Reactive Power Controlling Technique of PMSWG With Matrix Convertor

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Abstract

The reactive power is control by using Matrix converter 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 concept related to 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 the grid-side maximum achievable reactive power for all wind speeds and power conditions generator reactive current is improved.

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

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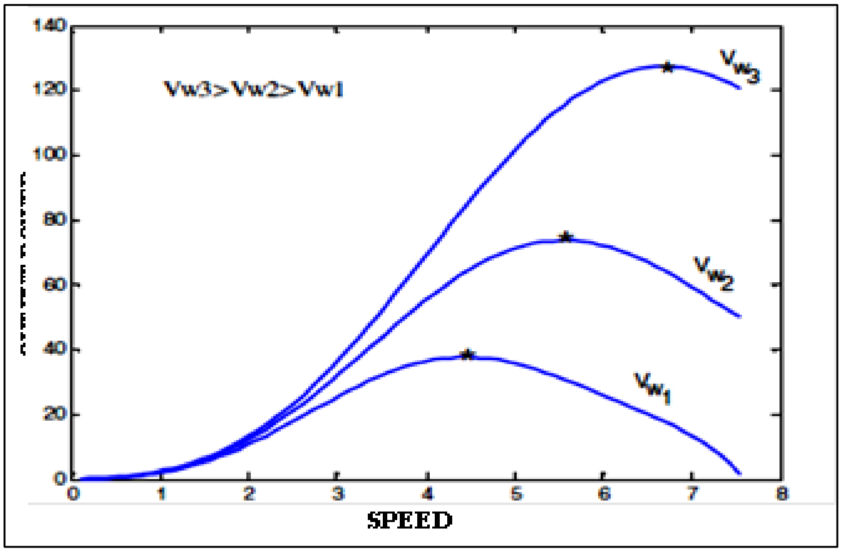
I. INTRODUCTION

The renewable energy sources are one of the biggest concerns of our times. High prices of oil and global warming make the fossil fuels less and less attractive solutions. Wind power is a very important renewable energy source. It is free and not polluter unlike the traditional fossil energy sources. It obtains clean energy from the kinetic energy of the wind by means of the wind turbine. The wind turbine transforms the kinetic wind energy into mechanical energy through the drive train and then into electrical energy by means of the generator. A growing proportion of energy is being met all over the world by electricity. This trend will be increasing day by day as the demand for electricity is increasing. This demand will have an increased impact on developing countries because their industrial progress will be based on modern technological developments in power generation.

During recent years, due to the depletion of fossil fuels and the environmental problems caused by the use of fossil fuels, renewable energy sources have become the most sought resources. Wind is one of the sources of renewable energy. Wind power is converted to electricity by wind turbine generators. Various technologies have been developed in wind energy conversion systems as the result of the effort to further improve wind energy conversion systems based on the permanent magnet generator.

Induction generators are most widely used in wind energy conversion systems. Although they are robust and inexpensive, the space-consuming capacitors are bulky and expensive. Induction generators with step-up gearboxes have low efficiency at low speeds. When compared to conventional generators, the permanent magnet generators have the advantages of being robust in construction, very compact in size, not requiring an additional power supply for magnetic field excitation, and requiring less maintenance. A variable-speed wind energy conversion system including a permanent magnet synchronous generator offers advantages over the constant-speed approach, such as maximum power-point tracking capability and reduced acoustic noise at lower wind speeds.

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.



Graph 1: wind characteristics

First, the large time scale variability describes the variations of the amount of wind from one year to another, or even over periods of decades or more. The second is the medium time scale, covering periods up to a year. These seasonal variations of the wind are much more predictable. Therefore, the suitability of a given site, in terms of wind variability, is usually assessed in terms of monthly variations, covering one year. The assessment is done by statistical analysis of long time (several years) measurements of wind speed.

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 Venturing 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.

