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Matrix Converter for PMSG based WECS Using Duty Ratio Based Switching with FOC

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Abstract - **This paper presents the direct AC to AC converter for Permanent Magnet Synchronous Generator (PMSG) based wind turbine. The direct AC to AC matrix converter is intended between the PMSG wind turbine and the grid. The power generated by the wind turbine is synchronized with the grid parameters through the converter. A modulation scheme based on duty ratio is proposed. Depending upon the duty ratio the switching of matrix converter is done. Conventional AC-DC-AC back to back converter is replaced by direct AC to AC converter. The modulation scheme can be also implemented using Field Programmable Gate Array (FPGA) so that the computational speed can be improved. The machine side control is done by Field Oriented Control (FOC). A three phase to three phase matrix converter is simulated using MATLAB simulink software and the results are shown.**

Keywords: **Ac-Ac Converter, Permanent magnet synchronous generator, Wind energy conversion system, Pulse Width Modulation.**

I. Introduction

Nowadays, renewable energies are becoming increasingly important as alternative energy sources. Many factors such as diminishing fossil-fuel resources, energy security concerns, and global warming increase the need for renewable energies. Their main advantages are the elimination of harmful emissions and inexhaustibility while the main drawbacks are the cost and uncontrollability [1-4]. The A comprehensive overview of the development in the field of matrix converter research is presented in [4-5]. Significant work is done to develop modulation techniques for their optimum performance, and their analysis is presented in [6-7]. Matrix converters are considered for several applications such as wind energy generation systems [8-9].

The conventional back-to-back voltage source converters are widely used to connect the generator to the grid. In this structure, DC-link capacitors are applied to decouple the generators and grid. However, they are bulky and have a limited life time. The matrix converter does not use the DC link capacitor and provides a direct AC/AC conversion. Thus, it is a good candidate for WECS applications. The matrix converter can control the magnitude, frequency and phase angle of the output voltage as well as the input power factor. Despite the attractive features of the matrix converter, the matrix converter suffers from some problems such as low voltage gain, complicated control, bi-directional switches and lack of ride-through capability [10-11]. The duty ratio based PWM technique is explained in [12].

In conventional WECS system AC-DC-AC back to back converter is used. AC-DC-AC back to back is a two stage converter that is initially the AC power generated by the generator is converted into dc with the help of rectifier and the rectified dc is converted back to ac with the help of PWM inverter. The various conversion losses can be overcome by the proposed scheme.

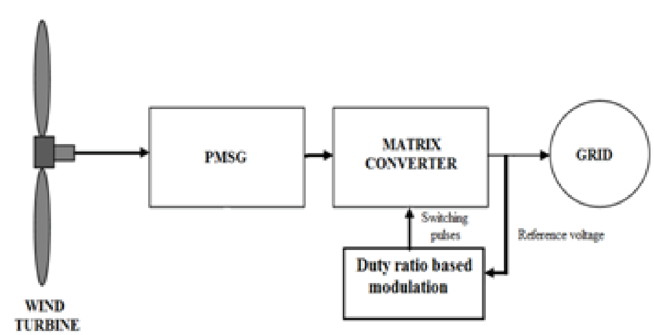


Fig. 1 Proposed Scheme.

In the proposed system the AC-DC-AC back to back converter is replaced by direct AC to AC converter. The duty ratio based modulation scheme is used to get the triggering pulses. The grid voltage is given as the reference voltage.

II. Proposed control scheme

The control scheme based on duty ratio is employed. In this control scheme the matrix converter utilize the input voltage to generate the desired output voltage. The desired output voltage is given as the reference voltage and the duty ratio is calculated. The triggering pulses are generated by comparing the duty ratio with the continuous triangular carrier wave.

A.Direct AC-AC Matrix converter

The matrix converter is the single stage direct AC to AC converter. It consists of m×n bi-directional switches to connect directly a m-phase voltage source to an n-phase load. Usually the input of converter is fed by the voltage source and hence at any instant the input should not be short circuited. The load is typically inductive in nature and hence the output side should not be open circuited at any instant.

