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Modeling of Six Switch Single Phase to Three Phase Matrix Converters

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Abstract

The Matrix Converter (MC) chosen in this work is capable of providing a variable three phase output voltage from a fixed single phase input using single stage phase conversion principle. This MC effectively provides three phase power to three phase variable speed drives. The implementation of MC requires solid state bidirectional switches. A new pulse generation scheme is developed to produce three phase voltage at the output. The performance of the Matrix Converter is evaluated using MATLAB/SIMULINK for different frequencies. Simulation results for three phase resistive and inductive loads are presented. The simulation results validate the developed conversion strategy.

Keywords: Matrix Converter, Six Switch TPMC, Three Switch TPMC

1. Introduction

In many parts of the world, applications requiring 15 to 100 horsepower range such as fluid handling, irrigation pumping, primary grain and pulse processing, etc. are performed in remote rural areas where only single phase AC power is available. In such scenario, where power requirements increase in integral multiple horsepower range, single phase motors result in lower performance and higher cost, compared to three phase motors. Consequently, three phase motors are preferred in these applications. It becomes important to deploy and use energy efficient, high performance, cost effective systems that convert the available single phase AC power to three phase AC power. To fulfil this, a Six Switch, single phase to three phase Matrix Converter is explored. This six switch TPMC is capable of providing output power for variable speed motor operation.

A Matrix Converter is an AC/AC converter that can directly convert fixed AC voltage into an AC voltage of variable amplitude and frequency without any energy storage element and is considered to be an alternative for two stage conversion. For any modulation scheme of matrix converter, the transfer functions for output voltage and input current can be obtained[1]. Through matrix converter, the terminal voltage and frequency of the induction generator in a WECS can be controlled in such way that the wind turbine is operating at its maximum power point for all wind velocities[2]. The reactive power supplied to the grid by a WECS based on an induction generator can be regulated[3]. Adaptive FLC can be used to achieve better efficiency and maximum wind power capture[5]. The power quality problems in grid connected WECS can be improved by matrix converters[4]. By using a matrix converter, it is possible to generate output frequencies that are not restricted by the source frequency. Most studies of the matrix converter have dealt with three-phase circuit topologies, modulation algorithms, and their implementation. A three switch single phase to three phase matrix power converter can be used in high power constant speed applications, where only single phase is available[7]. The above literature does not deal with the modelling of six switch single phase to three phase MCs.

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In this paper, a new control scheme that supplies a variable frequency three-phase power from a single phase source using Six Switch TPMC is presented. It is capable of providing a variable frequency three phase output voltage from a fixed single phase input. This work deals with the modelling of Six Switch MC.

2. Single Phase AC to Three Phase AC MCs

The matrix converter is a single stage converter with m x n bidirectional power switches designed to connect directly, an m-phase voltage source to an n-phase load. The most important characteristics of the matrix converter are: simple and compact power circuit, generation of load voltage with arbitrary amplitude and frequency, sinusoidal input and output currents, operation with unity power factor, bidirectional power flow capability and no energy storage elements[3].

The proposed MC converts a single phase AC input voltage of amplitude V_i at supply frequency ω_i directly to three phase AC output voltage at either required amplitude V_o or frequency ω_o in accordance with the pre-calculated switching angles[4]. It uses high frequency forced commutated switching devices which are capable of conducting in both directions.

Let the instantaneous input voltage be $v_i(t)$. The input voltage is given by

$$v_i(t) = \sqrt{2}\, V_i \cos \omega_i t \quad (1)$$

where ω_i is the input frequency.
The output voltages are given by

$$v_a(t) = \sqrt{2}\, V_o \cos \omega_o t \quad (2)$$

$$v_b(t) = \sqrt{2}\, V_o \cos (\omega_o t + 2\pi/3) \quad (3)$$

$$v_c(t) = \sqrt{2}\, V_o \cos (\omega_o t - 2\pi/3) \quad (4)$$

Where ω_o is the output angular frequency.

2.1 Six Switch TPMC Topology

Figure 1 shows a six switch TPMC which converts single phase AC to three phase AC.

It consists of six bidirectional switches S_1, S_2, S_3, S_4, S_5 and S_6 connecting the single phase input to the three phase output at the intersections[1]. This arrangement has the advantage of an independent control of the current in both directions. Only four switches are operated to develop 50 Hz output. All the six switches are operated for all other frequencies. Since each switch is a bidirectional switch, voltage reversal is possible[2].

