Modelling and Simulation of Single Phase Matrix Converter as a Cycloconverter, an Inverter and as a Rectifier using Power MOSFETs

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Abstract: The matrix converter is an advanced circuit topology that offers many advantages such as ability to regenerate energy back to the utility. It is very simple in structure and has powerful controllability. In matrix converter, input voltage is equal to output voltage. In matrix converter the bidirectional switch itself is used as the freewheeling paths with carefully arranged switching sequences, thus providing the required freewheeling operation similar to those available in other converter topologies. This paper presents the function of single phase matrix converter (SPMC) as a cycloconverter, an inverter and as a rectifier. Logic gates are used to generate control pulses for the matrix converter switches to produce output. The metal-oxide-semiconductor field-effect transistor (MOSFET) is used for the switching device. The switching sequences for the matrix converter to operate as a cycloconverter, an inverter and as a rectifier are presented and assessed using MATLAB/Simulink (MLS) with the SimPowerSystem block set and the results of simulations are presented to evaluate the behavior and feasibility of the proposed topology. The operation of proposed system has been found satisfactory.

IndexTerms: **Single phase matrix converter (SPMC), Logic gates, Metal-oxide-semiconductor field-effect transistor (MOSFET), MATLAB/Simulink (MLS).**

I. INTRODUCTION

Recently, there has been considerable, interest in the potential benefits of the matrix converter technology, especially in providing a universal "all silicon" solution for AC-AC conversion, removing the need for reactive energy storage components used in conventional rectifier-inverter based systems. The matrix converter has a distinct advantage of affording bi-directional power flow with any desired number of input and output phases [1]-[5]. The matrix converter is a forced commutated converter which uses an array of controlled bidirectional switches as the main power elements to create a variable output voltage system with unrestricted frequency. It does not have any dc-link circuit and does not require any large energy storage elements [6]. Matrix converters offer many advantages over traditional topologies, such as the ability to regenerate energy back to utility, sinusoidal input and output currents and a controllable input current displacement factor. The size of the converter can also be reduced since there are no large reactive components for energy storage [7]. The matrix converter concept was first introduced by Gyugyi and pelly [8] in 1976.

Obviously lot of research has been done on three phase matrix converter but very few of researchers have done research on single phase matrix converter [10]. The first SPMC was developed by Zuckerberger [9]. Today, the research is mainly focused on operational and technological aspects: reliable implementation of commutation strategies, protection issues, implementation of bidirectional switches and packaging, operation under abnormal conditions, ride-through capability and input filter design [6].

The aim of this paper is to describe the work involved in modelling and simulation on the implementation of single-phase matrix converter (SPMC) as a cycloconverter, an inverter and as a rectifier subjected to passive load conditions. The control pulses were generated for the matrix converter switches to produce output. The switching sequences for the matrix converter to operate as a cycloconverter, an inverter and as a rectifier are presented and determined using MATLAB/Simulink (MLS) with SimPowerSystem block set for providing a flexible and versatile simulation environment.

II. A SINGLE PHASE MATRIX CONVERTER

The SPMC is shown in Figure 1, which uses four bidirectional switches, each capable of conducting current in both directions, blocking forward and reverse voltages and are so arranged such that input terminals can be connected to output terminals in a matrix manner [11]. It comprises of four ideal switches S1, S2, S3 and S4 capable of switching between states without any delay. Nowadays, there is no bidirectional switch semiconductor that has the capability of blocking voltage and conducting current in both directions available in the market that is required for the application of the matrix converter [12]. However, as in Figure 2, in order to fulfill the requirement, two MOSFETs are used back to back that functions as bidirectional switch for the matrix converter. Diodes are used to provide reverse blocking capability of the switch itself. The process of switching on/off the bidirectional switches makes the required variable voltage and frequency waveforms at the output of matrix converter. One matrix converter can be used for different power circuit for various converters like Cycloconverter, Inverter, and Rectifier etc.