The output voltage of the converter is given by

$$\overline{v_o}(t) = D(t).v_i(t) \tag{1}$$

The relation between input and output current is given by

$$\bar{i}_i = D(t)^T . i_o \tag{2}$$

v_o and i_o represents output voltage and current respectively. v_i and i_i represents input voltage and current respectively. D (t) represents the duty ratio.

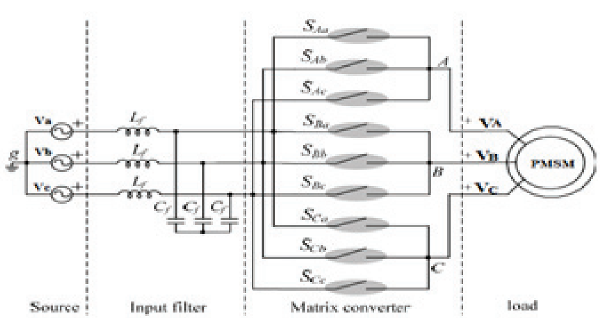


Fig. 2 Direct Ac-Ac converter

B.Control algorithm

In the proposed control algorithm the duty ratio value for the given reference and input voltage is calculated and this duty ratio value is compared with the carrier signal. There are two cases in this control scheme. At any instant two of the three input phases will conduct current to the load and one phase won't provide any current to the load. A switching period Ts is divided into two time periods, T_1 and T_2. Also, Max, Mid and Min denote the maximum, medium and minimum input voltage values, respectively. During T_1, the line-to-line voltage between Max and Min, which is the maximum line-to-line voltage among the three line-to-line input voltages at the sampling instant, is used. During T_2, the second maximum line to line voltage, which is the larger of Max to Mid and Mid to Min, is used. The figure 3 shows the way how the input line voltage is classified in to two cases.

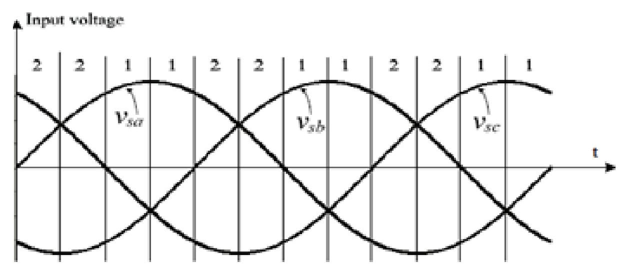


Fig. 3 Input phase voltage.

If Max-Min > Mid-Min, Max to Mid is used during T_2 and the resultant switching pattern is named switching pattern-I. Otherwise, Mid to Min is used during T_2, namely switching pattern-II.

C.Switching pattern-1

For the condition Max-Mid> Mid-Min, the generation of the gating pattern for the output phase is shown in Figure 4. To generate the pattern, at first, the duty ratio D_{k1}, with k ∈ a, b, c, is calculated and then compared with the high-frequency triangular carrier signal to generate the k^{th} output phase pattern. The gating pattern for the k^{th} leg of the matrix converter is directly derived from the output pattern. The switching pattern is drawn, assuming that Max is phase "A" of the input, Mid is phase "B," and Min is phase "C." The switching pattern changes in accordance with the variation in the relative magnitude of the input phases. The output follows Min of the input signal if the magnitude of the duty ratio is more than the magnitude of the carrier and if the slope of the carrier is positive. The output follows Max of the input signal if the magnitude of the carrier is greater than the magnitude of the duty ratio, irrespective of the slope of the carrier. Finally, the output tracks Mid if the magnitude of the carrier signal is less than the magnitude of the duty ratio and if the slope of the carrier is negative. Thus, the resulting output phase voltage changes like Min → Max → Max → Mid.

