Generator–Grid Interfaces for Wind Energy Systems using Matrix Converter

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***Abstract* — Generation of electrical energy is greatly being contributed by wind farm. Thus, researchers are finding various optimizing techniques in order to utilize it at its optimum. Power electronics devices play a major role in interfacing these plants with the power system. These devices can enhance energy conversion, power transmission, reactive power flow control, and reduce the unnecessary harmonics at the same time. Matrix converters have been presented here. Its operation as interfacing device between wind turbine and power system is thoroughly investigated. Simulations have been done in Matlab environment.**

Keywords: Wind power generation, Matrix converters, Power systems.

I. INTRODUCTION

Increased production of goods per head, increased prosperity and urbanization, rise in per head consumption, and easiness in energy access are the factors that are responsible for the increase in the total demand of electricity by a significant extent. Having a look at the difference of electricity demand and supply, huge quantities of coal and furnace oil are being used. These usages need to be reduced, as these are leading to tremendous costs in the form of subsidies and increment in the country's dependency on imports. Renewable energy sources have the ability to make a noteworthy contribution in these areas. Due to all of these, renewable energy needs to be studied and utilised to a great extent [1]. Therefore, commissioning of wind turbine units in the existing grid give rise to problems like, violation of bus voltages beyond the stipulated grid limits, power congestion, abnormal system losses and voltage instability. Wind power has an exceptionally good potential for providing electrical energy that is free & non-polluting. Its effectiveness as an electricity supply source has encouraged ambitious targets for wind turbine system in many countries around the world.

The most difficult challenge in utilizing the wind power in harnessing the energy is their random changing nature. The first element in harnessing this green energy is the wind turbine followed by electrical generator. The main function of these generators is to convert mechanical energy into electrical energy. Some of the electrical machines that can perform this operation are: doubly fed induction machines, induction machines, PMSM etc. Some special features of PMSM are:

- Simple construction
- Small size
- High efficiency
- Low Maintenance
- No need of DC excitation
- No need of brushes and slip rings

Because of the changing nature of the wind, the generator fails to produce a constant electrical voltage resulting in grid imbalance. To overcome this problem, maximum power point trackers are employed. Three phase ac supply coming out of the wind farm can be supplied to a matrix converter after suitable filters. This matrix converter will convert the input three phase supply into a variable voltage variable frequency supply. This variable supply can be used to drive an induction motor and PMSM.

II. PMSM

Permanent Magnet Synchronous Motors have a permanent magnet rotor and thus have very high efficiency and reliability. These motor have higher torque in comparison to their frame size as compared to Induction Motors (AICMs). With these advantages, the overall design of the system becomes smaller without sacrificing the torque requirement. Applications of PMSM are:

- Washing machines
- Air conditioner and refrigerator
- Power steering in Automobiles
- Data storage
- Machining tools

The stator equations of the induction machine in the rotor reference frames using flux linkages are taken to derive the model of the PMSM as shown in Fig 1.

So an PM machine is described by the following set of general equations: Voltage equations are given by:

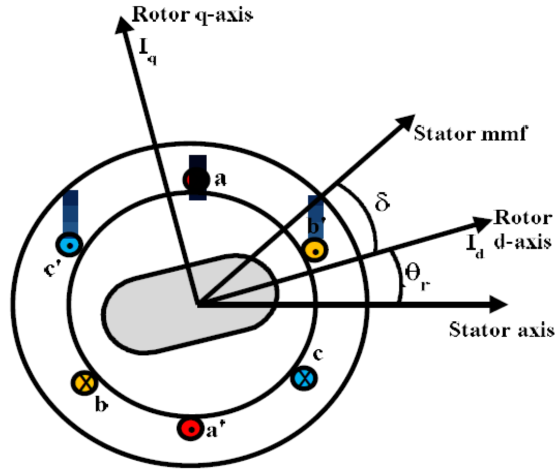

Fig .1 PM machine synchronously rotating d-q reference frame

$$V_d = R_s i_d - \omega_r \lambda_q + \frac{d\lambda d}{dt}$$
$$V_q = R_s i_q - \omega_r \lambda_d + \frac{d\lambda d}{dt}$$

Flux linkages are given by

$$\lambda_q = L_q i_q$$
$$\lambda_d = L_d i_d + \lambda_f$$

Upon substituting, we get

$$V_q = R_s i_q + \omega_r (L_d i_d + \lambda_f) + \frac{d}{dt}(L_q i_q)$$
$$V_d = R_s i_d - \omega_r L_q i_q + \frac{d}{dt}(L_d i_d + \lambda_f)$$