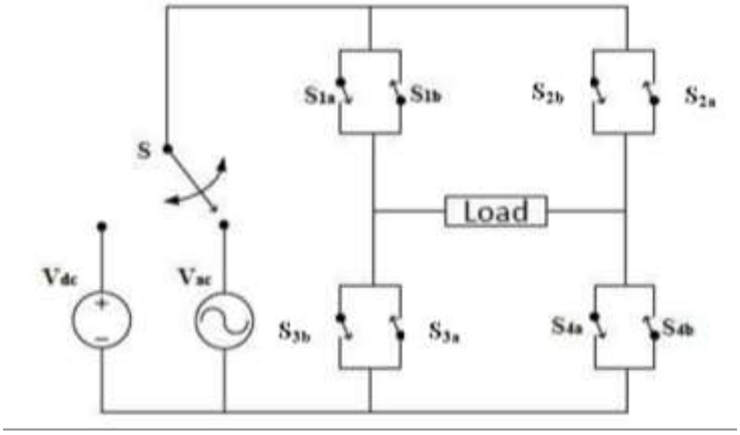

Figure 1: Power circuit of Single Phase Matrix Converter.

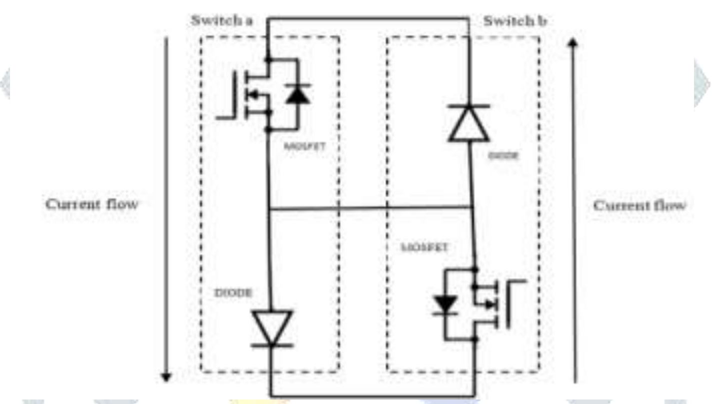

Figure 2: Bi-directional switch configuration module.

III. SPMC AS A CYCLOCONVERTER

A device which converts input power at one frequency to output power at different frequency with one-stage conversion is called cycloconverter.

In order to enable a single phase matrix converter (SPMC) to perform a function of cycloconverter driver circuits are designed to generate the control pulses that are used to control the power switches comprising MOSFETs in the SPMC circuit. Here the pulse generation is obtained by using pulse generator blocks and logic gates in MATLAB/Simulink software (MLS). The SPMC comprises four bidirectional switches S1-S4 “a” or “b” where “a” or “b” is current flow directions markers (“a” – forward direction, “b” – opposite direction) of each switch. If input is AC then there are four switching states that can be explained with the cycloconverter operation for 100Hz output frequency. Figures 3 to 6 shows the cycloconverter operation for both positive and negative half cycles of input.

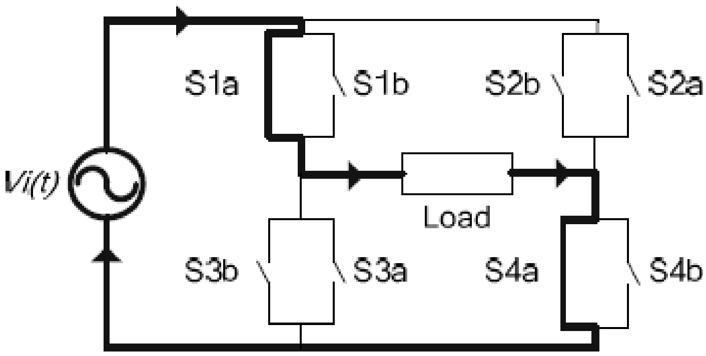

Figure 3: State 1 (Positive cycle).

