid side. The usage of a single diode bridge rectifier is an economical solution but it works only at high wind speed condition. A simple dc-link capacitor or an intermediate dc/dc buck-boost or boost converters separate the rectifier and inverter to enhance the system reliability and also used to generate the power in all wind speeds [10-13]. The reference [13-15] highlights the certain drawback in the above said topology are due to high harmonic distortions in the generator windings such as increasing heating, reduction in machine efficiency, torque oscillations. Back to- Back voltage source converter topologies associated with the PMSG provides full controllability of the system [12,16]. The advantage of this converter is to regulate the generator speed, power factor etc. The dc-link provides decoupling between the generator and grid side [17]. Multilevel topology converters are also widely used in high power applications [18-21]. The major drawback in the case of Diode Bridge and Back-to-Back power converter topology is the requirement of bulky dc-link capacitor for decoupling the generator side and grid side. The main technological defy in the multilevel topology is to maintain the capacitor voltage. If the voltage is not maintained properly it leads to higher switching stress and in case of modular multilevel converter large numbers of sub-module capacitor voltages are required for measurement and as a result have a complex control. The above said converters (AC-DC-AC) converts the PMSG output voltage into intermediate DC and then into required AC voltage. They called as two level converters. The Matrix Converter topology is a single stage voltage conversion converter to provide the desired AC output voltage from the PMSG without the need of any intermediate energy storage element [22-24]. This converter is compact and guaranties unity power factor operation for any load. Due to high reliability and efficiency, it gets the attention of researchers in the application of PMSG based wind farms. Several modulation methods are implemented to control the voltage of the matrix converter are reported in [25-30]. Amongst, Space Vector Modulation scheme is widely used because it reduces the switching losses and minimizes the output current distortion by optimizing the use of zero vectors. In this paper, three phase direct matrix converter is connected to the PMSG with the resistive load. The output from the PMSG is variable frequency variable voltage. Space Vector Modulation strategy is used to provide the proper controlling signal to achieve the desired frequency and output voltage.

1.1 MODELING OF WIND TURBINE

The schematic representation of the matrix converter based wind energy conversion system is shown in figure 1.

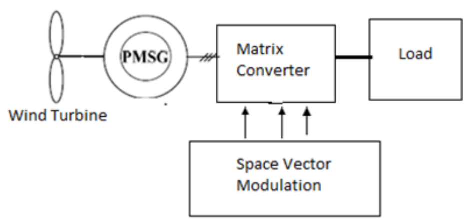


Fig.1. Block diagram of Matrix Converter based WECS

The mechanical power extracted by a wind turbine from the wind is expressed as

$$P_w = \frac{1}{2}\rho\, A\, C_p(\beta, \lambda \qquad (1)$$

$$\lambda = \qquad (2)$$

where P_w is the mechanical output power of the wind turbine, is the air density, R the length of the blade and v is the wind speed. The power coefficient Cp is the function of pitch angle of the rotor blade and the tip speed ratio , which is the ratio between blade tip speed and wind speed. The computation of the power coefficient requires the use of blade element theory and the knowledge of blade geometry. These complex issues are normally empirically considered. In this paper, the numerical approximation developed in reference [31] is followed, where the power coefficient is given by

$$C_p = 0.73(\frac{151}{\lambda_i} - 0.58\theta - 0.002\theta^{2.14} - 13.2)e^{-18.} \qquad (3)$$

$$\lambda_i = \frac{1}{\frac{1}{(\lambda - 0.02\partial)} - \frac{0.0}{\theta^3}} \qquad (4)$$

The mechanical power output from the wind turbine is given by substituting equation (2) and (3) into equation (1). From equation (2), the maximum power coefficient at zero pitch angle is

$$C_{pmax} = 0.44 \qquad (5)$$

Corresponding to an optimal tip speed ratio at zero pitch angle is given by

$$\lambda_{opt} = 7.0 \qquad (6)$$

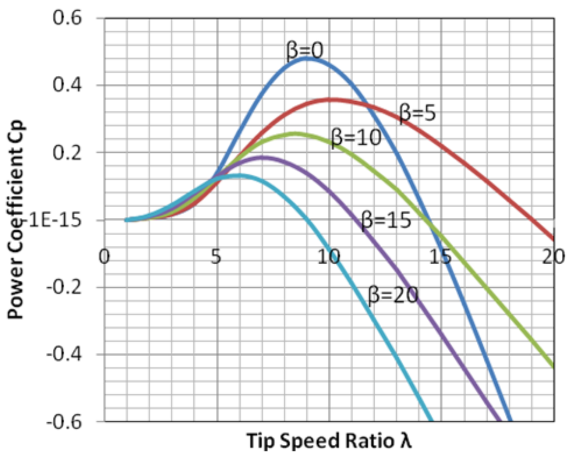


Fig 2. Power coefficient as a function of the tip speed ratio

Fig. 2 shows the power coefficient as a function of tip speed ratio.