Arranging equations in matrix form

$$\begin{pmatrix} V_q \\ V_d \end{pmatrix} = \begin{pmatrix} R_s + \frac{dL_q}{dt} & \omega_r L_d \\ -\omega_r L_q & R_s + \frac{dL_d}{dt} \end{pmatrix} \begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} \omega_r \lambda_f \\ \frac{d\lambda_f}{dt} \end{pmatrix}$$

The developed torque motor is being given by

$$T_e = 3/2\ (P/2)\ (\lambda_d i_q - \lambda_q i_d)$$
$$T_e = 3/4\ P[\lambda_f i_q + (L_d - L_q)\ i_q i_d]$$

The mechanical torque equation is

$$T_e = T_L + B\omega_m + J\frac{d\omega m}{dt}$$

Solving for rotor mechanical speed, we get

$$\omega_m = \int 1(\ T_e - T_L - B\omega_m / J\ )\ dt$$

and rotor electrical speed is

$$\omega_r = \omega_m (P/2)$$

III. MATRIX CONVERTER

Matrix converter is an AC to AC converter that converts fixed ac voltage into a variable voltage and variable frequency supply without employing a bulky energy storing device such as capacitor. Due to this advantage, matrix converter is replacing conventional AC-DC-AC converters. The main advantage of a matrix converter is that it can convert the input three phase supply into a variable voltage variable frequency supply. Its input and output waveforms are purely sinusoidal, and does not contain higher Order harmonics. Furthermore, sub harmonics are absent in the output. This variable supply can be used to drive an induction motor and permanent magnet synchronous motors. Other advantages include absence of DC link capacitor and reduced no of switches. Therefore, size of the converter also minimizes. On the other hand, as other circuits matrix converter too has some disadvantages. It can transfer maximum of 87% of input voltage to the output side. No of semiconductor devices are more as compared to ordinary converters. Lastly, it is very sensitive to the fluctuations. Such converter comes with 9 units of bi-directional switches. With the help of these switches, any of the output phase can be connected to any of the input phase resulting in variable voltage variable frequency output. Total of 512 switching combinations can be employed on a single three phase matrix converter. Even though most of these combinations are not useful. The usefulness of the switching combination depends on 2 things. The three phase input terminal should be connected to a voltage fed system and the output three phase terminals should be connected to a current fed system. Secondly, the input terminals should never be short circuited and output current should never be interrupted. Based upon these rules, it can be concluded that only one output phase should be connected to the input.

