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A Novel PMSG Based WECS for Grid Integration Using Direct Matrix Converter

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***Abstract** The project explains the work done to achieve required active and reactive power in the output of converter with maximum wind power extracted through matrix converter with space vector modulation (SVM) fed grid combined Voltage Oriented Vector Control scheme (VOC). Direct matrix converter is applied and PMSG based Wind Energy Conversion System (WECS) is used for the proposed work. The reference for active power is the maximum extractable power which is calculated while reactive power reference is considered as zero. The change in wind speed changes generated power which is regulated using PI controller and it regulates the voltage ratio of the Matrix Converter (MC). This VOC scheme evaluates WECS maximum power and it is fed to the grid at the required output voltage and frequency, also at approximately unity input power factor. Under variable wind speed, the generated power voltage and frequency fluctuates in grid side and also load side. Even changes in speed of wind mill, the proposed system regulates the output power at evaluated maximum power of wind.*

***Keywords:** WECS, Matrix Converter, Unity power factor, SVM, PI controller*

I. INTRODUCTION

Increase in the electrical energy demand, deficiency occurs in non-renewable energy sources such as conventional fuels, coals, natural gas etc., Wind energy is most available renewable sources of energy in nature and electrical energy is generated from this. Wind energy is cheaper according to the availability and is low running cost. Various generators are incorporated with wind turbines generators such as Induction type, synchronous type, DC generator etc., In that synchronous generator with permanent magnet is most suitable generator for variable wind speed mill due to its reduced weight, high efficiency, reduced size and reduced maintenance cost [1,2].

The generated power voltage and frequency under different wind speeds also fluctuate hence Power converters are needed to connect WECS using PMSG with the grid. A dual stage AC-DC-AC converters used for conversion of power and also for regulation of power. But the DC link provides an enlarged losses, size, weight and also cost. To overcome these single stage AC-AC conversion is used. MCs are bidirectional AC/AC direct power converters. It is skilled of producing desired voltage and frequency at nearly unity power factor in the output [5,6]. It is also most suitable converter due to less commutation problems, increased voltage gain, reduced in size and weight [7].

Different control techniques have been introduced for power regulation. VOC is one of the better control strategy method to produce less harmonic components in output. Line current and voltage is taken as reference from the grid and/or load is given as the feedback for PI controller. It generates voltage reference signal. The generated voltage signal is given using voltage modulator to the converter.

The objective of this work is to edge variable speed PMSG using direct MC with grid. The maximum power is extracted from WECS is fed to reference for Space vector modulation algorithm [12]. This SVM based matrix converter together with VOC scheme and also PI controller is used to achieve desired active and reactive at the output side.

II. SYSTEM MODEL & CONTROL STRATEGY

The proposed matrix converter with PMSG based WECS block diagram is shown in Fig. 1.

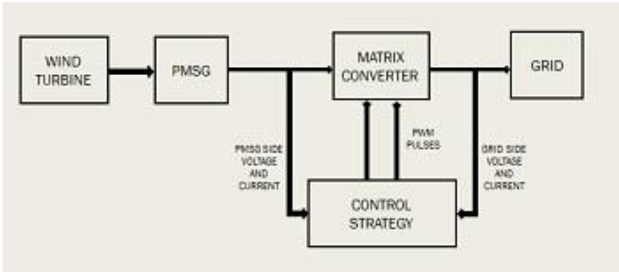

Fig.1 Proposed model Block diagram

The system modeling split into five sections PMSG based wind turbine, matrix converter, SVM technique for MC, VOC scheme, results and discussions.