2 MODELING OF WIND GENERATOR

The equations for modeling a PMSG can be found in the literature [32]. Using the motor machine convection is given by

$$\frac{di_d}{dt} = \frac{1}{L_d}\left[u_d + p\omega_g\ L_q i_q -\ R_d\right. \quad (7)$$

$$\frac{di_q}{dt} = \frac{1}{L_q}\left[u_q - p\omega_g\left(L_d i_d + M i_f\right) - R_d\right. \quad (8)$$

where is the equivalent rotor current, M is the mutual inductance, p is the number of pair of pole and and are the stator currents, and are the stator inductance, and are the stator voltages, and are the stator resistance in dq axes. The electrical power is given by

$$P_g = \left[u_d \quad u_q \quad u_f\right] \qquad \left[i_d \quad i_q \quad i_f\right. \quad (9)$$

the PMSG, a null stator current i_d is usually imposed [33]. The output power P and Q injected in $\alpha\beta$ axes [34] is given by

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix} \Bigg[\qquad (10)$$

3 MODELING OF MATRIX CONVERTER

The matrix converter is a single stage AC-AC converter with nine bidirectional switches. It is connected between the PMSG and the load via filter network. The switching strategy is chosen so that the output voltage has sinusoidal waveform at the desired frequency. For the matrix converter modeling; assume the input terminals should not be short circuited and output phase never be open circuited. During the switching operation of a single switch

$$S_{ij} = \begin{cases} 1, on \\ 0, off \end{cases} \qquad i, j \in 1,2,3 \qquad (11)$$

This assumptions corresponds to

$$\left.\begin{aligned} \sum_{j=1}^{3} S_{ij} &= 1 \qquad i \in \{1,2 \\ \sum_{i=1}^{3} S_{ij} &= 1 \qquad j \in \{1,2,3\} \end{aligned}\right\} \qquad \textbf{(12)}$$

With these restrictions, the 3x3 matrix converter has 27 possible states [35]. The relationship between load and input voltage and current can be expressed as

$$\begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = [S] \Bigg[\qquad (13)$$

$$[\, i_a \quad i_b \quad i_c]^T = [S]^T \; [i_A \quad i_B \quad i_{(} \qquad (14)$$

Hence, the matrix converter is modeled by [36-40]

6

4 MODULATION TECHNIQUE

The modulation scheme for the matrix converter topology was developed since 1980s. An overview of three phase to three phase matrix converter control algorithm is presented in [35]. In this paper, space vector modulation approach is employed to generate the gating signal for the switches. Though various modulation techniques are available for providing the control signals to the switches, space vector modulation technique is consider as more reliable modulation technique because with the vector control it gives less total harmonics distortions.The primary objective of this paper is to obtain the desired frequency output voltage from the variable frequency variable input voltage. The detailed analysis of space vector modulation method is explained in [36]. The modulation strategy for direct matrix converter is quiet complex to implement. In this proposed system, indirect matrix converter based space vector modulation scheme is employed for implementation. It is a two stage power converter (Rectifier and Inverter AC/DC/AC) without DC link. The modulation complexity is less when compared to direct matrix converter.

a. Voltage Source Rectifier SVM

The space vector of the desired input current can be approximated by two adjacent vectors. The duty cycles for VSR are calculated as (7)-(8)

$$\begin{aligned} d_{\alpha i} &= m_i \sin\left(\tfrac{\pi}{3} - \theta_i\right) \\ d_{\beta i} &= m_i \sin\theta_i \\ d_{0i} &= 1 - d_{\alpha i} - d_{\beta i} \end{aligned}$$

The transfer matrix of the VSR, TVSR is defined as

$$\begin{bmatrix} \overrightarrow{i_a} \\ \overrightarrow{i_b} \\ \overrightarrow{i_c} \end{bmatrix} = m_i \begin{bmatrix} \cos\left(w_i t - \varphi_i\right) \\ \cos\left(w_i t - \varphi_i - \frac{2\pi}{3}\right) \\ \cos\left(w_i t - \varphi_i + \frac{2\pi}{3}\right) \end{bmatrix} .I_{dc} = \overline{T}_{VSR}.I_{dc}$$

