IJIRST –International Journal for Innovative Research in Science & Technology| Volume 3 | Issue 01 | June 2016
ISSN (online): 2349-6010

A New Advanced Controlling Technique of PMSWG with Matrix Convertor

Daunde Poonam Dilip
M.E Student
SND College of Engineering & RC, Yeola. Savitribai Phule University of Pune, India

Hurpade Santosh N
M. Tech Student
RKDF College of Engineering, Bhopal. RGPV University, India

Abstract

In this paper, matrix converter is used to control the reactive power at variable speed permanent-magnet synchronous wind generator and improving the performance. The frequency and amplitude of induced voltage also changes due to variation of wind speed. A matrix convertor is used to overcome this problem. A generalized modulation technique based on singular value decomposition of the modulation matrix is used to model different modulation techniques and investigate their corresponding input reactive power capability. A new control method is proposed for the matrix converter based on this modulation technique, which uses active and reactive parts of the generator current to increase the control capability of the grid-side reactive current compared to conventional modulation methods. A new control structure is also proposed which can control the matrix converter and generator reactive current to improve the grid-side maximum achievable reactive power for all wind speeds and power conditions.

Keywords: Matrix converter, permanent-magnet synchronous generator (PMSG), singular value decomposition (SVD) modulation, variable-speed wind generator

---

I. INTRODUCTION

In recent few years the power generation through wind-turbine has been increased worldwide drastically. Particular interest has been increased on distributed generation through small wind-turbines because of their advantages like: lower impact on the landscape, lower noise level, grid codes and national laws imposing simpler grid connection and higher feed-in tariffs and capability to work in island-mode for isolated communities.

Variable speed wind energy conversion systems are now a day most popular because these are capable of extracting higher power. In double fed induction generators speed of generator should be maintained within a certain limit and that is achieved by connecting the turbine and generator through gear box which sometimes suffers from faults and hence its reliability gets affected and also it increases the maintenance of the system. But in case of permanent magnet alternator the turbine and the alternator can be coupled directly for variable speed operation. The elimination of gear box arrangement increases the reliability of the overall system. Permanent magnet alternator does not require any reactive power for its excitation.

Hence it has a higher power factor and efficiency than other machines. PMSG can run at lower speed with higher number of pole without compromising the efficiency and hence gear box can be eliminated. But the challenge in integrating the turbine generator set with grid or micro grid or islanded grid is the variable frequency and amplitude of induced voltage due to variation of wind speed. This problem can be overcome by either back-to-back converter or matrix converter. In back to back converter the induced voltage of variable amplitude and frequency is first converted to dc through a converter and again converted back to ac voltage of desired amplitude and frequency through an inverter.

The generator side quantities such as generator speed and torque are controlled by the converter near the generator so that maximum power can be achieved from wind and the converter near the grid controls the grid side quantities such as voltage, active and reactive power flow to grid, improves the stability of the system and quality of power and maintains the dc link capacitor voltage at constant value.

A matrix converter is a direct ac to ac converter that can convert ac voltage of variable amplitude and variable frequency to ac voltage of fixed amplitude and fixed frequency which does not require any energy storage element like capacitor or battery storage. In the absence of bulky energy storing element, reduces the size, cost and weight of the converter and also improves the reliability of the system. Matrix converter has some drawbacks like large number of switches, complex modulation technique and four step switching of bidirectional switches. These problems are solved by high speed digital signal processors with great performance [6]. Hence now matrix converter with small packed module has become a suitable alternative to the conventional converter for it advantages like higher reliability, sinusoidal voltage and current, improved power factor. Thus the combination of matrix converter and PMSG with multiple poles gives greater performance for low power local load and micro grid applications.

Unlike conventional converter, both the generator side quantities as well as the grid side quantities are controlled simultaneously in matrix converter. As it does not require any reactive power, this reactive power can be used to feed local load

to control voltage at grid or micro grid. Different modulation techniques are there for matrix converter such as Alesina and Venturini method, space vector modulation (SVM) method and singular value decomposition (SVD) modulation technique.
The block diagram representation of PMSG connected to load through matrix converter is shown in Figure 1.

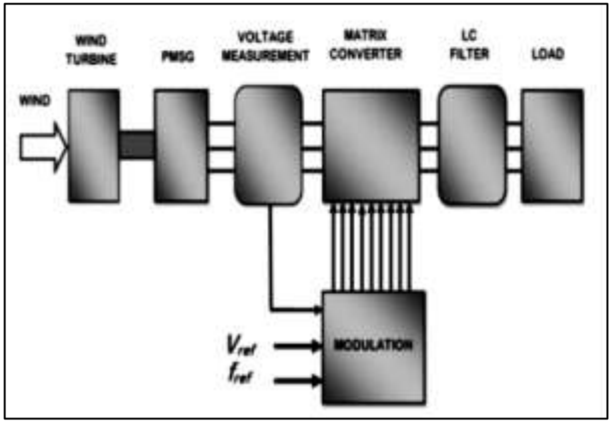


Fig. 1: Block diagram of PMSWG with matrix convertor

II. PM SYNCHRONOUS GENERATOR

Different type of generators, such as dc generator, induction generator and synchronous generator, can be used to extract electrical energy from wind by connecting it with wind turbine. The main advantage of synchronous generator is that it does not draw reactive power from grid and its output reactive power can be controlled by its field excitation control and the reactive power can be used for reactive power compensation or to improve voltage profile of power system. Permanent magnet synchronous generators have some advantages over electrically excited synchronous generator are:

1) It has higher efficiency.
2) Power loss is less as there is no requirement of dc excitation.
3) In absence of field current, the thermal stability of PMSG increases.
4) No requirement of slip ring and brushes resulting in higher reliability and less maintenance.
5) High power to weight ratio.