A. Wind Turbine Performance

The power (mechanical) can be formulated as :

$$P_{Mech} = 0.5\rho A C_p V_w^3 \qquad \text{---------- 1}$$

$$A = \pi R_r^2$$

Where,

P_{mech} = output mechanical power (watts)
ρ = air density (Kg/m^3)
A = area of rotor turbine (m^2)
C_p = coefficient of power
V_w = velocity of wind (m/s)
R_r = rotor blade (radius).
C_p can be expressed as follows:

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$$Cp = \frac{P_{turbine}}{P_{wind}} \quad \text{---------- 2}$$

$$C_p = 0.516\left[\frac{116}{\lambda_i} - (0.4\theta - 5)\right] e^{-21/\lambda_i} + (0.0086\lambda) \quad \text{-----3}$$

$$\lambda_i = \frac{1}{1/_{\lambda + 0.08\theta} - \frac{0.035\theta}{\theta^3 + 1}}$$

Where β is pitch angle, which is assumed as zero.

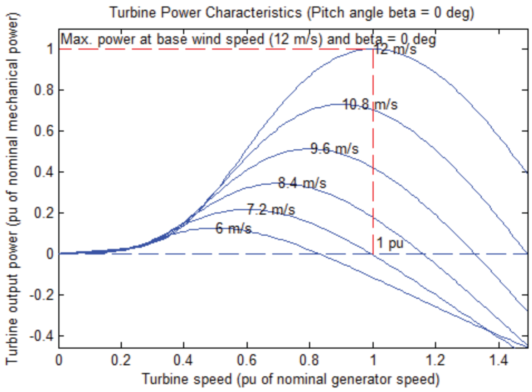

Fig 2. Wind turbine power coefficient versus ratio of tip speed.

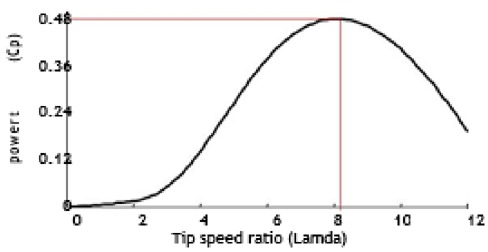

Fig 3. Turbine characteristics

The coefficient of Power is not a constant value. It varies with ratio of tip speed of the wind turbine which is shown in Fig. 2. Turbine characteristics are shown in Fig.3.

The maximum locus of these curves is used to obtain the maximum power which is extracted at any particular speed from the wind turbine.

From [20] the expression for maximum power which is extracted at particular wind speed (Vw) for the generator is as follows:

$$P_{max} = -3 + 1.08V_w - 0.125V_w^2 + 0.842V_w^3 \quad \text{--(4)}$$

Let generator efficiency is y, then the total power produced by the wind generator is y * Pmax . It is set as a reference active power (P_{ref}).

$$P_{Total} = yP_{max} = P_{ref} \quad \text{------- 5}$$

For this work y is taken as 100%(=1) and reactive power reference is taken as zero.

B. Matrix Converter

The AC-AC direct matrix converter is an electrical power conversion with variable frequency and voltage, M inputs and N outputs [5,21,22]. Fig.4 corresponds to the three inputs and three outputs Matrix converter.

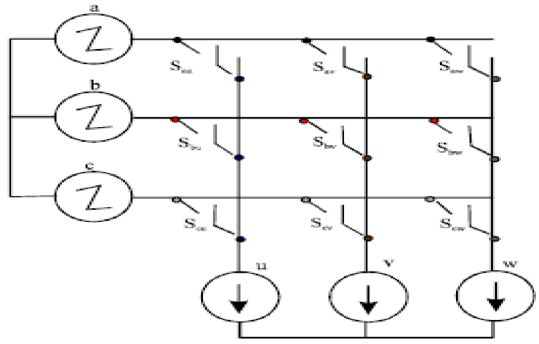

Fig 4. Three phase Matrix Converter

Line to line input short circuits and open circuits can be avoided with inductive currents and to satisfy the following equation

$$S_{Ao}(t) + S_{BO}(t) + S_{Co}(t) = 1 \quad \text{---- 6}$$

Bidirectional power flow is possible and it is a four quadrant converter. It is mostly sinusoidal input and output currents waveforms and no control on frequency within switching frequency limits. 9 bidirectional switches (18 IGBT and 18 DIODES) can be used. Output voltage is restricted to 86.6% of input voltage (cos 30). The input current and output voltage of the matrix converter can be characterized by the switching function S and S^T such as,

$$[Vout] = [S]*[Vin]$$

$$\begin{bmatrix} V_{AN} \\ V_{BN} \\ V_{CN} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{21} & S_{31} \\ S_{12} & S_{22} & S_{32} \\ S_{13} & S_{23} & S_{33} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad \text{-- 7}$$

$$[V_{in}] = [S^T] * [V_{out}]$$

$$\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = \begin{bmatrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ V_{31} & V_{32} & V_{33} \end{bmatrix} * \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad \text{---- 8}$$