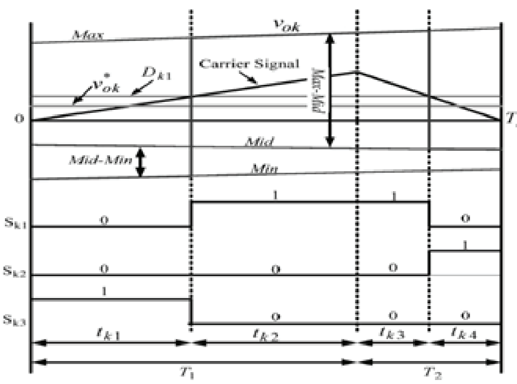


Fig. 4 Switching pattern 1

These transition periods are termed as t_{k1}, t_{k2}, t_{k3}, and t_{k4}, and these four subintervals can be expressed as

$$\begin{aligned} t_{K1} &= D_{K1}\delta T_S \\ t_{K2} &= (1 - D_{k1})\delta T_s \\ t_{K3} &= (1 - D_{k1})(1 - \delta)T_s \\ t_{K4} &= D_{K1}(1 - \delta)T_s \\ T_s &= t_{K1} + t_{K2} + t_{K3} + t_{K4} \end{aligned} \tag{3}$$

Where D_{k1} is the k[th] phase duty ratio value when Case I is under consideration and δ is defined by $\delta = T1/Ts$, which refers to the fraction of the slope of the carrier. The duty ratio is obtained from (4) as

$$D_{k1} = \frac{\mathrm{Max}\{v_A,v_B,v_C\} - v_{ok}^*}{\Delta + \delta(\mathrm{Mid}\{v_A,v_B,v_C\} - \mathrm{Min}\{v_A,v_B,v_C\})} \tag{4}$$

Where $\Delta = (\mathrm{Max}\{V_A,V_B,V_C\} - \mathrm{Mid}\{V_A,V_B,V_C\}$ similarly, the duty ratios of other output phases can be obtained and can be subsequently used for the implementation of the PWM scheme.

D. Switching pattern-2

Consider another situation of Max − Mid < Mid − Min. The output and the switching patterns can be derived once again by following the same principle laid down in the previous section. Figure 5 shows the output and switching patterns for the k[th] output phase. Here, once again, a high-frequency triangular carrier wave is compared with the duty ratio value D_{k2} to generate the switching pattern. The only difference in this case compared to the previous case is the interval when the magnitude of the carrier signal is greater than the magnitude of the duty ratio and when the slope is negative. Then, the output should follow Mid instead of Max. Contrary to Case I, for this situation, the output must follow Max of the input. The time intervals t_{k1}, t_{k2}, t_{k3}, and t_{k4} are the same as in (3), and now, the output phase voltage is changed with the sequence of Min → Max → Mid → Min. The duty ratio value for switching pattern-2 is given by

$$D_{k2} = \frac{\delta.\Delta + (\mathrm{Mid}\{v_A,v_B,v_C\} - v_{ok}^*)}{\delta.\Delta + (\mathrm{Mid}\{v_A,v_B,v_C\} - \mathrm{Min}\{v_A,v_B,v_C\})} \tag{5}$$

The switching signals for the bidirectional power switching devices can be generated by considering the switching states of Figures. 5 and 6. Depending upon the output pattern, the gating signals are derived. If the output pattern of phase "k" is Max (or Mid and Min), then the output phase "k" is connected to the input phase whose voltage is Max (or Mid and Min). The control algorithm can be explained by the block diagram shown in Figure.6.

The input voltages are, at first, examined for their relative magnitudes, and the phases with computation block either uses (4) or (5) to generate the duty ratios. Depending upon the relative magnitude of the input voltages. The obtained duty ratio goes to the PWM block.