However, permanent magnet synchronous generators have some disadvantages like:

1) Cost of the material for permanent magnet is high.
2) Manufacturing is difficult.
3) At higher temperature the permanent magnet gets demagnetized.

Permanent magnet synchronous generators are more attracting due to the improvement of magnetic characteristics and the reduction of the cost of permanent magnet. A permanent magnet synchronous generator with suitable converter for variable speed operation gives very good performance. PMSGs are the most suitable option for wind power generation at the offshore due to the improvement of PM, reduction of the PM material and the power electronics converters.

III. MATRIX CONVERTOR

Three-phase matrix converter is used for the system. In a matrix converter, the input and output phases are related to each other by a matrix of bidirectional switches such that it is possible to connect any phase at the input to any phase at the output Therefore, the controllable output voltage is synthesized from discontinuous parts of the input voltage source, and the input current is synthesized from discontinuous parts of the output current source.

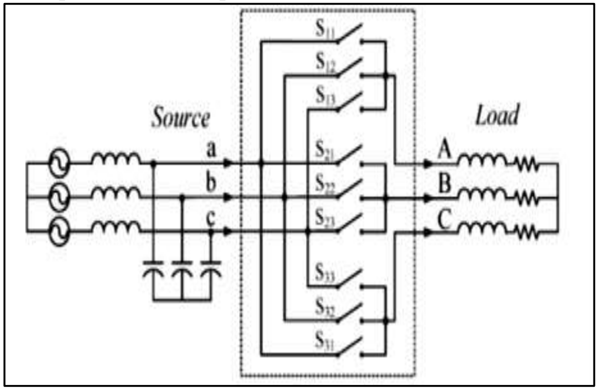


Fig. 2: three phase to three phase matrix convertor

Matrix converter is a converter that can convert a voltage waveform of fixed frequency and fixed amplitude to a voltage waveform of desired amplitude and frequency or vice versa and it does not require any dc link or energy storing element like conventional back-to-back converter, hence results a converter of smaller size, cost, weight and higher reliability.

The input and output voltage and current of matrix converter are related to each other through an array of bidirectional switches of IGBT that are arranged in a matrix form such that any phase at the output can be generated from any phase of input.

For m*n phase matrix converter the number of bidirectional switches required are m*n, where m is the number of phases at the input side and n is the number of phases at output side of matrix converter. Hence three phases to three phase matrix converter total 9 bidirectional switches are required.

The output voltage and current of matrix converter are obtained from the input voltage and current of matrix converter and hence the relationship between the output voltage and current of matrix converter and the input voltage and current of matrix converter are related to each other by the following relation:

$$V_{o,ABC} = SV_{i,abc}$$

$$T_{i,abc} = S^{T}\,T_{o,ABC}$$

$$S = \begin{pmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{pmatrix}$$

$$\begin{cases} S_{kj} \mathcal{E} \{ 0,1) \\ S_{k1} + S_{k2} + S_{k3} = 1 \end{cases} \quad k\,, j = 1,2,3$$

$$V_{i,abc} = \begin{pmatrix} v_{ia} \\ v_{ib} \\ v_{ic} \end{pmatrix}, \qquad I_{i,abc} = \begin{pmatrix} i_{ia} \\ i_{ib} \\ i_{ic} \end{pmatrix}$$

$$V_{o,\ ABC} = \begin{pmatrix} v_{oA} \\ v_{oB} \\ v_{oC} \end{pmatrix},\ I_{o,ABC} = \begin{pmatrix} i_{oA} \\ i_{oB} \\ i_{oC} \end{pmatrix} \qquad (1)$$

Switching function of matrix S can be developed by the equation 3 and 4 if the desired output voltage and the input current are known.

Matrix converter is a combination of bidirectional switches arranged in matrix form that can convert a voltage waveform of fixed frequency and fixed amplitude to a voltage waveform of desired amplitude and frequency or vice versa and does not require any dc link or energy storing element. The working principle of matrix converter is to calculate the duty cycle and accordingly produce switching pulses of very high frequency for the bidirectional switches to obtain the output voltage of desired low frequency.

Where and are the output phase voltages and currents, respectively; and are the input phase voltages and currents; and is the switching function of switch.