Where V_a, V_b, and V_c are , input phase voltages ,i_a, i_b and i_c are input phase currents, V_A ,V_B, and V_C ,are output phase voltages, I_A ,I_B ,and I_C are output phase currents.

C. Space Vector Modulation Technique

SVM is one of the control method of pulse width modulation .It is improved method than the PWM techniques because of advantages as it generates controlled output voltage magnitude and frequency. SVM generates lower Total Harmonic Distortion (THD) which is suitable for digital controllers. [13] In simplified direct MC states, indirect SVM method is considered.[22]

This space vector modulation method depends on two stages one is the rectification and another one is the inversion stages. The modulation index [23] for the matrix converter is sub divided into the product of the rectifier stage matrix and inverter stage matrix.

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A=Iinverter * Rrectifier

$$\begin{bmatrix} S11 & S21 & S31 \\ S12 & S22 & S32 \\ S13 & S23 & S33 \end{bmatrix} = \begin{bmatrix} S7 & S8 \\ S9 & S10 \\ S11 & S12 \end{bmatrix} * \begin{bmatrix} S1 & S3 & S5 \\ S2 & S4 & S6 \end{bmatrix}$$

S11=$(S1 * S7) + (S8 * S2)$)
S21=$(S9 * S1) + (S10 * S2)$
S31=$(S11 * S1) + (S12 * S2)$ and so on., ---- 9

The rectifier and the inverter duty cycle is used to generate all switches duty cycles of the matrix converter. In the switches S1 to S6 represents the rectification stage and S7 to S12 represents the inversion stage switches.

D. VOC Scheme

The control strategy in this work is based on Voltage Oriented Control (VOC), which is incorporated in Matrix Converter based WECS. To model the VOC, the grid side AC voltage and matrix converter production current is measured and its angle is identified for the voltage orientation method [16-19]. In this method the transformation from static reference frame variables and further into synchronously rotating frame variables transformation are required and it is given

$$V^e_{ds} = \frac{2}{3}[V_R \cos\theta_e + V_Y \cos(\theta_e - \frac{2\pi}{3}) + V_B \cos(\theta_e + \frac{2\pi}{3})$$

$$V^e_{qs} = \frac{2}{3}[V_R \sin\theta_e + V_Y \sin(\theta_e - \frac{2\pi}{3}) + V_B \sin(\theta_e + \frac{2\pi}{3})$$

---------- 9

Similarly isds ,ieqs are calculated. The actual value of active power (Ps) and reactive power (Qs) which is given for the input of controller are calculated using the following equations[15]

$$P_s = v^e_{ds} i^e_{ds} + v^e_{qs} i^e_{qs}$$

$$Q_s = v^e_{qs} i^e_{ds} - v^e_{ds} i^e_{qs}$$

----------- 10

These actual real and reactive power are compared with the reference values P*S and Q*S and reference values of the matrix converter phase voltages is generated [14]. Compared output is given to the PI controller. The output of PI controller generates signal which is taken as the reference modulating signal of MC. q_v - gain of reference voltage modulating signal