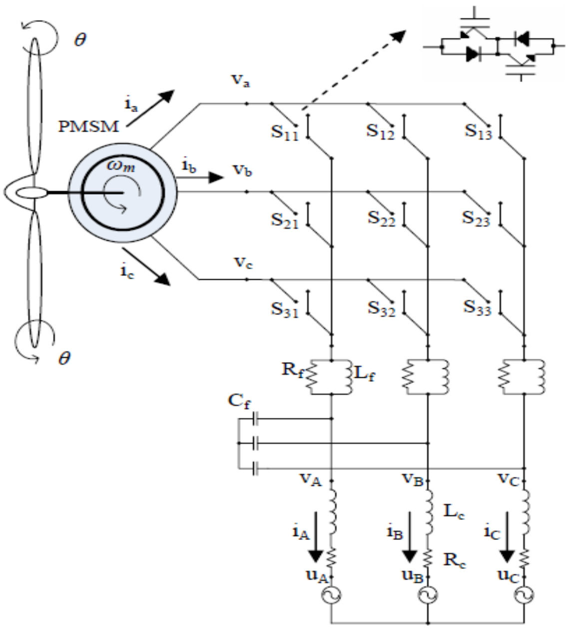

Fig. 2 Matrix Converter Configuration

IV. SIMULATION AND RESULTS

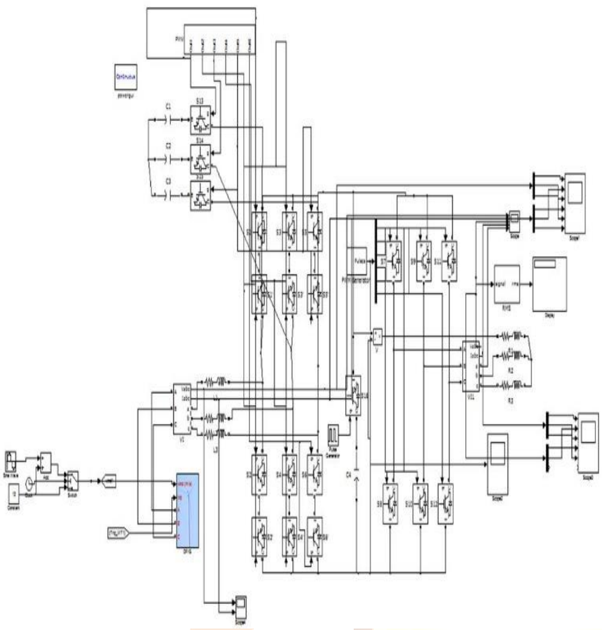

Fig. 3 Matlab Simulink model

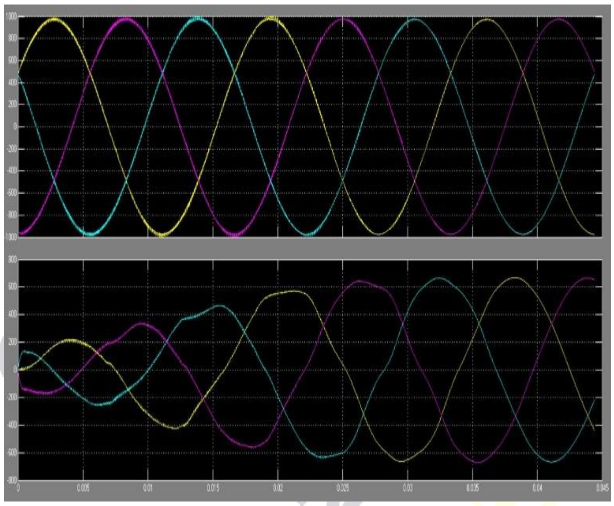

Fig. 4 Supply voltage and current waveforms

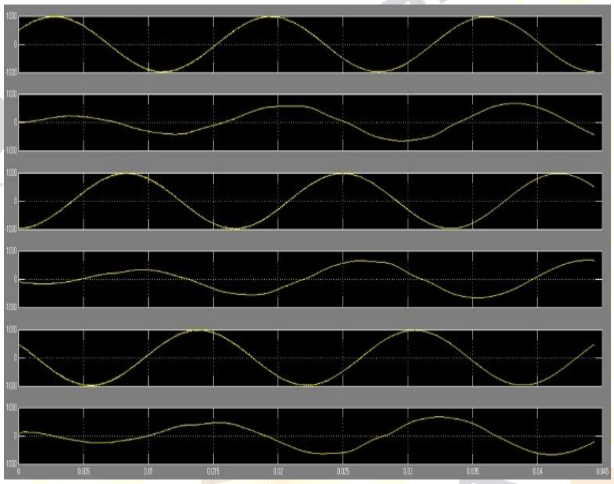

Fig. 5 Output waveforms of matrix converter

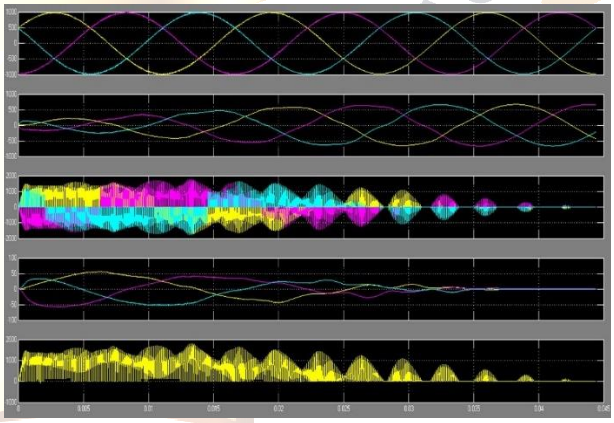

Fig. 6 Load side waveforms

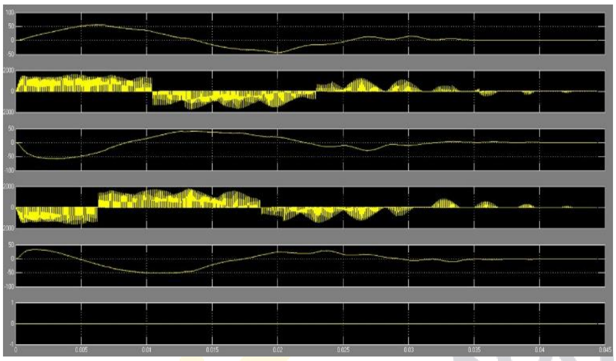

Fig. 7 Load side waveforms

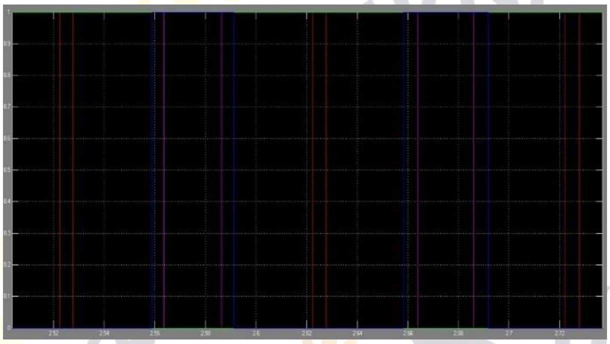

Fig. 8 Switching pulses

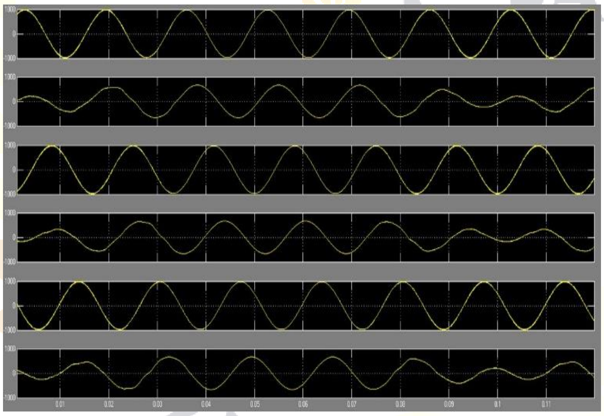

Fig. 9 (a) DC voltage. (b) Input phase current and voltage for sub-synchronous speed. (c) Input phase current and voltage for super synchronous speed.

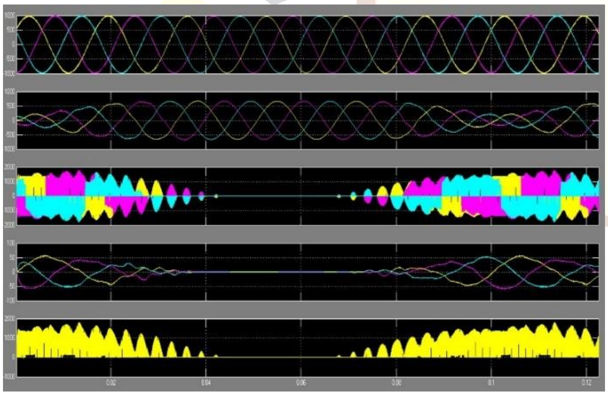

Fig. 10 DFIG performance in a variable speed wind energy system

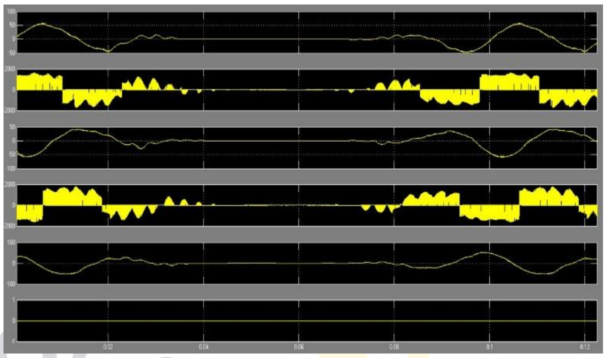

Fig. 11 Current controller performance for both machines at variable speed

V. CONCLUSION

The switched-inductor and quasi-Z-source circuits, embedded in the ultra-sparse matrix converter topology, allow interfacing a low-voltage generator with the grid in wind energy systems. The efficiency of the proposed converters is expected to be high due to reduced number of power electronic switches. Furthermore, the shoot-through state is no longer a hazard, which improves the reliability of the proposed converters. The THD analysis of input and output currents has shown slight superiority of the SIZMC over the QZMC with respect to the quality of input currents. It should be noted that the SIZMC and QZMC do not allow bidirectional power flows. Thus, the generator cannot be used for starting the turbine. The bidirectional power flow would require adding three more switches to the rectifier part, converting the ultra-sparse matrix input stage to a sparse-matrix one.

VI. REFERENCE

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