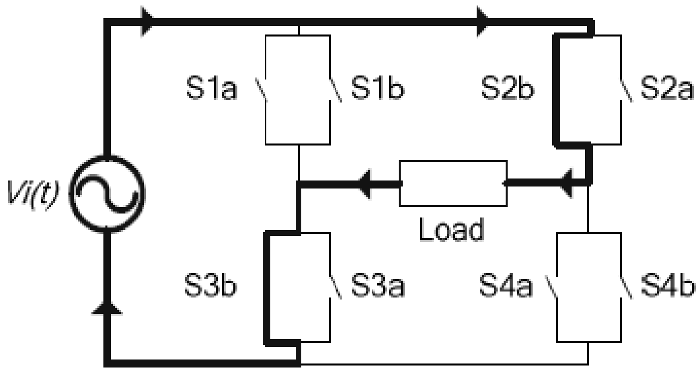

Figure 4: State 2 (Positive cycle).

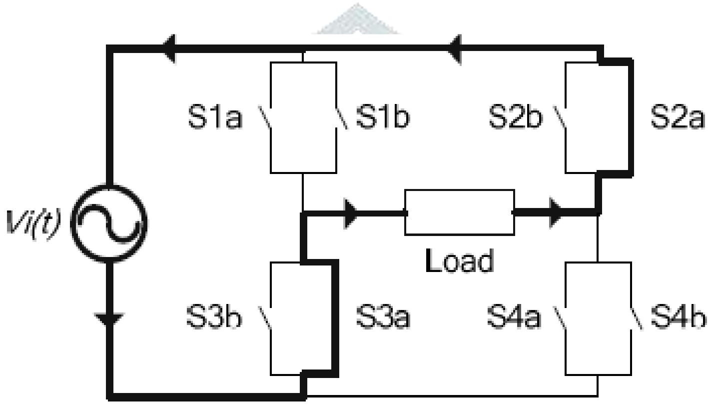

Figure 5: State 3 (Negative cycle).

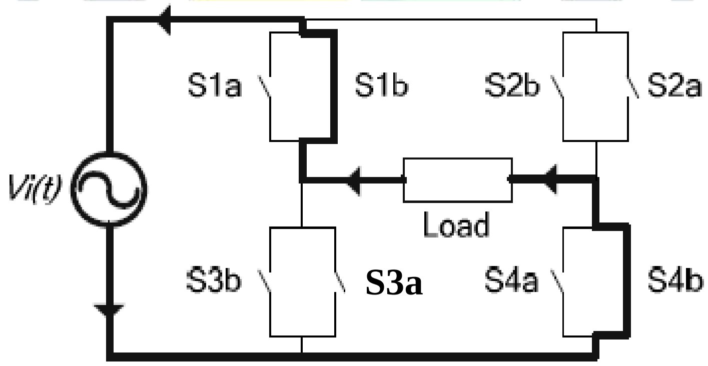

Figure 6: State 4 (Negative cycle).

- During state 1 only two switches S1a and S4a will be ON and conduct the current flow during positive cycle of the input supply. Due to reverse biasing of diodes, the Switches S1b, S4b, S2a & S3a will not conduct the current flow through them. During state 1, no pulses are applied to the switches S2b and S3b (i.e. switches S2b & S3b are in OFF state).

- During state 2 only two switches S2b and S3b will be ON and conduct the current flow during positive cycle of the input supply. Due to reverse biasing of diodes, the Switches S2a, S3a, S1b & S4b will not conduct the current flow through them. During state 2, no pulses are applied to the switches S1a and S4a (i.e. switches S1a & S4a are in OFF state).

- During state 3 only two switches S3a and S2a will be ON and conduct the current flow during negative cycle of the input supply. Due to reverse biasing of diodes, the Switches S3b, S2b, S4a & S1a will not conduct the current flow through them. During state 3, no pulses are applied to the switches S4b and S1b (i.e. switches S4b & S1b are in OFF state).

- During state 4 only two switches S4b and S1b will be ON and conduct the current flow during negative cycle of the input supply. Due to reverse biasing of diodes, the Switches S4a, S1a, S3b & S2b will not conduct the current flow through them. During state 4, no pulses are applied to the switches S3a and S2a (i.e. switches S3a & S2a are in OFF state).