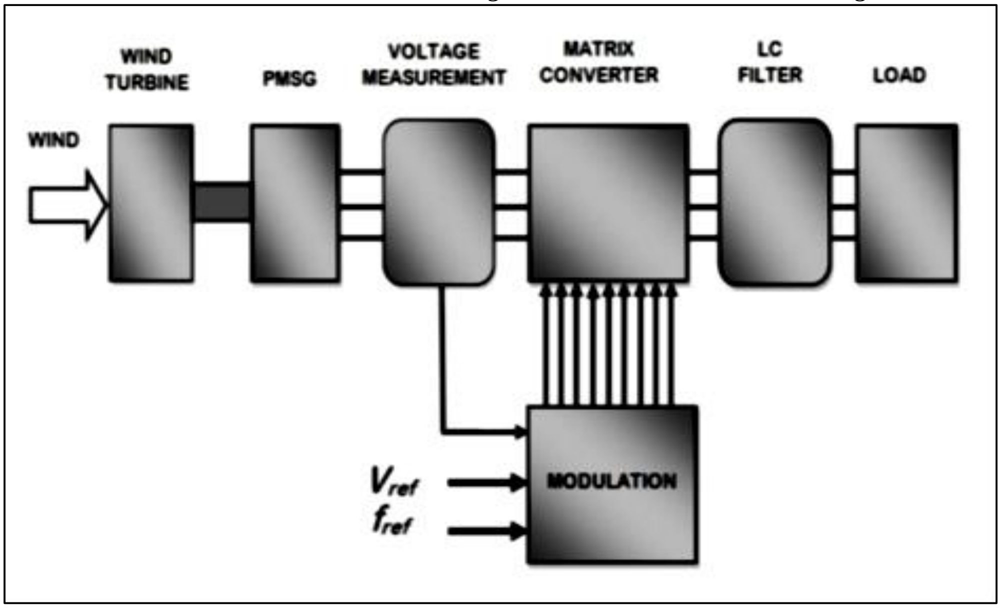


Fig. 1: Block diagram of PMSWG with matrix convertor

A. 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 off shore due to the improvement of PM, reduction of the PM material and the power electronics converters.

B. 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.

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.

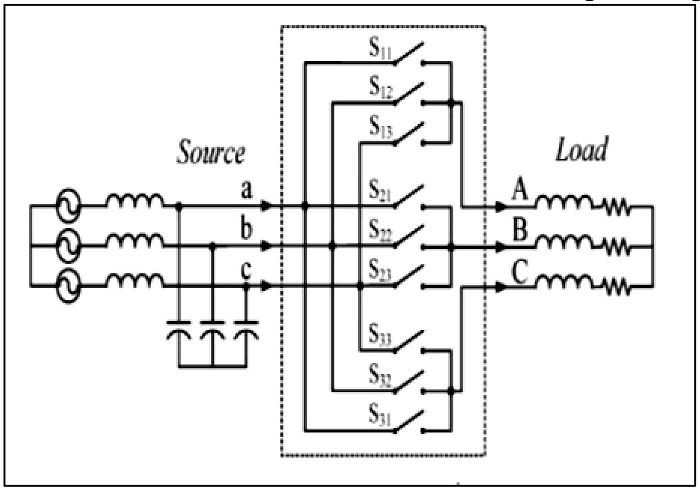


Fig. 2: three phase to three phase matrix convertor

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.

$$V_{o,ABC} = SV_{i,abc}$$
$$T_{i,abc} = S^{T} T_{o,ABC}$$
$$S = \begin{pmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{pmatrix}$$

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

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

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

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

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

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.