The VSR output voltage is determined by

$$\begin{aligned} \overrightarrow{v}_{pn} &= \overrightarrow{T}^{T}_{VSR}.V_{iph} \\ \overrightarrow{v}_{pn} &= \tfrac{3}{2}.m_i.\cos\varphi_i = const \end{aligned}$$

b. Voltage Source Inverter SVM

The voltage source inverter (VSI) switches can assume only six allowed combinations which yield nonzero output voltages. Hence, the resulting output line voltage space vector is defined by (18) can assume only seven discrete values, V0 V6 is known as voltage switching state vectors.

$$\vec{v}_o = \frac{2}{3}\left[v_a(t) + v_b(t)\, e^{\frac{j2\pi}{3}} + v_c(t)\, e^{\frac{j4\pi}{3}}\right] = v_o e^{jw_o t}$$

The duty cycle of the switching state vectors are

$$d_{\alpha i} = m_v \sin\left(\frac{\pi}{3} - \theta_i\right)$$
$$d_{\beta i} = m_v \sin\theta_i$$

$$d_{0v} = 1 - d_{\alpha v} - d_{\beta v}$$

$$0 \le m_v = \frac{\left(\sqrt{3}v_{oi}\right)}{v_{dc}} \le 1$$

The transfer matrix of the VSR, TVSR is defined as

$$\begin{bmatrix} \overrightarrow{i_a} \\ \overrightarrow{i_b} \\ \overrightarrow{i_c} \end{bmatrix} = m_i \begin{bmatrix} \cos(w_i t - \varphi_i) \\ \cos\left(w_i t - \varphi_i - \frac{2\pi}{3}\right) \\ \cos\left(w_i t - \varphi_i + \frac{2\pi}{3}\right) \end{bmatrix} .I_{dc} = \overline{T}_{VSR}.I_{dc}$$

The output line voltages are synthesized inside each switching cycle from samples of two input line voltages. It can be concluded that the simultaneous output voltage and input current of SVM can be obtained by employing the standard VSI SVM sequentially in two VSI sub-topologies of the three-phase MC.

5 SIMULATION RESULTS

The mathematical model for the wind energy conversion system with matrix converter topology was implemented in MATLAB simulink. The wind energy conversion system simulated in this paper has a rated electric power of 1.5kW. The wind speed variation considered for simulation is step change from 3 m/s to 18m/s. the switching frequency is 5 kHz.

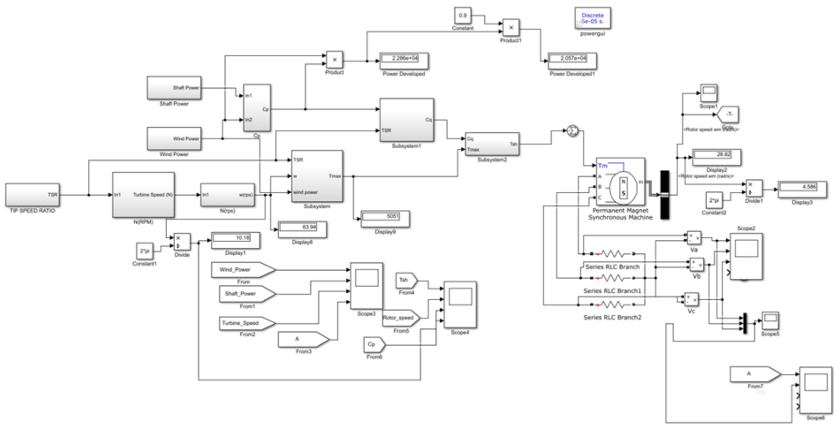


Fig. 3. Wind Turbine and Generator Modeling in MATLAB simulink

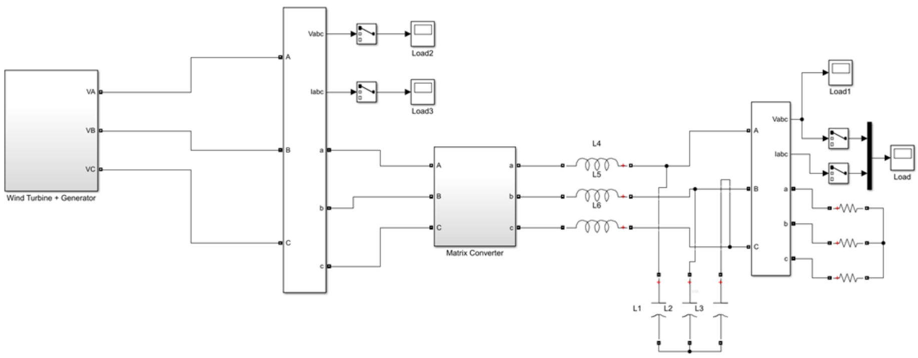


Fig. 4. Matrix Converter based WECS

The simulation is done for fixed wind speed and variable wind speed conditions.