Lack of an energy storage component in the structure of a matrix converter leads to an equality between the input–output active power, i.e.,

$$P_i = V^{T}_{i,abc}.\,I_{i,abc} = V^{T}_{o,ABC}.\,I_{o,ABC} = P_o \qquad (2)$$

A MATRIX converter is a direct ac/ac frequency converter which does not require any energy storage element. Lack of bulky reactive components in the structure of this all silicon-made converter results in reduced size and improved reliability compared to conventional multistage ac/dc/ac frequency converters. Fabrication of low-cost and high-power switches and a variety of high-speed and high-performance digital signal processors (DSPs) have almost solved some of the matrix converter drawbacks, such as complicated modulation, four-step switching process of bidirectional switches, and the use of a large number of switches . Therefore, its superior benefits, such as sinusoidal output voltage and input current, controllable input power factor, high reliability, as well as a small and packed structure make it a suitable alternative to back-to–back converters. One of the recent applications of matrix converters is the grid connection of variable-speed wind generators. Variable-speed permanent-magnet synchronous (PMS) wind generators are used in low-power applications.

The use of a matrix converter with a multi pole PMSG leads to a gearless, compact, and reliable structure with little maintenance which is superior for low-power micro grids, home, and local applications. The wind generator frequency converter should control the generator-side quantities, such as generator torque and speed, to achieve maximum power from the wind turbine, and the grid-side quantities such as grid-side reactive power and voltage to improve the system stability and power quality (PQ). Unlike conventional back-to–back converters in which a huge dc-link capacitor makes the control of the generator and grid-side converters nearly independent, a matrix converter controls the generator and grid-side quantities simultaneously. Therefore, the grid-side reactive power of a matrix converter is limited by the converter voltage gain and the generator-side active or reactive power. One necessary feature for all generators and distributed generators (DGs) connecting to a grid or a micro grid is the reactive power control capability.

IV. A SVD MODULATION TECHNIQUE

Different modulation techniques are proposed for a matrix converter in the literature [21]–[23]. A more complete modulation technique based on SVD decomposition of a modulation matrix is proposed in [24]. Other modulation methods of a matrix converter can be deduced from this SVD modulation technique. The technique proposed in [24] has more relaxed constraints compared to other methods. The SVD modulation method is a duty cycle method in which the modulation matrix M, which is defined in (3), is directly constructed from the known input voltage and output current and desired output voltage and input current, i.e,

$$M = \mathrm{Ave}_{Te}\{S\} = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix}$$

$$\begin{cases} 0 \le m_{kj} \le 1 \\ m_{k1} + m_{k2} + m_{k3} = 1 \end{cases} \quad k, j = 1,2,3 \qquad (3)$$

Where is the average of over a switching period. To represent the input and output voltages and currents in space vector forms, all quantities of the input and output of the matrix converter are transferred from the reference frame to the reference frame by the modified Clarke transformation of (4). Therefore, the new modulation matrix is obtained as

$$\begin{aligned} V_{o,\alpha\beta0} &= M_{\alpha\beta0} V_{i,\alpha\beta0} \\ I_{i,\alpha\beta0} &= M^{T}_{\alpha\beta0} T_{0,\alpha\beta0} \\ M_{\alpha\beta0} &= K M_{abc} K^{T} \end{aligned}$$

$$K = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

$$K^{-1} = K^{T} \text{ or } KK^{T} = I \qquad (4)$$

A. Flow chart of modulation method:

Space vector pulse width modulation method has been used for the modulation of the matrix to generate the pulses for the bidirectional switches of the matrix converter. The flow chart of the modulation method described above is shown in Figure 4.

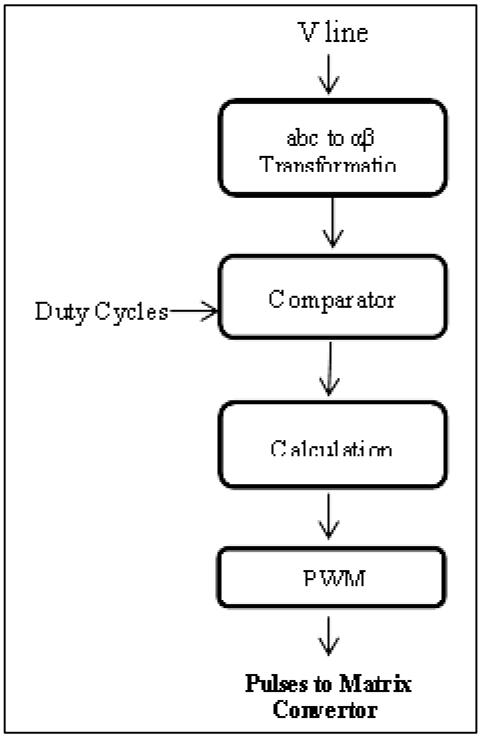


Fig. 3: Flow chart of matrix converter modulation method.