C. SVD Modulation Technique

Different modulation techniques are proposed for a matrix converter in the literature. A more complete modulation technique based on SVD decomposition of a modulation matrix is proposed in. Other modulation methods of a matrix converter can be deduced from this SVD modulation technique. The technique proposed in 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, is directly constructed from the known input voltage and output current and desired output voltage and input current, i.e

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

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

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. Therefore, the new modulation matrix is obtained as

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

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

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

D. 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.

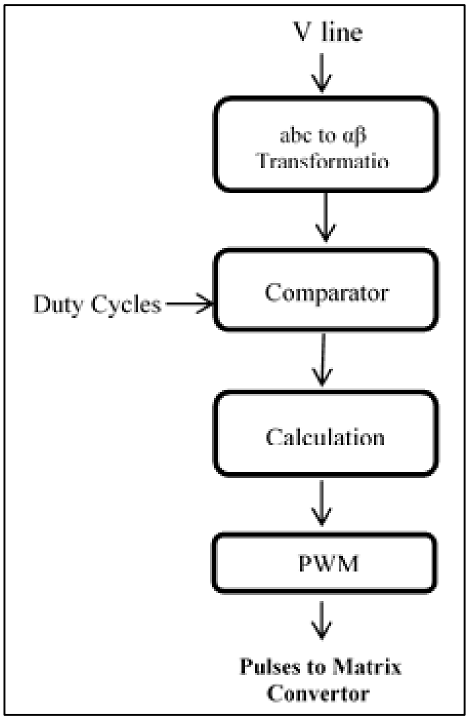


Fig. 3: Flow chart of matrix converter modulation method

E. Proposed Scheme

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

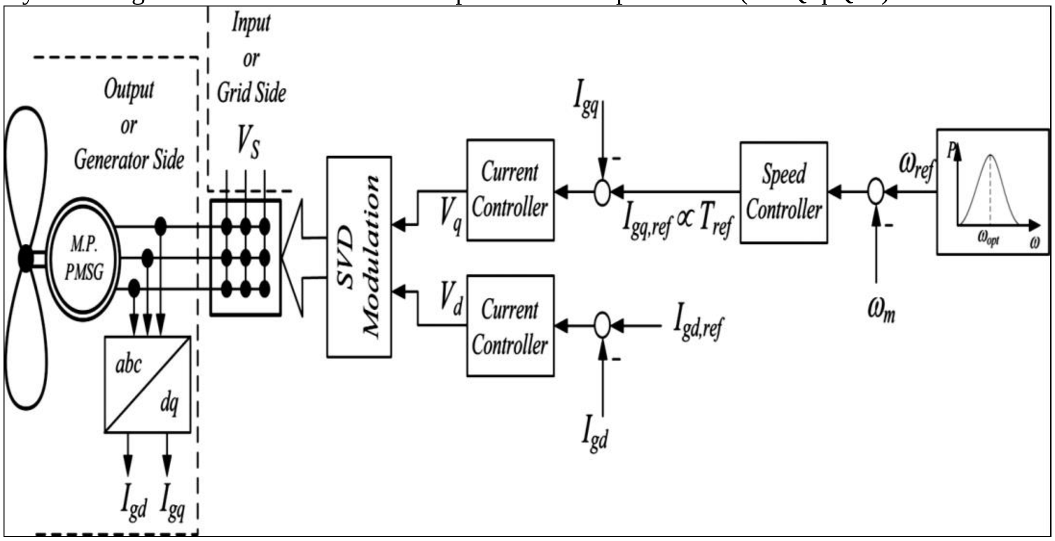


Fig. 4: Simplified control block diagram of PMSWG

$$Q_i = \mathcal{T}m\{S_i\} = V_{iq} I_{id} - V_{id} I_{iq} = q_d V_{iq} I_{od} - q_{dq} V_{iq} I_{oq} = Q_{id} + Q_{iq} \qquad (5)$$

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.

F. 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

$$\begin{cases} V_0 = V_{0d} = q_d V_i \\ I_{id} = q_d I_{0d} \\ I_{iq} = q_q I_{0q} \end{cases} \Rightarrow \begin{cases} Q_i = Q_{iq} = \dfrac{q_q}{q_d} Q_0 \\ q_d = G_v = \dfrac{V_0}{V_i} \end{cases} \qquad (5)$$

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

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

G. 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.

$$\begin{cases} V_0 = q_d V_{id} = q_d V_i \cos\emptyset_i \\ I_i = q_d I_{0d} = q_d I_0 \cos\emptyset_0 \end{cases}$$