Case I : Fixed Wind Speed

Fig.5(b) shows the generator output voltage for the wind speed of 7m/s. The generator output voltage has a frequency of 8.772 Hz and the maximum output voltage of 110V. The three output voltage wave from the matrix converter is depicting in fig.5.(c) and fig 5.(d) shows the output voltage and current at a wind speed of 7m/s after placing the filter at the output of matrix converter. The output frequency from the matrix converter is 50Hz and maximum phase voltage of 171V is obtained.

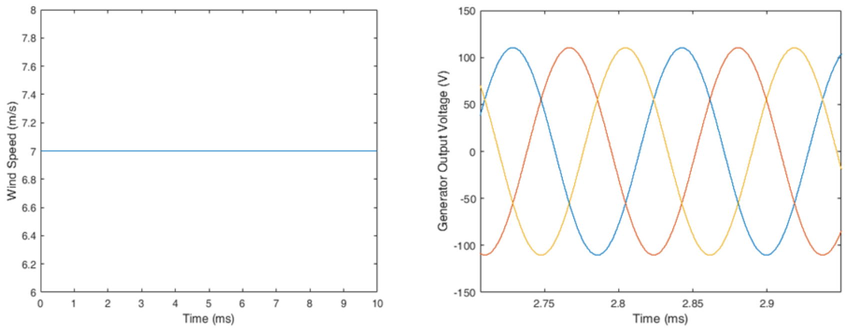
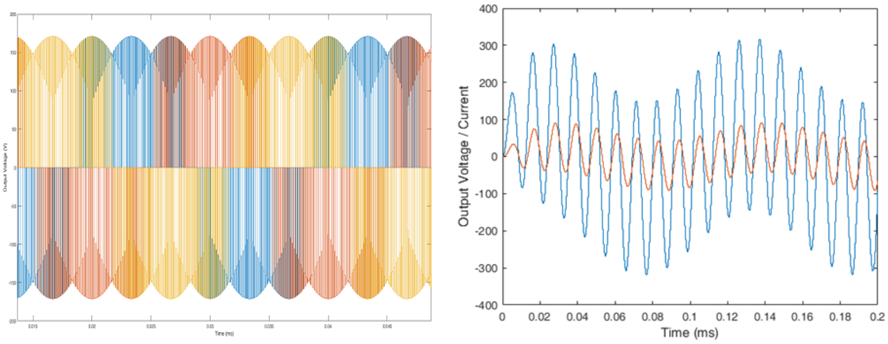


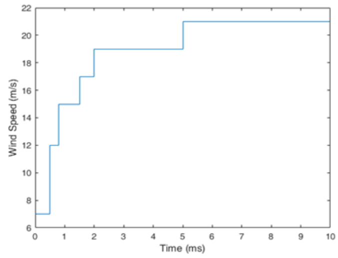
Fig. 5. Simulation output waveform (a) wind speed at 7m/s (b) Generator output voltage at 8.77Hz



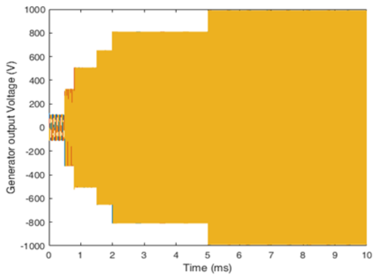
Output Voltage waveform of Matrix Converter at 50Hz (c) without filter (d) with filter

Case II Variable Wind Speed

Wind speed is varied from 5m/s to 21m/s .The generator output voltage for the corresponding wind speed is shown in fig.6.At the wind speed of 12m/s, the generator output frequency is 25.64 Hz and wind speed of 15 m/s, generator frequency is 40 Hz and the maximum output voltage at that wind speed is 501V. The output voltage waveform from the matrix converter has a frequency of 50Hz. Table I provides the specifications of wind turbine. The simulated output parameters such as input frequency, output voltage and converter output frequency for different wind speed can be viewed from table II. Table II elucidate how PMSG based matrix converter provide the constant frequency output against various wind speed. This table the proposed system offer good results for variable frequency operations.