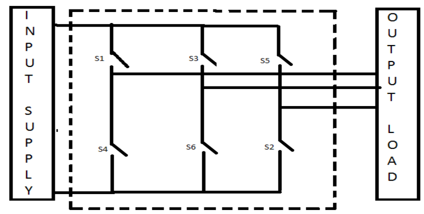

Figure 1. Block Diagram of single phase to three phase Six Switch TPMC.

2.2 Bidirectional Switches

The key element in a matrix converter is the fully controlled four-quadrant bidirectional switch, which allows high-frequency operation[5]. Each of the individual switches are capable of conducting current in both the directions, while at the same time capable of blocking forward and reverse voltages[6]. At present a true Bidirectional Switch (BDS) is still not available in the market and thus it must be realized by the combination of conventional unidirectional semiconductor devices as shown in Figure 2.

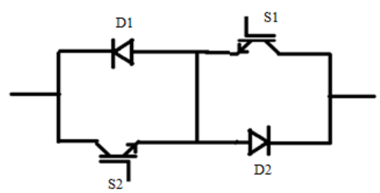

Figure 2. Common Emitter Bi-directional Switch.

3. Six Switch TPMC

The topology has three output legs with two bidirectional switches in each leg.

3.1 Simulink Model of Six Switch TPMC Operating at 50 Hz

The simulink model of Six Switch TPMC is shown in Figure 3. The model is developed for time domain simulation and the input is assumed to be 50 Hz[7]. From the available 230 V single phase AC, a step-up transformer is used to produce 440 V output voltages. In this work, a

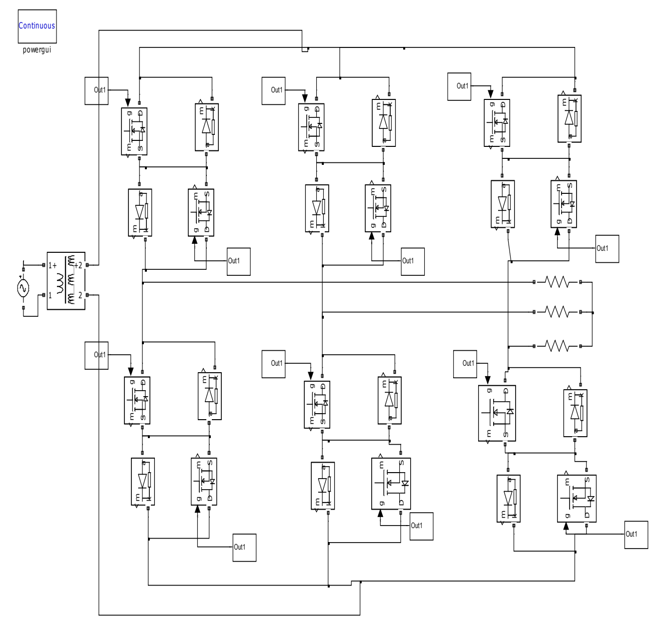

Figure 3. Simulink Model of Six Switch TPMC with R load.

new pulse generation module is developed for six switch three phase matrix converter and it is used for simulation[8].

3.1.1 *Simulation Results*

The output phase voltages of Six Switch TPMC with R load is shown in Figure 4. The simulations were done for a time period of 0.02 sec[10]. The control strategy is designed for an output frequency of 50 Hz.

From the waveforms, it can be seen that the output voltages are displaced by 120˚ .

3.1.2 *FFT Analysis*

The spectrum for phase voltages of Six Switch TPMC operating at 50 Hz is shown in Figure 5. It is obtained using FFT analysis available in POWERGUI block in SIMPOWERSYSTEM[9].

From the spectrum analysis, the average THD using six switch TPMC is found to be 50.44%. If PWM or SVM techniques are used, THD can be reduced considerably[11].

3.2 Simulink Results of Six switch TPMC Operating at 100 Hz for RL Load

The output phase voltages of Six Switch TPMC for 100 Hz output frequency with RL load are shown in Figure 6. It is observed that in one cycle of the input, two cycles of the output voltage are produced[12]. The frequency of the output voltage is changed from 50 Hz to 100 Hz. It is observed that the three phase output voltages are displaced by 120˚ . By proper switching strategy, output frequency that is integral multiple of input frequency can be produced[13].

It is observed that spikes are introduced during the switching instants. They can be reduced by proper switching strategy with safe commutation. The over voltages can be reduced by using diode clamp circuits[14].