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

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

Where, Po is the output active power

H. 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.

I. Frequency Control of Matrix Converter

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

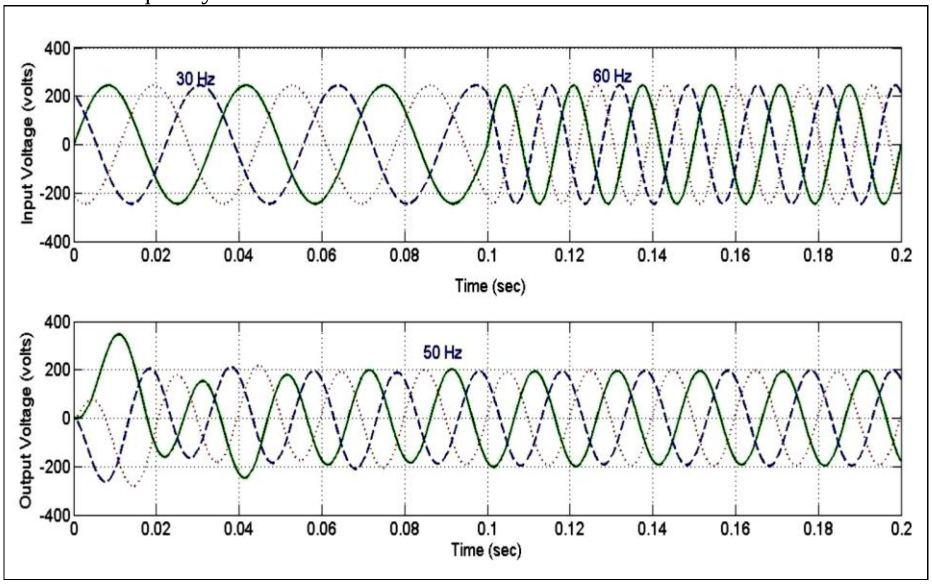


Fig. 5: Output voltage of matrix converter for input voltage of different frequencies.

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.

J. Voltage Control of Matrix Converter

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

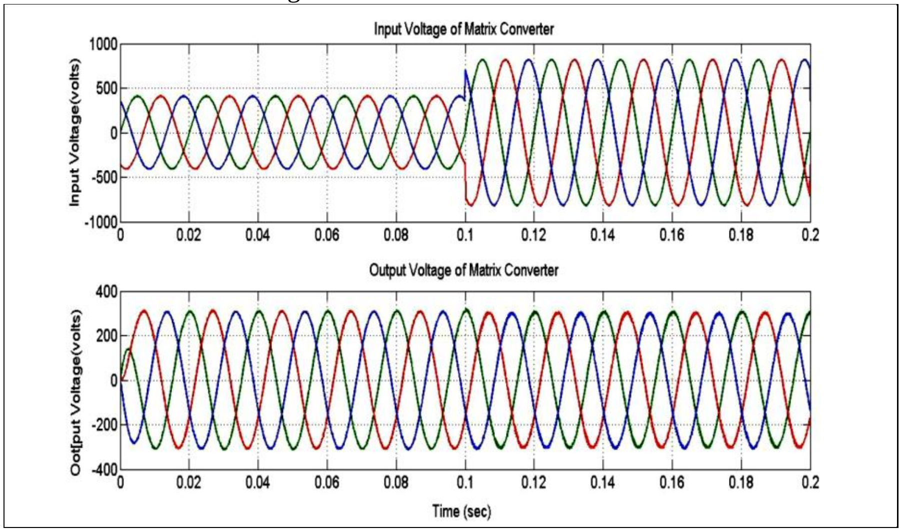


Fig. 6: Output of matrix converter for different input voltage at different time.

Closed loop control of voltage is shown in Figure 5. 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).

II. SIMULATION

Simulink diagram of three phase load connected to the wind turbine coupled permanent magnet synchronous generator through matrix converter is shown in Figure 6. 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.