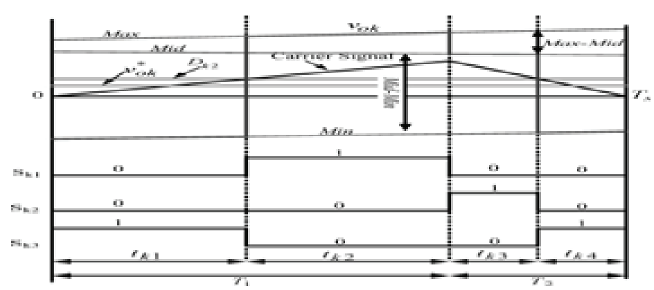
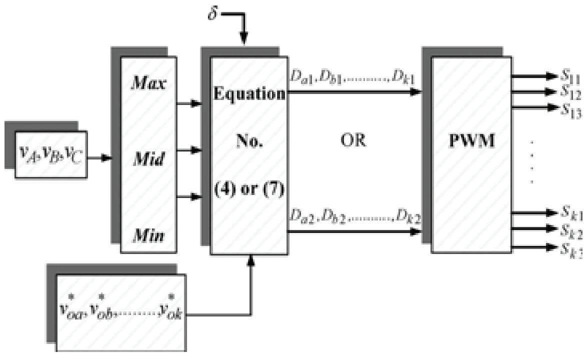


Fig. 6 Block diagram of control scheme.



The PWM block calculates the time subinterval using (3). The gating pattern is then accordingly derived and given to the matrix converter. Maximum, medium, and minimum values are determined. The information about their relative magnitudes is given to the next computation block, along with the commanded output phase voltages.

III. Simulation and Results

In this section the three phase to three phase matrix converter is simulated using MATLAB simulink. Duty ratio based PWM technique is used to generate the triggering pulse for the switches of matrix converter and the results are shown. The input is fed by 50 Hz voltage source of amplitude 100 volts. The bi-directional switches are realized by IGBT switches with diodes. Each input phase is connected to all the three output phases through bi-directional switches. The subsystem1, 2 and 3 represents the switching arrangement of the matrix converter. The control technique is implemented in the subsystem 4.

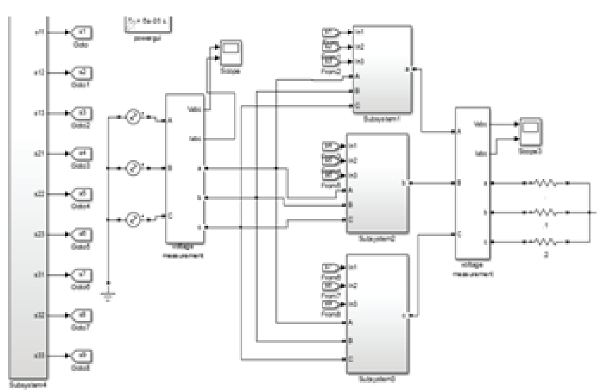


Fig.7 Simulation of converter.

A.bi-directional switches

The diode bridge arrangement is the most simple bi-directional switch structure. This arrangement consists of an IGBT at the centre of a single phase diode bridge. The main advantage of this arrangement is that only one active device is need, reducing the cost of the power circuit. Conduction losses are relatively high since there are three devices in each conduction path. The gate pulse for IGBT is obtained from triggering block implemented in subsystem 4. The power flow can be done in both the direction. While conducting two diodes and a IGBT switch will be in conduction.

B. FOC

The FOC block is shown below. The Speed and generated voltage is taken and fed as input to FOC block and the reference signal is generated.

C.Results

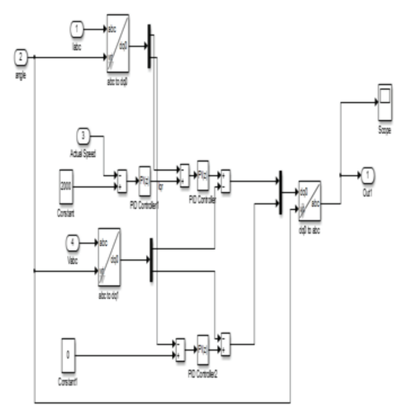


Fig.7a FAC Block

The three phase to three phase matrix converter that convert a input voltage of 50 hz to the output frequency of 25 hz is designed. The input is fed by a three voltage source with frequency 50 hz and amplitude 100 volts. Each phase has an phase shift of 120 degree to eachother. Input voltage waveform is shown in figure 8.