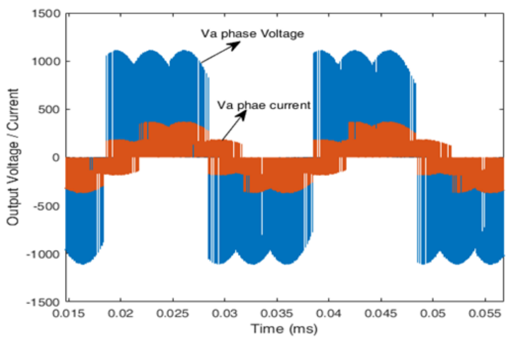


(a)

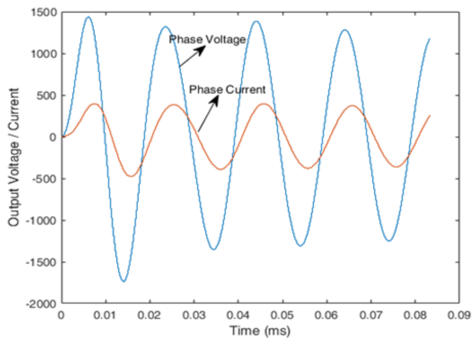


(b)

Fig.6. Simulation Output waveform (a) Variable Wind Speed (b) Generator output voltage



(c)

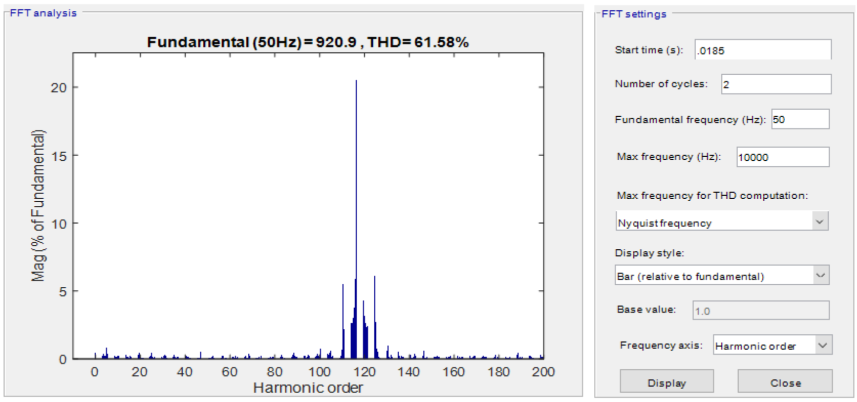


(d)

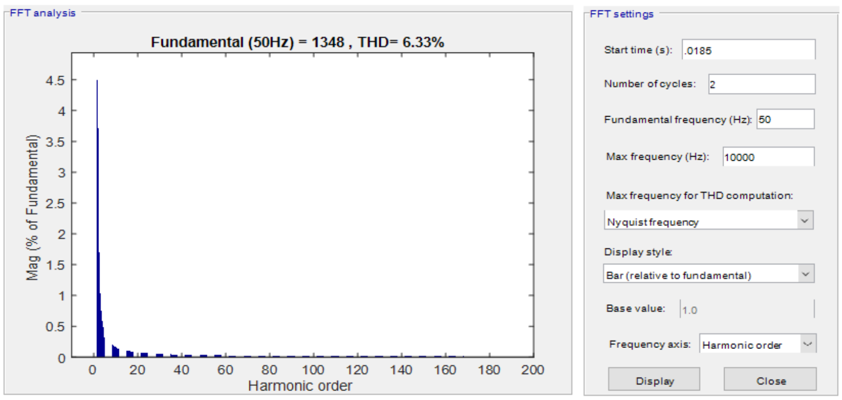
Output phase voltage and Current of matrix converter at the wind speed of 17m/s (c) without filter (d) with filter

TABLE II. INPUT OUTPUT FREQUENCY OF MC FOR A VARIABLE WIND SPEED CONDITION

Time (ms)	Wind speed (m/s)	Input Frequency (Hz)	Maximum Generator Output Voltage (V)	Output Current (A)	Output frequency (Hz)
0 – 0.5	7	8.92	110	0.58	50
0.5 – 0.8	12	25.64	319	1.733	
0.8 – 1.5	15	40	501	2.016	
1.5 – 2	17	51	642	4.131	
2 -5	19	64.52	805	4.98	
>5	21	78.13	983	5.199	