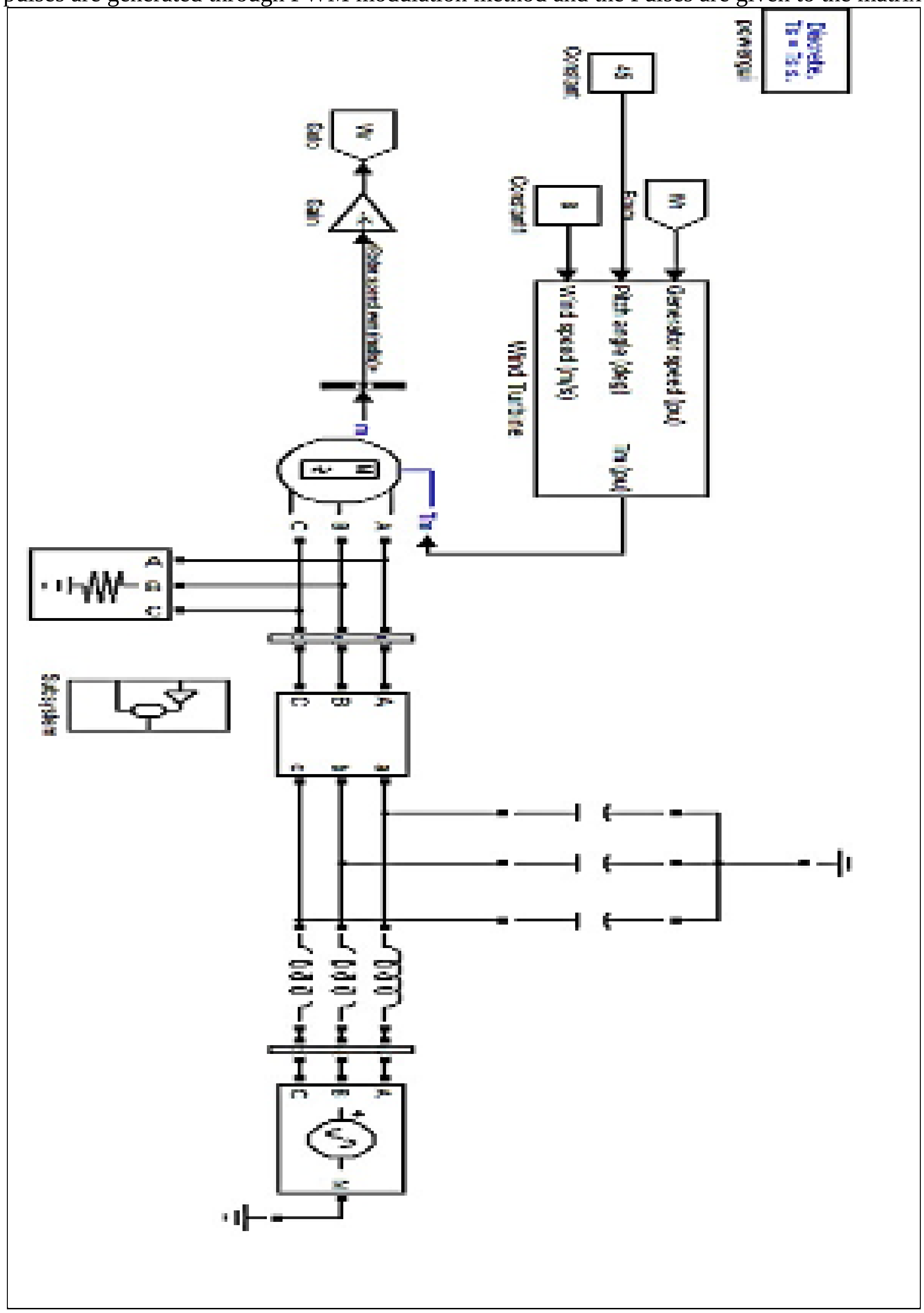
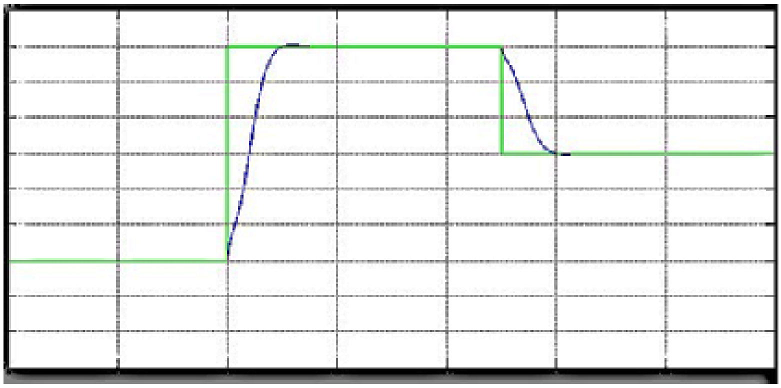
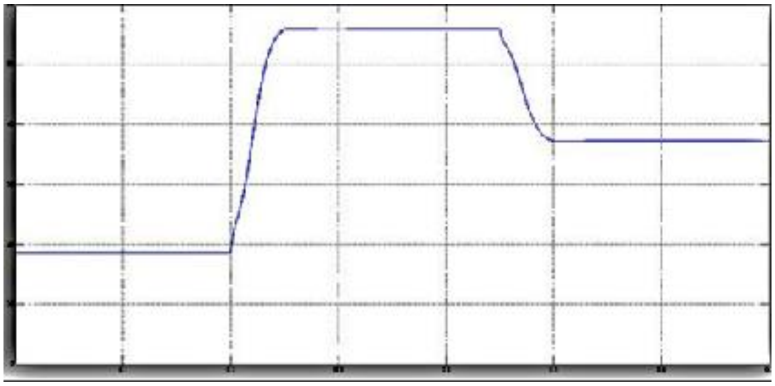