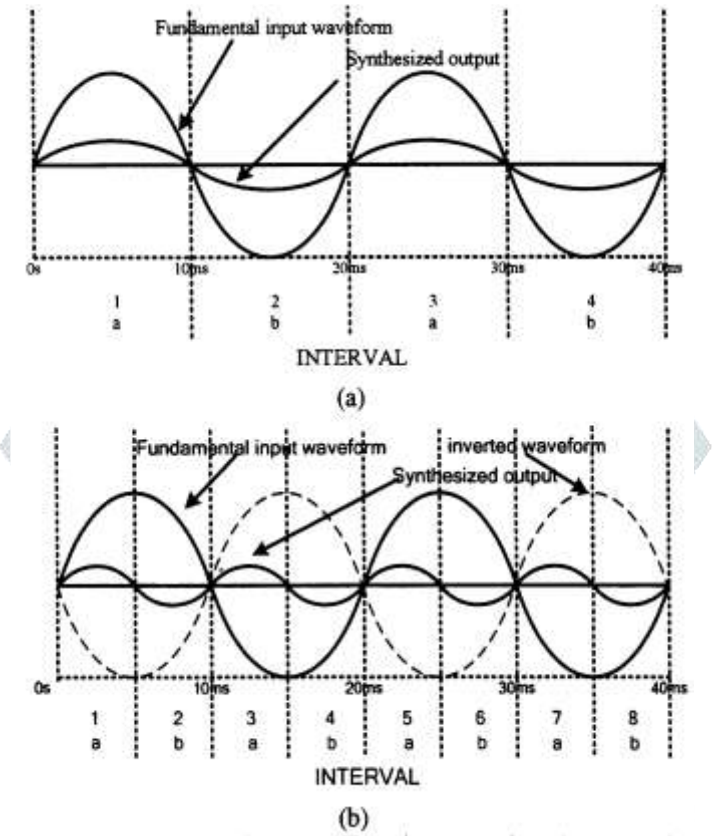

Figure 7: Sinusoidal input and synthesized output (a) 50Hz (b) 100Hz reference.

Table 1: Switching sequence of SPMC as a Cycloconverter

Input frequency	Target output frequency	State	Conducting switches	Input cycle
50Hz	100Hz	1	S1a & S4a	Positive
		2	S2b & S3b	Positive
		3	S3a & S2a	Negative
		4	S4b & S1b	Negative
	50Hz	1	S1a & S4a	Positive
		2	S4b & S1b	Negative

IV. SPMC AS AN INVERTER

Inverter refers to the process of converting a DC voltage or current to AC voltage or current.

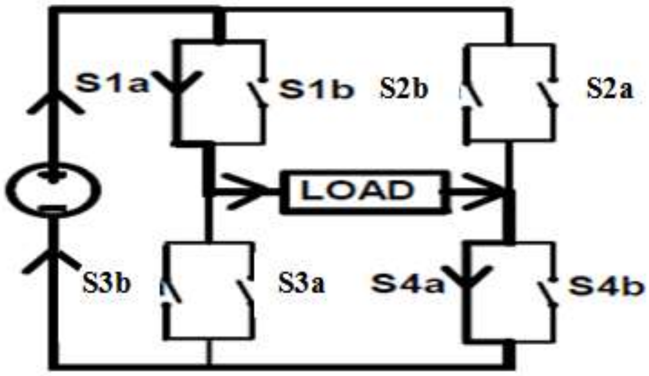

Figure 8: State 1 (Positive), for positive output.

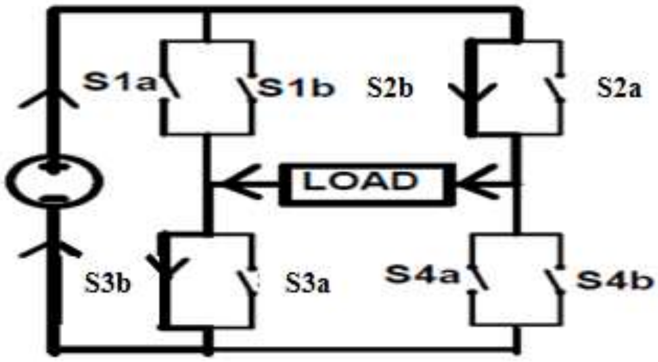

Figure 9: State 2 (positive), for negative output.