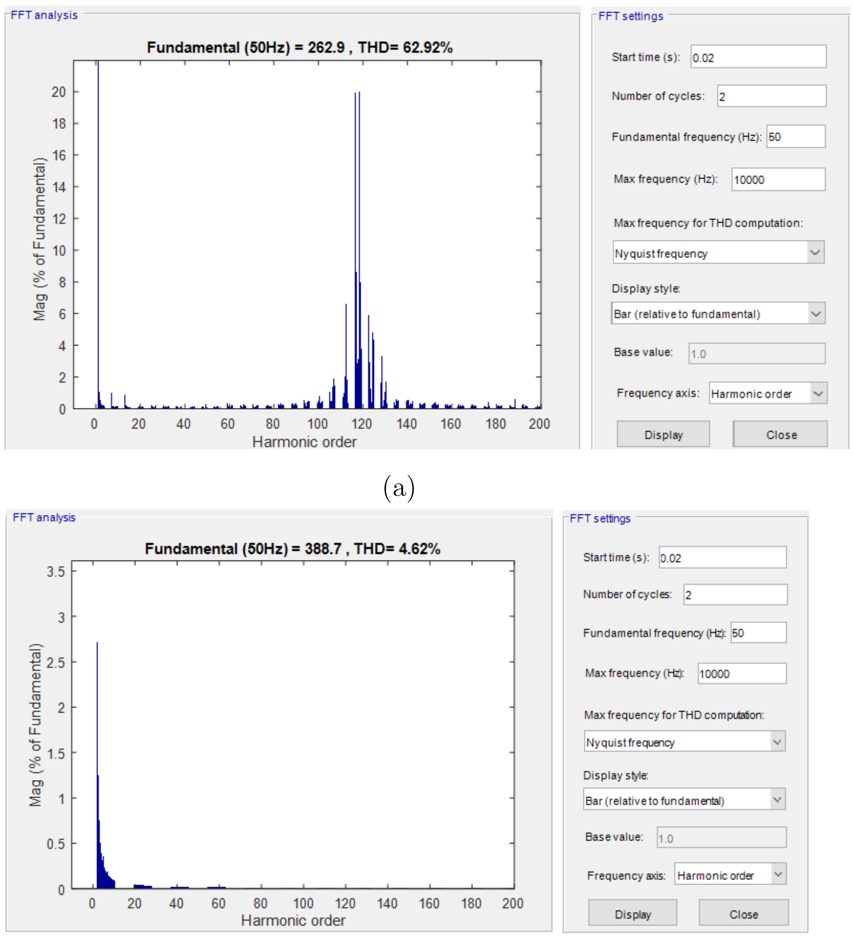


(a)



(b)

Fig. 7. Output Line voltage THD Spectrum (a) without filter (b) with filter



(a)

(b)

Fig. 8 Output current THD Spectrum (a) without filter (b)with filter

Fig.7 (a) provides the THD value of the line voltage. Its value is around 61%. By employing proper filter circuit at the output side of converter the line voltage THD is found to be 6.33%. The current THD for the matrix converter is found to be 4.62%. This can be achieved by the proper designing of filter circuit. Thus the quality of the output voltage is improved. The simulation results shows that the proposed matrix converter based wind energy conversion system offers good performance under various wind speed conditions.

TABLE - 1 WIND TURBINE POWER RATING IS 1.5KW

Swept area	$6.8m^2$
Number of blades	3
Air density	1.226 kg/m^3
Tip speed ratio	8.3
Power coefficient Cp	0.59

6 CONCLUSION

In this paper, three phase matrix converter based wind energy conversion system is designed and simulated for fixed wind speed and variable wind speed conditions. In both the cases the matrix converter produced desired frequency (50Hz) output voltage by using space vector modulation strategy. The output voltage THD of 6.33% is obtained in the proposed system. Thus, the simulation result of proposed work proves that PMSG based Matrix converter system is offer reliable output under variable wind speed conditions.

References

[1] Global Wind Report, Annual Market Update 2012, Global Wind Energy Council (GWEC) [Online]

[2] S. Mller, M. Deicke, and W. De DonckerRik, Doubly fed induction generator system for wind turbines, IEEE Ind. Appl. Mag., vol. 8, no.3, pp. 2633, May/Jun. 2002

[3] H. Polinder, F. F. A. van der Pijl, G. J. de Vilder, and P. J. Tavner,Comparison of direct-drive and geared generator concepts for windturbines, IEEE Trans. Energy Convers., vol. 21, no. 3, pp. 725733,Sep. 2006.