B. *Proposed scheme:*

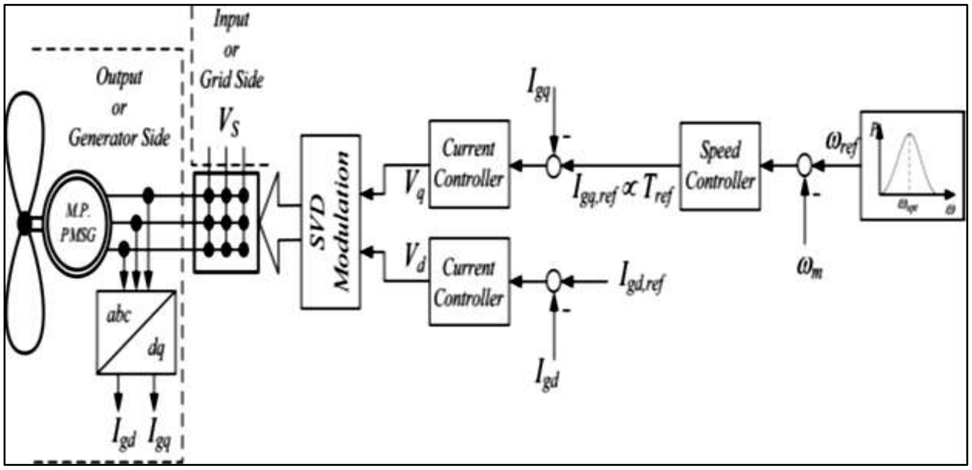


Fig. 4: Simplified control block diagram of PMSWG

- Strategy 1: synthesizing from the reactive part of the output current (i.e. Qiq)
- Strategy 2: synthesizing from the active part of the output current (i.e. Qid);
- Strategy 3: Synthesizing from the active and reactive parts of the output current (i.e. Qiq Qid).

$$\begin{aligned} Q_i &= \mathcal{I}m\,\{S_i\} = V_{iq}\,I_{id} - V_{id}\,I_{iq} \\ &= q_d\,V_{iq}\,I_{od} - q_{dq}\,V_{iq}\,I_{oq} \\ &= Q_{id} + Q_{iq} \qquad (5) \end{aligned}$$

Where Si is the input complex power, Qid is the part of the input reactive power made from Iod, and Qiq is the part of the input reactive power made from Ioq. Therefore, the above three different strategies of synthesizing the input reactive power of a matrix converter can be investigated.

C. *Synthesizing From the Reactive Part of the Output Current*

If in the SVD modulation technique, θi is set to the input voltage phase angle as shown in Fig.5. the output voltages will also be aligned with the d–axis of the output synchronous reference frame which is de fined by θ0, and the generalized modulation technique will be the same as the Alesina and Venturini modulation technique with a more relaxed limitation on dq and qq Fig.5. Modelling the SVM modulation method by the SVD modulation technique.

In this case, controls the voltage gain and controls the reactive current gain of the matrix converter. Therefore, the input reactive power is limited by the voltage gain and the output reactive power as given by

$$\begin{cases} V_0 = V_{0d} = q_d V_i \\ I_{id} = q_d I_{0d} \\ I_{iq} = q_q I_{0q} \end{cases} \Rightarrow \begin{cases} Q_i = Q_{iq} = \dfrac{q_q}{q_d}\,Q_0 \\ q_d = G_v = \dfrac{V_0}{V_i} \end{cases}$$

$$(5) \Rightarrow |Q_i| \le \frac{1 - q_d}{q_d}\,|Q_0| = \frac{1 - G_v}{G_v}\,|Q_0| \qquad (6)$$

Where the voltage is gain of the matrix converter and is the output reactive power.

D. *Synthesizing from the active Part of the Output Current:*

If qq is set to zero, as shown in Fig. 5. The output voltage will be aligned with the d–axis of the output reference frame and the input current will be aligned with the d–axis of the input reference frame. Therefore, the SVD modulation technique will be the same as the SVM modulation technique. In this case, qd controls the voltage gain and φi controls the input reactive current of the matrix converter.

$$\left.\begin{aligned} &\begin{cases} V_0 = q_d V_{id} = q_d V_i \cos \emptyset_i \\ I_i = q_d I_{0d} = q_d I_0 \cos \emptyset_0 \end{cases} \\ &\Rightarrow Q_i = Q_{id} = V_i I_i \sin \emptyset_i = P_i \tan \emptyset_i \\ &\Rightarrow G_v = q_d \cos \emptyset_i \le \frac{\sqrt{3}}{2} \cos \emptyset_i \Rightarrow \tan \emptyset_i \le \frac{\sqrt{\frac{3}{4} - G_v^2}}{G_v} \end{aligned}\right\}$$

$$\Rightarrow |Q_i| \le \frac{\sqrt{\frac{3}{4} - G_v^2}}{G_v}\,|P_0| \qquad (7)$$

Where, Po is the output active power

E. Synthesizing from both the active Part and Reactive part of the Output Current:

The two previous strategies do not yield the full capability of a matrix converter. To achieve maximum possible input reactive power, both active and reactive parts of the output current can be used to synthesize the input reactive current. To increase the maximum achievable input reactive current in a matrix converter for a specific output power, its input current should be maximized. Since M^T transforms I0 from the output space onto the input space, to maximize |Ii|, the free parameter θi must be chosen such that I0 is located as close as possible to the direction over which the M^T gain is maximum.

$$\max|I_i| = \underbrace{\max}_{M}\{|M^T I_0|\}$$

$$\text{Subject to}: \begin{cases} V_0 = MV_i \\ |q_d|, |q_q| \le \dfrac{\sqrt{3}}{2} \\ G_v \le k = |q_d| + |q_q| \le 1 \end{cases} \qquad (8)$$

Where is a positive parameter which is used to vary the matrix converter constraint? Can be changed from its minimum possible value (i.e.,) to its maximum possible value (i.e.,) to change the maximum current gain of the matrix converter (i.e.,) and control its input reactive power.