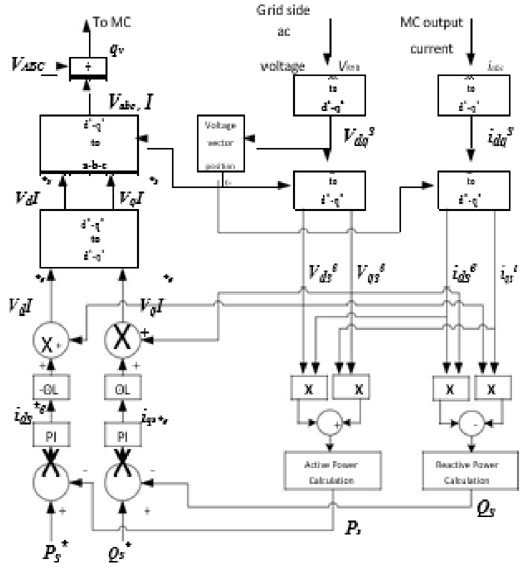

Fig 5. VOC based Control Scheme

The d-axis and q-axis current references are obtained from

$$I^*_{ds} = \frac{P^*_g}{1.5 v_{ds}}$$

$$I^*_{qs} = \frac{Q^*_g}{-1.5 v_{ds}}$$

--------- 11

Fig (5) shows the proposed system to regulate active and reactive power delivery.

E. Simulation Model

Fig. 6 shows the simulink model WECS based on PMSG connected grid through MC with VOC and PI scheme

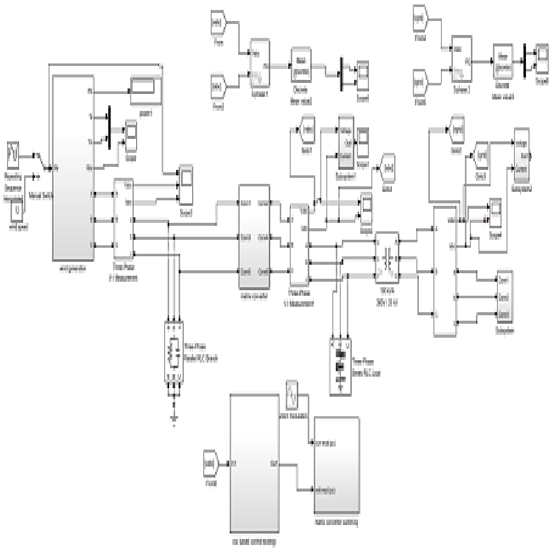

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Fig. 6 simulink model of PMSG based WECS connected grid through MC with VOC scheme

III. RESULTS & DISCUSSIONS

The grid connected wind turbine model through three phase to three phase MC with control strategy has been supported by matlab/simulink. Fig .7 shows the performance parameters of PMSG with different wind speeds. These

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wind speeds at PMSG, change the generated voltage and current.

Fig.8 shows the output generated voltage of PMSG. From the output it is noted that increase or decrease in wind speed lead to either increase or decrease in PMSG generated voltage and current. Hence the active power and reactive power are also changed corresponding to various wind speed.

Active power depends on the output frequency. With increase in frequency, load demand decreases and vice versa. Frequency is directly proportional to the active power. This closed loop system has very good performance than the system without control scheme in terms of active power and power factor. In the open loop system the frequency is varied for different load conditions which affect the performance of the grid or load .It is in terms of active power, output voltage and output frequency. In a variable wind speed PMSG based drive, the output active power is varied. So it is regulated using Voltage Oriented Vector scheme.

Fig,10 and 11 show output side active power and reactive power. The active power is maintained irrespective of speed in wind due to VOC scheme.

Fig .9 shows the voltage of matrix converter at different wind speed. The MC have sinusoidal output voltage and current wave form l. The matrix converter input power factor is maintained constant under any speed condition and it is shown in Fig.12

It is observed that grid side voltage waveform remains constant, but the grid side current is varied for corresponding variation in wind speed in open loop system. The output active power is also varied depend on variation in wind speed. In closed loop control, irrespective of wind speed active power is regulated for set maximum power. The grid reactive power is also settled to the set zero value. Compared to system without VOC, closed loop system gives good performance in terms of regulated output power.

From the attained system performance, it is concluded that the proposed system gives better result under variable wind speed situation.