[4] T. F. Chan and L. L. Lai, Permanent-magnet machines for distributed generation: A review, in Proc. 2007 IEEE Power Engineering Annual Meeting, pp. 16.

[5] Design Limits and Solutions for Very Large Wind Turbines, March 2011. UpWind Project. [Online]. http://www.ewea.org/fileadmin/ewea_documents /documents/upwind/21895_UpWind_Report_low_web.pdf

[6] X. Yang, D. Patterson, J. Hudgins Permanent magnet generator design and control for large wind turbines, in Proc. IEEE Power Electronics and Machines in Wind Applications (PEMWA), July 2012

[7] K. Ahsanullah, R. Dutta and M. F. Rahman, Review of PM generator designs for direct-drive wind turbines, in Proc. IEEE 22nd Australasian Universities Power Engineering Conference (AUPEC), September 2012

[8] Juan Manuel Carrasco, Leopoldo Garcia Franquelo, Jan T. Bialasiewicz, Eduardo Galvn, C. Ramn, Portillo Guisado, Ma. ngeles Martn Prats, Jose Ignacio Leon, Narciso Moreno-Alfonso, Power Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey, IEEE Transactions on Industrial Electronics, Vol. 53, No. 4,pp. 1002-1016, August 2006.

[9] Zhe Chen, M. Josep Guerrero, Frede Blaabjerg, A Review of the State of the Art of Power Electronics for Wind Turbines, IEEE Transactions on Power Electronics, Vol. 24, no. 8, pp. 1859-1875, August 2009.

[10] M. Arifujjaman, L. Chang, Reliability comparison of power electronic converters used in grid-connected wind energy conversion system, in Proc. 3rd IEEE Symposium on Power Electronics for Distributed Generation Systems (PEDG), 2012

[11] T. de Freitas, P. Menegz, D. Simonetti, Converter topologies for permanent magnetic synchronous generator on wind energy conversion system, in Proc. IEEE Brazilian Power Electronics Conference (COBEP), September 2011

[12] Orlando A,LiserreM, MastromauroRA, Dell'AquilaA. ASurvey of Control Issues in PMSG Based Small Wind-Turbine Systems. IEEETrans Ind Inform 2013;9(3):121121.

[13] RajaeiA, Mohamadian M,YazdianVarjani A.Vienna-Rectifier-Based Direct Torque Control of PMSG for Wind Energy Application IEEE Trans. Ind. Elec- tron 2013;60(7):291929.

[14] Zhang Shao,TsengKing-Jet, VilathgamuwaDM ,DuyNguyen-Trong, Wang Xiao-Yu. Design of a Robust Grid Interface System for PMSG-Based Wind Turbine Generators .IEEE Trans Indus Electron 2011;58(1):31628.

[15] IovF.,Ciobotaru M.,BlaabjergF. Power electronics control of wind energy in distributed power systems.In:Proceedings of the11thInternational Conference on Optimization of Electrical and ElectronicEquipment.OPTIM2008. (Brasov,Romania); May2008. p.XXIXXLIV.

[16] Jain B,JainS ,NemaRK. Control strategies of grid interfaced wind energy conversion system: Anoverview .Renewable Sustain Energy Rev. 2015;47:983 96.

[17] YaramasuV,BinWu,SenPC,KouroS,NarimaniM.High power wind energy conversion systems: State-of-the-art and emerging technologies.ProcIEEE 2015;103(5):74088.

[18] Abbes M,Belhadj J,ABABennani. Design and control of a direct drive wind turbine equipped with multilevel converters.Renew Energy2010;35:936 45.

[19] KeMa, LiserreM, BlaabjergF. Comparison of multi-MW converters considering thedetermining factors in wind power application In:Proceedings of IEEE Energy Conversion Congress and Exposition(ECCE).(Denver,Color- ado, USA); September2013. p.47544761.

[20] FaulstichA.,StinkeJ.K.,WittwerF.Medium voltage converter for permanent magnet wind power generators upto 5MW.In:Proceedings of the2005 European Conference on Power Electronics and Applications.(Dresden, Germany).2005.

[21] Shu Z,HeX, WangZ, QiuD, JingY Voltage balancing approaches for diode- clamped multilevel converters using auxiliary capacitor-based circuits .IEEE Trans. Power Electronic 2013;28(5):211124.