3.3 Simulink Model of Six Switch TPMC for RL Load, 100 Hz with Diode Clamper

Figure 7 shows the six switch TPMC with RL load and diode clamping. The output voltage waveforms are obtained for 100Hz. The input frequency is assumed to be 50Hz[16]. When over voltage occurs, the diode conducts and the RC circuit maintains the voltage level at a safe value. In normal operation, the diodes are off and the clamp circuit has no influence on the MC operation. It is important to note that the power level is very low for the clamp circuit [15].

3.3.1 *Simulation Results*

The simulation parameter for diode clamp circuit is R = 100 ohms and C = 1 mF.

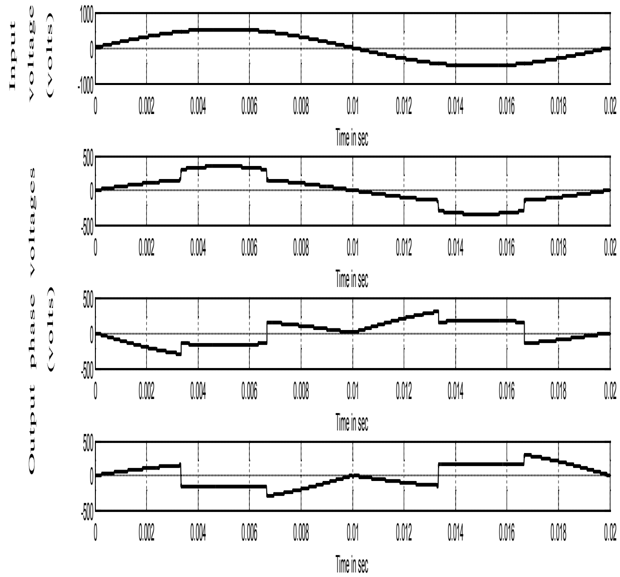

Figure 4. ˚ Output voltages of Six Switch TPMC with R load for 50Hz.

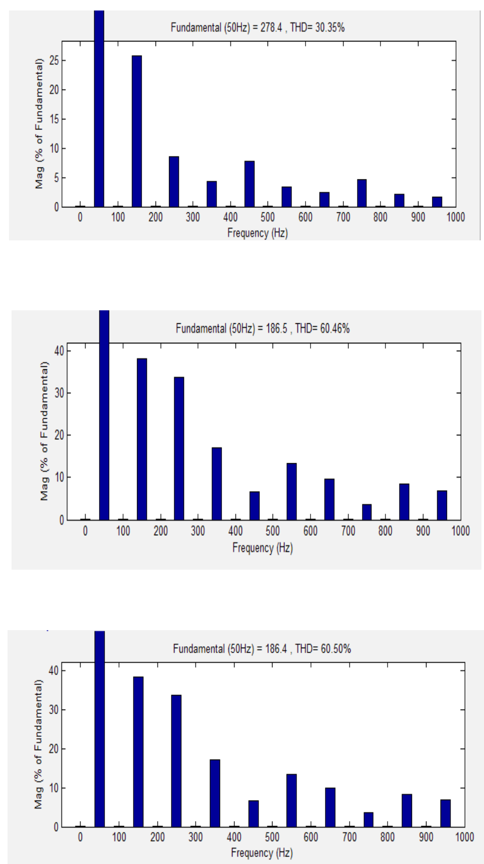

Figure 5. Spectrum of output phase voltages for Six Switch TPMC.

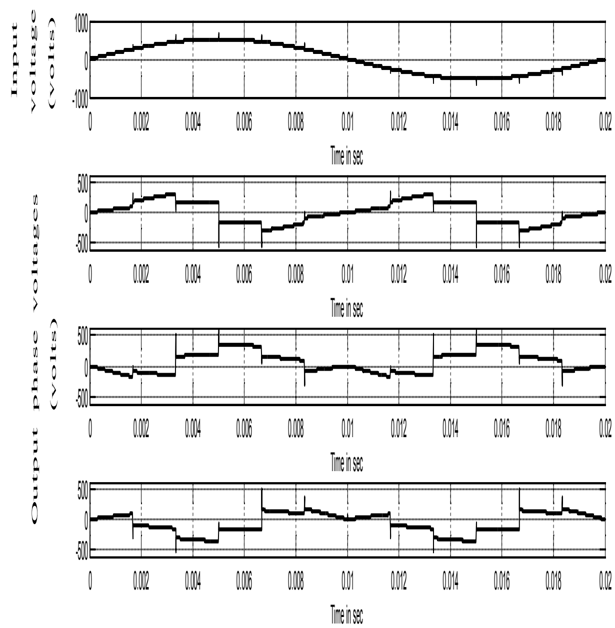

Figure 6. Output voltages of Six Switch TPMC with RL load for 100 Hz and without commutation.