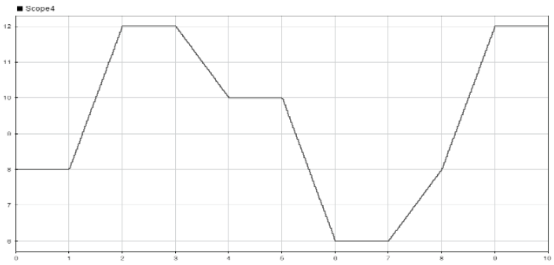

Fig .7 Variable wind speed

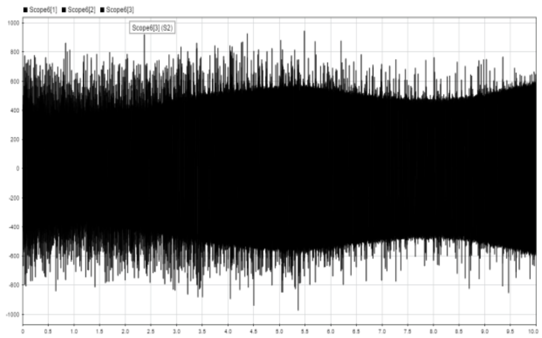

Fig .8 PMSG output voltage

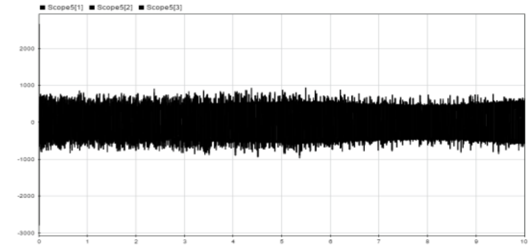

Fig .9 Matrix converter output voltage

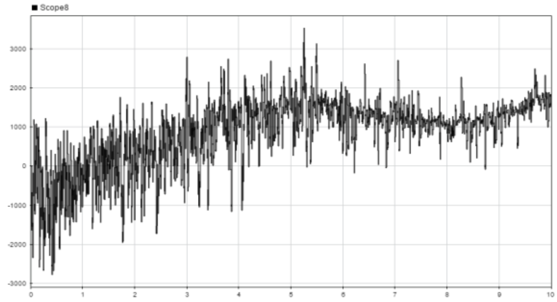

Fig .10 Active power

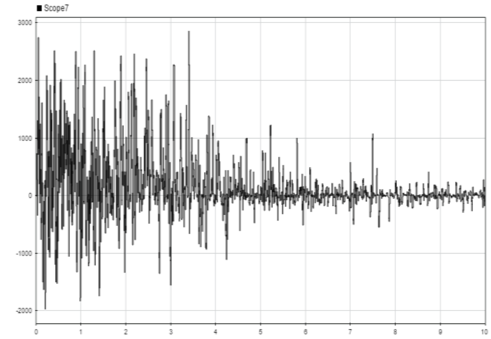

Fig .11 Reactive power

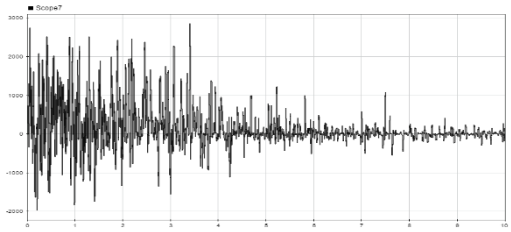

Fig .12 input Power factor

IV. CONCLUSION AND FUTURE SCOPE

PMSG based WECS with Matrix Converter fed to grid is modeled using matlab. The aim of the proposed system has to line the adjustable speed PMSG through grid using direct MC and extract power drawn which is maximum from WECS is directly transported to the grid. The proposed space vector modulation process together with the VOC scheme and PI controller has been simulated and it is to normalize active and reactive power at converter output side and results are obtained. The performance of the output power is good compared to the results which are obtained without VOC scheme and input power factor is also maintained nearly unity with VOC scheme. The modifications in MC switching algorithms will be done to improve the output further [24]. It can also be verified with different load conditions further [25]

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