This optimization problem can be solved with different solvers. However, in this section, a closed form formulation is derived to simplify computations of the control system. It is proved in Appendix A that if , , and are chosen as given in (16), the input current gain of the matrix converter will be equal to its maximum achievable value for a given parameter , voltage gain and output power factor.

The three methods of controlling the input reactive power of a matrix converter described in the previous section can be used to control the reactive power of a PMS wind generator. A gearless multi pole PMS wind generator, which is connected to the output of a matrix converter, is simulated to compare the improvement in the matrix converter input or grid-side reactive power using the proposed strategy. The control block diagram of the system is shown in Fig. 9, and its parameters are listed in Table I. The simulations are performed using PSCAD/EMTDC software. To control the generator torque and speed, generator quantities are transferred onto the synchronous reference frame such that the rotor flux is aligned with the –axis of the reference frame. Therefore, will become proportional to the generator torque, and can be varied to control the generator output reactive power. Usually, is set to zero to minimize the generator current and losses. However, in this section, the effect of on the input reactive power is also studied, and a new control structure is proposed which can control the generator reactive power to improve the reactive power capability of the system.

F. Frequency control of matrix converter

50 Hz is taken as the reference frequency for the modulation of matrix converter.

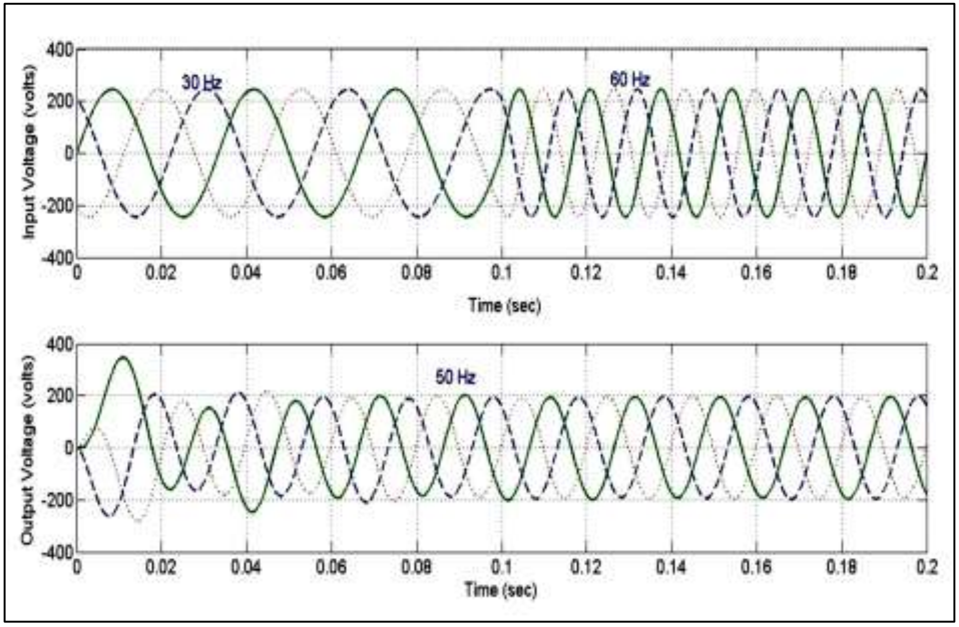


Fig. 6: Output voltage of matrix converter for input voltage of different frequencies.

The matrix converter is connected to controllable voltage source and voltage of frequency 30 Hz up to 0.1 sec and frequency of is 60 Hz from 0.1 sec to 0.2 sec are given as input signal to the matrix converter and the output voltage of matrix converter is of 50 Hz for the entire time.