The simulation result of six switch TPMC for RL load with diode clamping is discussed here. Figure 8 shows the three phase output voltages V_{RN}, V_{YN} and V_{BN} for 100Hz output. The input frequency is assumed to be 50Hz. The three phase output voltages are displaced by 120° each. It is observed that the over voltages are reduced by using diode clamp circuit[17-19].

4. Conclusion

Six Switch single phase to three phase matrix converters are modelled and simulated. From the results, it is observed that six switch TPMC produces 50.44 % harmonics. From this it is inferred that Six Switch TPMC is better than three switch TPMC.

It is also inferred that six switch TPMC can be used for loads requiring integral multiple of input frequency and six switch TPMC produces fewer harmonic than the three switch TPMC. Simulation results for three phase resistive and inductive loads were presented. MC is designed for output frequencies of 50Hz and 100Hz. The effectiveness of the six switch TPMC is verified by observing the output for various frequencies. The simulation results validate the developed conversion strategy. The simple control logic circuits developed make the proposed Six Switch TPMC highly attractive for drive applications. The simulation results are in-line with the predictions.

To reduce the load side over-voltages, diode clamp circuits are implemented. This concept can be extended with PWM and SVM techniques to produce better three phase output voltages. Consequently, the THD can be further reduced. The proposed Six Switch TPMC can be used to control the induction motor or synchronous motor.

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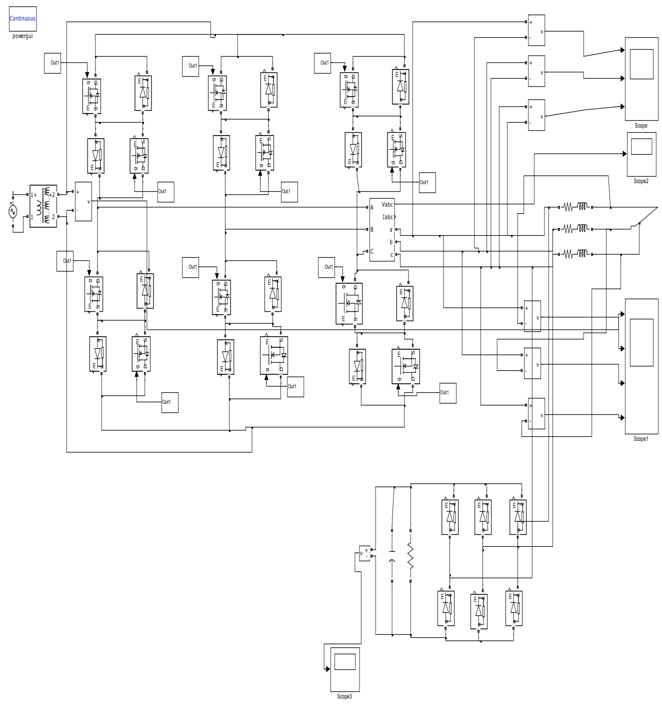

Figure 7. Simulink Model of Six Switch TPMC for RL load with diode clamper.

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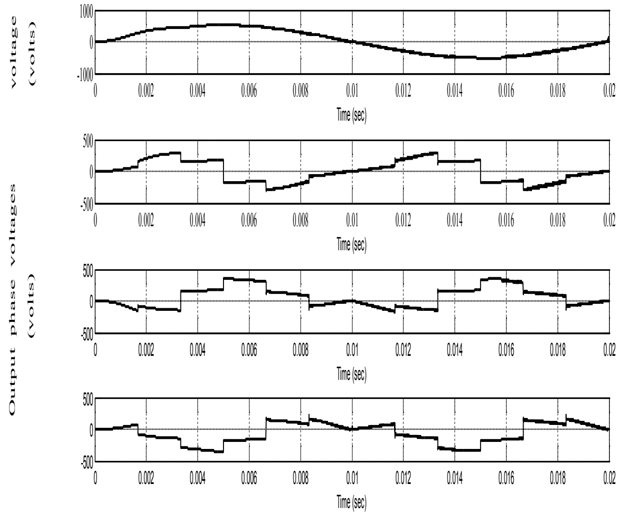

Figure 8. 3° Output voltages of Six Switch TPMC with RL load for 100 Hz and with diode clamping.

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