For a single phase matrix converter (SPMC) to perform a function of an inverter DC supply is used instead of AC supply. Here only two states (Positive) are implemented (state 1 and state 2) because of DC supply there will be no negative cycle portion. For positive half output, switches S1a and S4a will conduct while for negative output, switches S2b and S3b will conduct as shown in Figures 8 and 9 respectively.

Table 2: Switching sequence of SPMC as an Inverter

State	Conducting switches	Input (DC)
1	S1a & S4a	Positive
2	S2b & S3b	Positive

V. SPMC AS A RECTIFIER

Rectifier refers to the process of converting an AC voltage or current to DC voltage or current. The entire operation of SPMC as a rectifier can be explained in two states (State 1 & State 2). During the positive cycle of the input source, switches S1a and S4a are turned 'ON' and the current flow is given in fig 10. During the negative cycle of the input source, switches S3a and S2a are turned 'ON' and the current flow is given in fig 11.

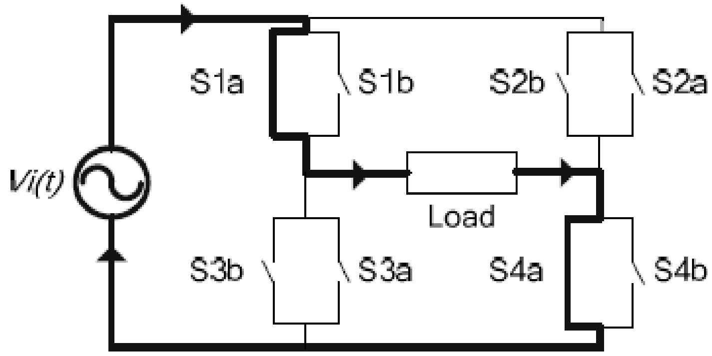

Figure 10: State 1 (Positive).

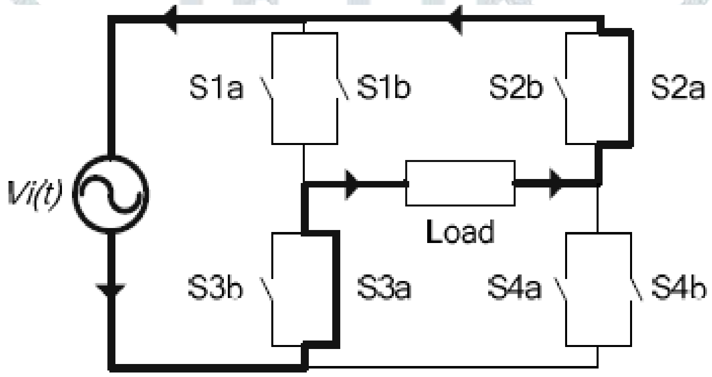

Figure 11: State 3 (Negative).

Table 3: Switching sequence of SPMC as a Rectifier

State	Conducting switches	Input supply (AC)
1	S1a & S4a	Positive
3	S3a & S2a	Negative

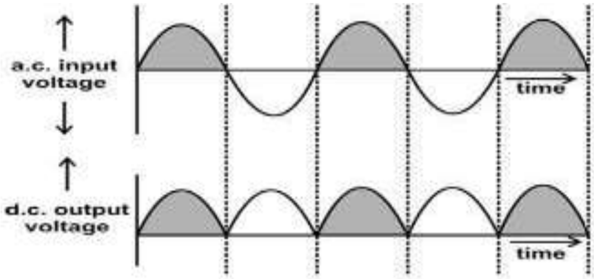

Figure 12: Theoretical waveform of SPMC as a rectifier.

VI. SIMULATION MODEL AND RESULTS

Simulation is carried out for a single phase matrix converter as a cycloconverter, an inverter and as a rectifier using MATLAB/Simulink software. Figures 20 and 21 illustrate input voltage, output voltage and output current for cycloconverter operation wherein the input voltage is 34 V (AC), 50Hz with Resistive load.