G. *Voltage control of matrix converter:*

220 V (rms) has been taken as the reference voltage for the matrix converter modulation.

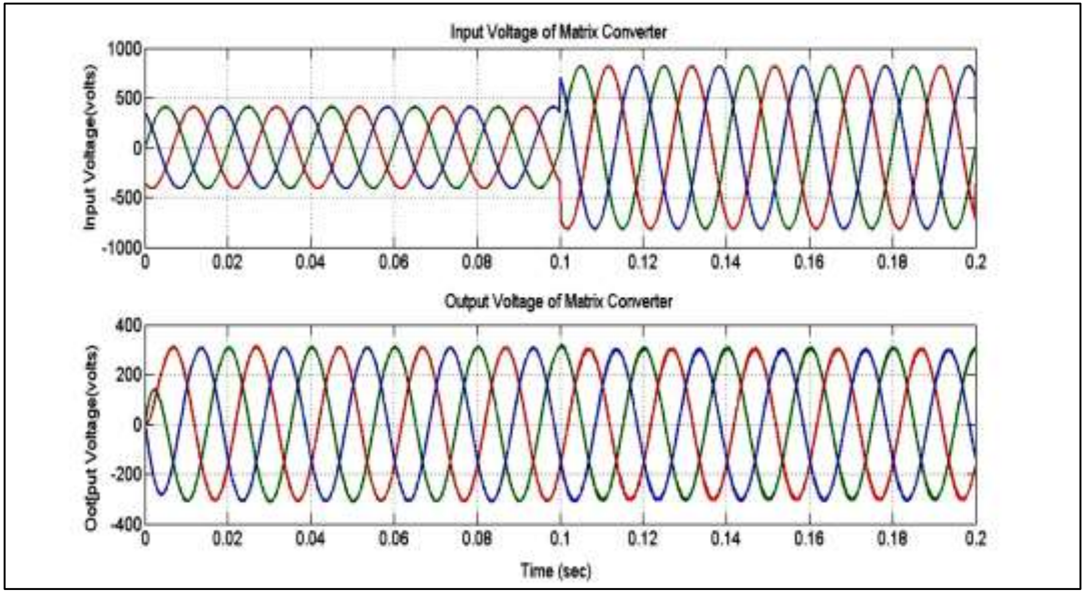
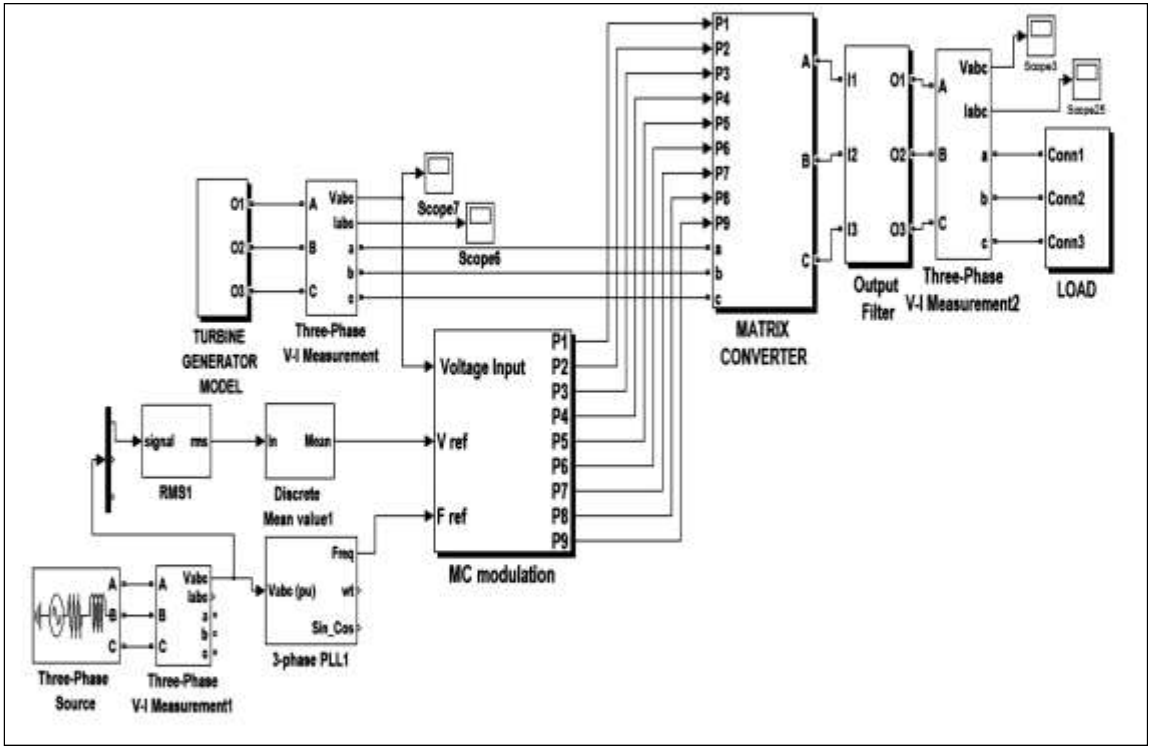


Fig. 7: Output of matrix converter for different input voltage at different time.

Closed loop control of voltage is shown in Figure 6. The magnitude of input voltage is 280 V (rms) up to 0.1 sec and 530 V (rms) between 0.1 sec to 0.2 sec is given to the matrix converter through controllable voltage source and the output voltage of matrix converter is 220 V (rms).

V. SIMULATION

Simulink diagram of three phase load connected to the wind turbine coupled permanent magnet synchronous generator through matrix converter is shown in Figure 7. Here the phase voltages of generated output of turbine generator set is measured through three phase measurement unit and the reference voltage and frequency are taken from grid. From his actual voltage and reference signals switching pulses are generated through PWM modulation method and the
Pulses are given to the matrix converter