[22] P. Wheeler, Matrix converters: a technology review , IEEE Trans. Ind. Electron., vol. 49, no. 2, pp. 276-288, April 2002

[23] J.W. Kolar, Novel three-phase AC-DC-AC sparse matrix converter IEEE Trans. Power Electron., vol. 22, no. 5, pp. 1649-1661, September 2007

[24] J. W. Kolar, T. Friedli, J. Rodriguez and P. Wheeler, Review of three-phase PWM AC-AC converter topologies, IEEE Trans. Ind. Electron., vol. 58, no. 11, pp. 4988-5006, November 2011

[25] Pankaj Bisht, Akhilesh Dobhal, Modeling, Design and Analysis of Three-Phase Matrix Converter for Different Loads, International Journal Of Engineering Research & Technology (IJERT)ISSN: 2278-0181 Vol. 3 Issue 9, September- 2014

[26] Ibrahim A.M. Abdel-Halim, Hamed G. Hamed, and Ahmed M. Hassan, Modeling and Simulation of a Matrix Converter/Inductive Load System. International Journal of Electrical And Power Engineering, 5: 144-14,2011

[27] Sagar. S. Pawar, Design of Three-Phase Matrix Converter AC-AC Utility Power Supply using SPWM Technique, Int. Journal Of Engineering Research And Applications ISSN: 2248-9622, Vol. 5, Issue 4, (Part -7), Pp.125-128, April 2015

[28] J. Rodriguez, M. Rivera, J. W. Kolar, P. W. Wheeler, A Review of Control and Modulation Methods for Matrix Converters, IEEE Transactions On Industrial Electronics Vol. 59, No. 1, Pp. 58-70, January 2012.

[29] Ruzlaini Ghoni, Ahmed N. Abdalla, Analysis And Mathematical Modelling Of Space Vector Modulated Direct Controlled Matrix Converter, Journal Of Theoretical And Applied Information Technology, Vol21 No1/5, 2005 3 Issue 9, September-2014

[30] Johann W. Kolar, Frank Schafmeister, Simon D. Round, and Hans Ertl, Novel Three-Phase AcAc Sparse Matrix Converters, IEEE Transactions On Power Electronics, Vol. 22, No. 5, September 2007

[31] Slootweg JG, de Haan SWH,Polinder H, Kiling WL General Model for representing Variable Speed Wind Turbine in Power

Dynamic Smulations IEEE Trans Power Sys 2003,18(1),144-151

[32] Ong CM. Dynamic Simulationof Electric Machinery Upper Saddle River, Prentice-Hall:1988,P.259-350

[33] Senjyu T, Tamaki S, Urasaki N, Uezato K Wind velocity and position sensorless operation for PMSG wing generators In.Proc. fifth Int. Conf. on Power Electronics and Drives Systems, Singapore;2003,PP787-792.

[34] Wtanable EH, Stephen RM,Aredes M. New Concepts of instantaneous active and reactive power in electrical systems with generic loads IEEE Trans Power Deli 1993;8(2):697-703.

[35] L. Huber and D. Borojevic, Space vector modulated three phase to three phase matrix converter with input power factor correction, IEEE Trans.Ind. Applicat., vol. 31, pp. 12341246, Nov./Dec. 1995.

[36] Melicio R, Mendes VMF, Catalao JPS. Modeling and Simulation of a wind enrgy system: Matrix verus Multilevel Converters In.Proc.14th IEEE Mediterr. Electrotechnical Conf., Ajaccio, France: 2008.604-609.

[37] Eldien M. M. Hassan, Mahmoud A. Sayed, Essam E. M. Mohamed,Three-phase Matrix Converter Applied to Wind Energy Conversion System for Wind Speed Estimation, International Journal of Sustainable and Green Energy -4(3): 117-124, May 2015

[38] Naggar H. Saad, Ahmed A. El-Sattar, Mohamed I. Marei, A Current Controlled Matrix Converter For Wind Energy Conversion systems Based On Permanent Magnet Synchronous Generator, Journal of Electrical Systems and Information Technology 3: 108118, 2016.

[39] Wheeler and D. Grant, Optimized input filter design and low loss switching techniques for a practical matrix converter, Proc. Inst. Elect. Eng., pt. B, vol. 144, no. 1, pp. 5360, Jan. 1997.

[40] X. Chen, X. Chen, and Q. Wei, The improvement of space vector modulationstrategy for matrix converter under unbalanced input voltages, Trans. China Electrotech. Soc., vol. 15, no. 2, pp. 7982, Apr. 2000.