Figure 22 illustrates input voltage and output voltage for inverter operation wherein the input voltage is 30 V (DC). Switching sequences have been provided using a pulse generator. Bi-directional switches are used to block the voltage and conduct the current in both directions. Results were obtained for 50Hz to 100Hz, 50Hz to 50Hz with switching sequences as given in [TABLE 1 and TABLE 2]. Fig 23 illustrates rectifier operation [TABLE 3].

The scheme of the block diagram describing the matrix converter as cycloconverter is shown in figure 13.

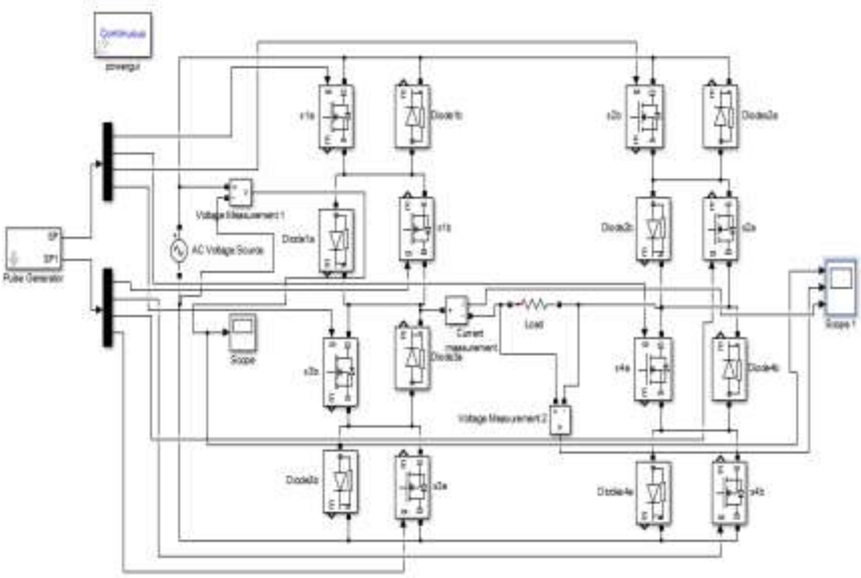

Figure 13: Simulation model of SPMC as Cycloconverter.

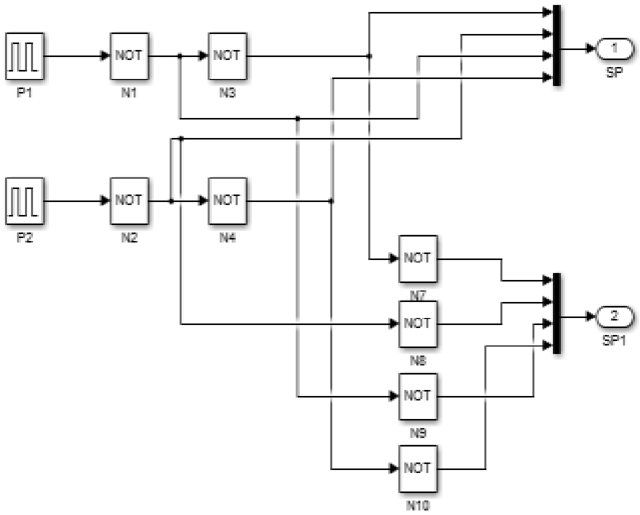

Figure 14: Driver circuit.

Driver circuits are designed to generate the pulses that are controlled using the switching states as in table 1 for generating 100Hz and 50 Hz output frequency. In Fig.14, two pulse generator blocks (P1 and P2) are used to generate control pulses. The time period of 10ms is given to both pulse generator blocks. The pulse width is taken as 50% of the time period and delay for P2 is given as 5ms. Output from the pulse generator block is complemented using NOT gate blocks. The multiplexer block is used to select several digital input signals from NOT gate blocks and forwards the selected input into a single line (SP & SP1). The input to the multiplexer should be always given through logic gates; it will not be directly connected from pulse generator block.

The scheme of the block diagram describing the matrix converter as an inverter is shown in figure 15.