A continuous triangular wave which varies from 0 to 1 is chosen as carrier wave. The frequency of carrier wave is chosen as 700 Hz. The triangular carrier wave is compared with the duty ratio of each and every phase at every instant and depending upon the compared value the switching pulse is generated. Figure: 9 show the carrier wave.

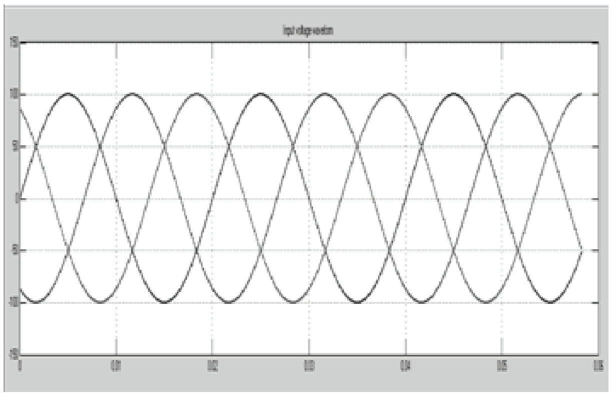


Fig. 8 Reference voltage generated by FOC

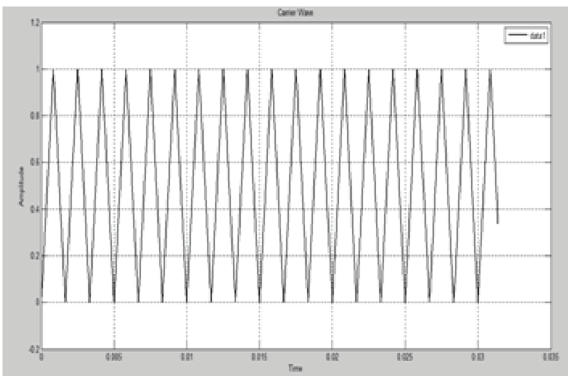


Fig. 9 carrier wave

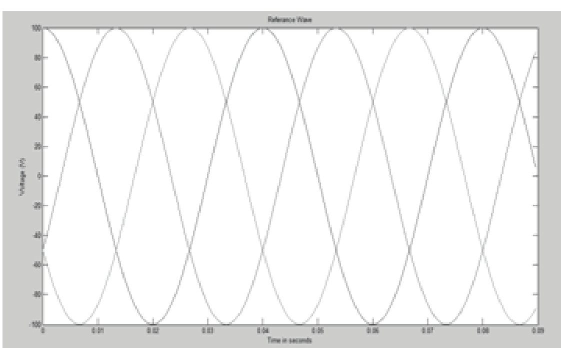


Fig.10 Reference wave

The reference output waves are generated with 25 Hz and the amplitude is 100 volts. The reference wave is used to calculate the duty ratio value. Depending upon the output reference wave the duty ratio gets varied and the output gets varied. Usually the desired output is chosen as the reference wave. The figure 10 shows the reference wave.

The duty ratio for all the three phases with respect to reference wave is generated for the switching pattern-1 and the waveform is shown in figure 11. This duty ratio is

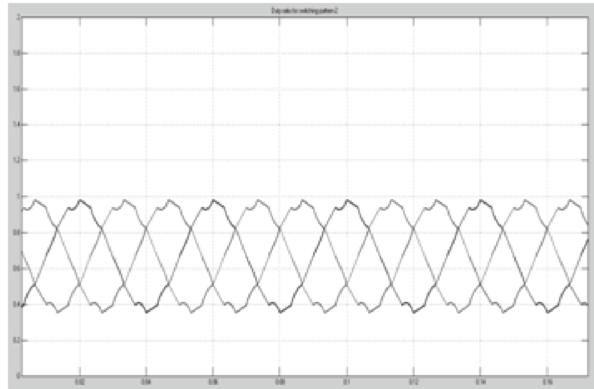


Fig. 11 Duty ratios for all the three phase

compared with the common continuous triangular carrier wave and thus the switching pulse for each switch is generated. Since the reference signal is 25 Hz the duty ratio wave is also generated for 25 Hz. Depending upon the duty ratio the switching pulse each phase switches are generated. At any instant only one of the three bi-directional switches will be in conduction depending upon the maximum, minimum and medium values of input.