VI. RESULTS

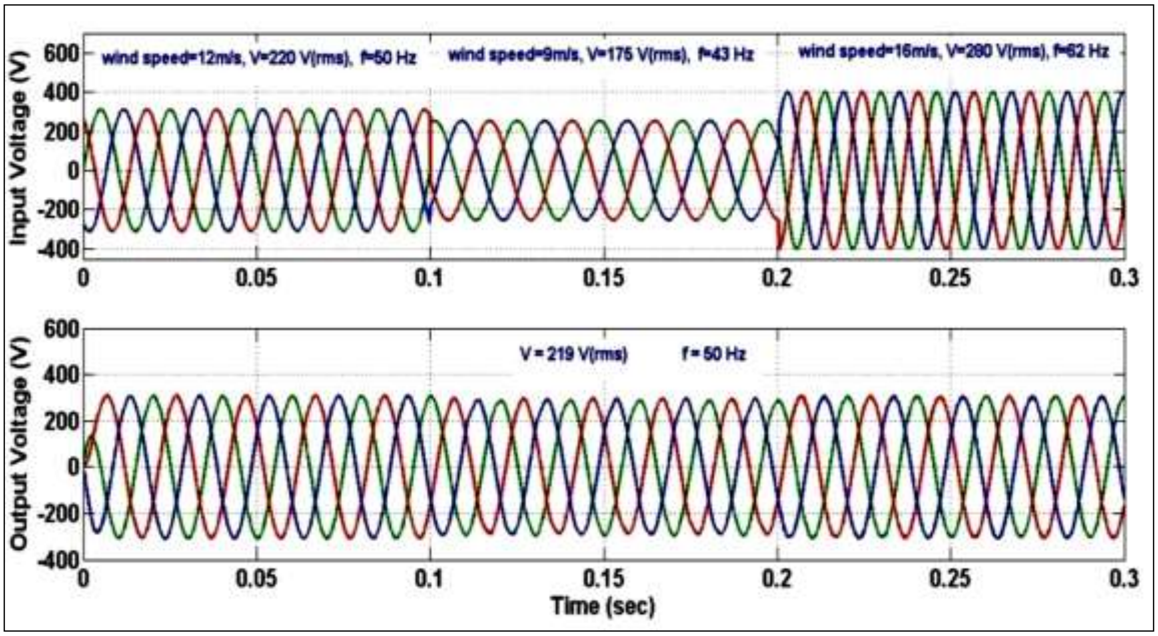


Fig. 8: Input and output voltage of MC with filter for different wind speed.

Different wind speeds are applied to the turbine of the turbine generator model. At the wind speed of 12 m/sec, the voltage is 220 V (rms) and the frequency is 50 Hz and at the wind speed of 9 m/s, the voltage is 175 V (rms) and the frequency is 43 Hz and at the wind speed of 16 m/sec the voltage is 280 V (rms) and frequency is 62 Hz.. Connecting this turbine generator model to matrix converter the voltage is stabilized to 219 V (rms) and frequency to 50 Hz irrespective of the input voltage and frequency as shown in Figure 8.