Fig. 7: Simulation

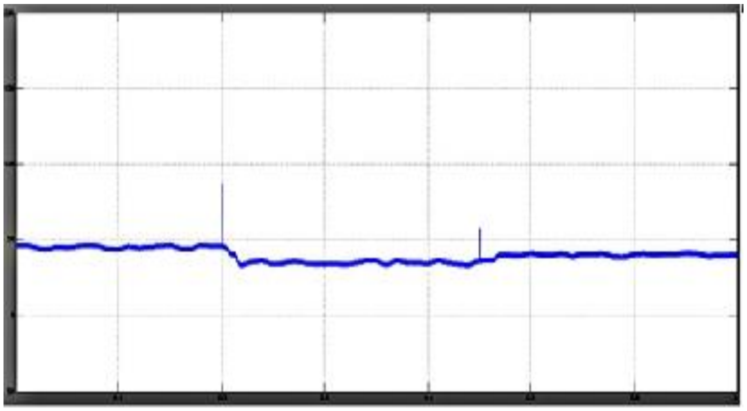
III. RESULTS



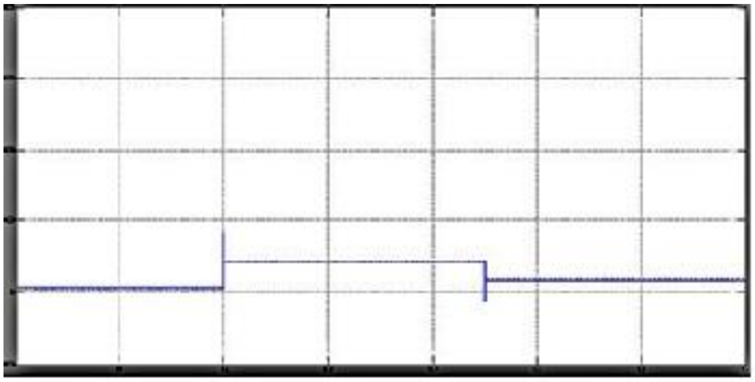
Graph 2: Reactive power (Qs) QVAR



Graph 3: Igd current (Amp)



Graph 4: Voltage (volt)



Graph 5: Power Loss (kW)

IV. CONCLUSION

In this paper, 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.

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