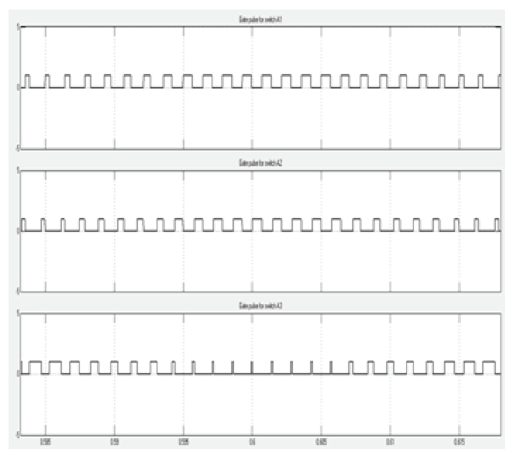


Fig. 12 Switching pulses for phase 'a'

At any instant one of the three switches in each phase will be in conduction. Overall three switches will be in conduction at any time depending on the duty ratio and the carrier wave.

The output phase voltage for each phase is shown in figure13. The peak value of voltage is 100 volts. The waveform is similar to the reference wave but chopped due to high switching frequency. If the switching frequency is reduced the chopping will be less. The output frequency is 25 Hz. The output line voltage is shown in figure 14.

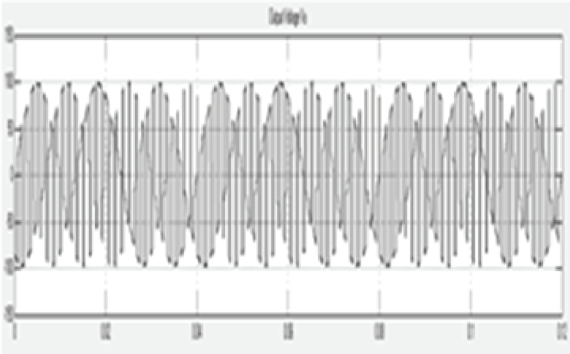


Fig. 13 Output phase voltage ’a’

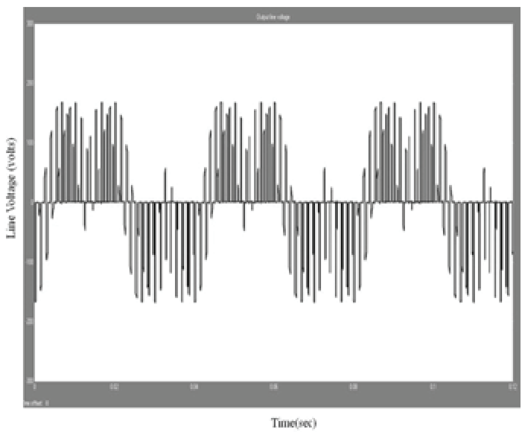


Fig.14 Output line voltage V_{ab}

IV. Conclusion

Three phase to three phase matrix converter with duty ratio based modulation scheme was designed using MATLAB and the results are shown. In existing modulation techniques the voltage transfer ratio is up to 0.87. From the results we can understand that, in the proposed model the voltage transfer ratio is improved up to 1. This matrix converter can be used in wind energy conversion system in order to synchronize the power generated by generator with the grid. The performance can be further increased by implementing the modulating technique in FPGA. By replacing the conventional AC-DC-AC back to back converter by matrix converter the conversion losses can be also reduced and also the DC link can be eliminated. Since the DC link is eliminated the cost can be also reduced.

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