A. *Performance of matrix converter with variable wind speed:*

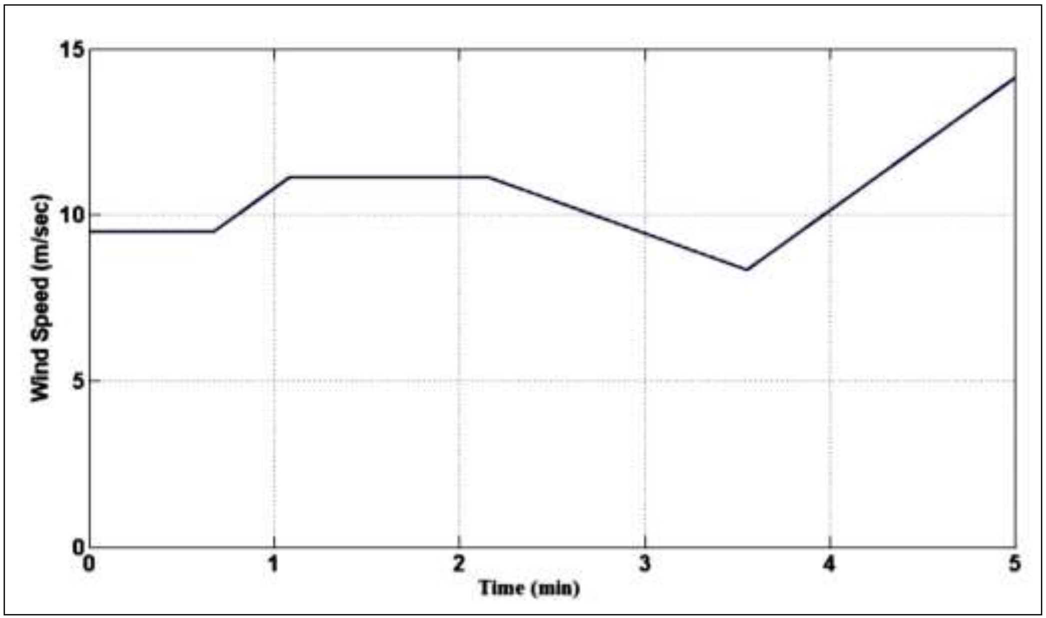


Fig. 9: Variable wind speed

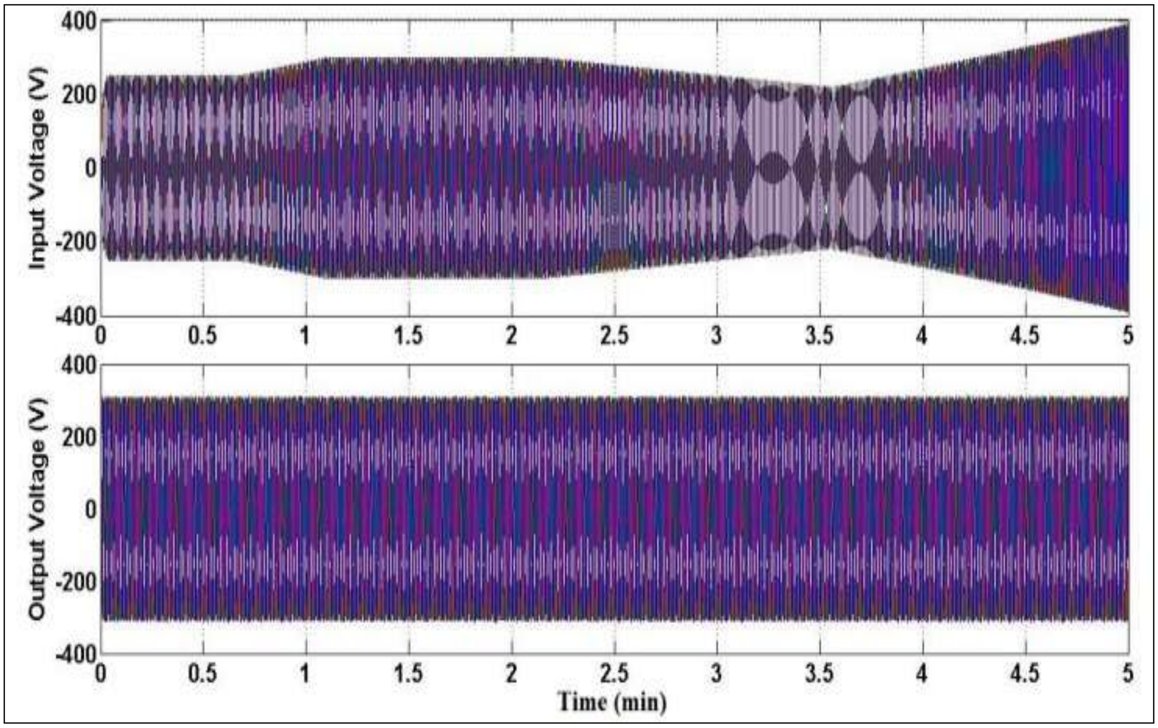


Fig. 10: Input and output voltage of Matrix Converter.

The wind speed of time 5 min has been taken as shown in Figure 9 and given as input to the turbine of turbine generator model. As the wind speed is varying the generated voltage of PMSG is also varying as shown in Figure 10.

The generated output voltage of PMSG is given as input to the matrix converter and the output voltage at the output or load side of matrix converter is of fixed amplitude and frequency at rated values which is fed to the three phase load as shown in Figure 10

VII. CONCLUSION

In this report, a new control strategy is proposed to increase the maximum achievable grid-side reactive power of a matrix converter-fed PMS wind generator. Different methods for controlling a matrix converter input reactive power are investigated. It is shown that in some modulation methods, the grid-side reactive current is made from the reactive part of the generator-side current. In other modulation techniques, the grid-side reactive current is made from the active part of the generator-side current. In the proposed method, which is based on a generalized SVD modulation method, the grid-side reactive current is made from both active and reactive parts of the generator-side current. In existing strategies, a decrease in the generator speed and output active and reactive power will decrease the grid-side reactive power capability. A new control structure is proposed which uses the free capacity of the generator reactive power to increase the maximum achievable grid-side reactive power. Simulation results for a case study show an increase in the grid side reactive power at all wind speeds if the proposed method is employed.

REFERENCES

[1] ”Reactive Power Control of Permanent-Magnet Synchronous Wind Generator With Matrix Converter” Hossein Hojabri, Hossein Mokhtari, Member, IEEE, and Liuchen Chang, Senior Member, IEEE
[2] P. W.Wheeler, J. Rodríguez, J. C. Clare, L. Empringham, and A.Weinstein, “Matrix converters: A technology review,” IEEE Trans. Ind. Electron., vol. 49, no. 2, pp. 276–288, Apr. 2002.
[3] M. Chinchilla, S. Arnaltes, and J. C. Burgos, “Control of permanent magnet generators applied to variable-speed wind-energy systems connected to the grid,” IEEE Trans. Energy Convers., vol. 21, no. 1, pp. 130–135, Mar. 2006.
[4] ”Design and Simulation of Matrix Converter for Wind Turbine Coupled Permanent Magnet Synchronous Generator” by Priyabrata Nayak , KanhuCharan Patra , Pradeep Kumar Department of Electrical Engineering, NIT Calicut.
[5] P. W.Wheeler, J. Rodríguez, J. C. Clare, L. Empringham, and A. Weinstein “Matrix converters: A technology review,” IEEE Trans. Ind. Electron., vol. 49, no. 2, pp. 276–288, Apr. 2002.
[6] G. Yang and H. Li, “Application of a matrix converter for PMSG wind turbine generation system,” in Proc. Int. Conf. Clean Elect. Power, Jun. 9–11, 2009, pp. 619–623.
[7] M. E. Haque, K. M. Muttaqi, and M. Negnevitsky, "Control of a standalone variable speed wind turbine with a permanent magnet synchronous generator," in Proc. IEEE Power and Energy Society General Meeting, Jul. 2008, pp. 20-24.
[8] “Simulation of Power Control of a Wind Turbine Permanent Magnet Synchronous Generator System” Nantao Huang Marquette University.
[9] “Wind Energy Conversions Systems Performance Is Improved Using Integrated Matrix Converter Topology”by 1N.Prakash, 2Dr.Ranithottungal, 3B.Vaikundaselvan,4G.Jegan