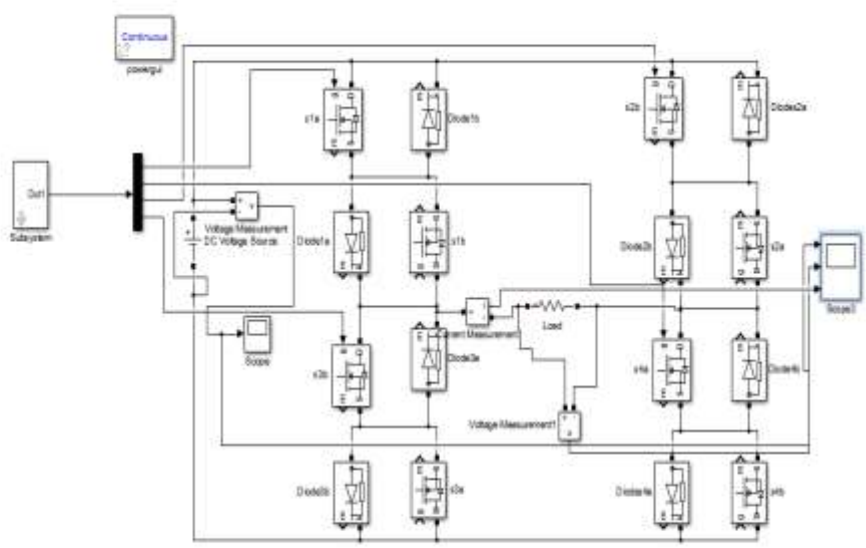

Figure 15: Simulation model of SPMC as an Inverter.

The scheme of the block diagram describing the matrix converter as a rectifier is shown in figure 16.

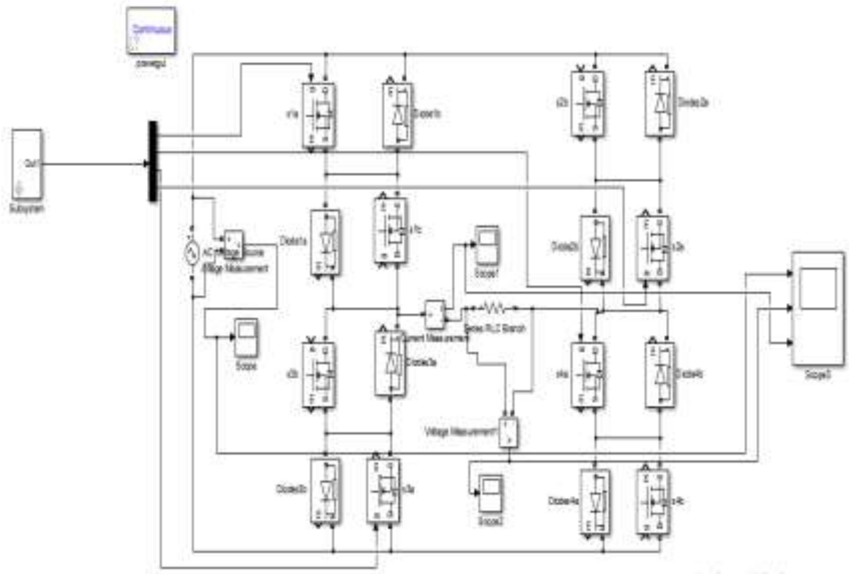

Figure 16: Simulation model of SPMC as a Rectifier.

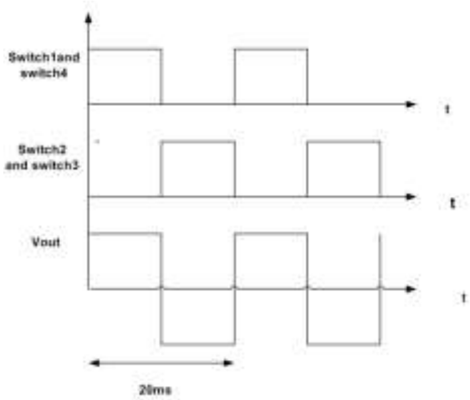

Figure 17: Theoretical waveform of SPMC as an Inverter.

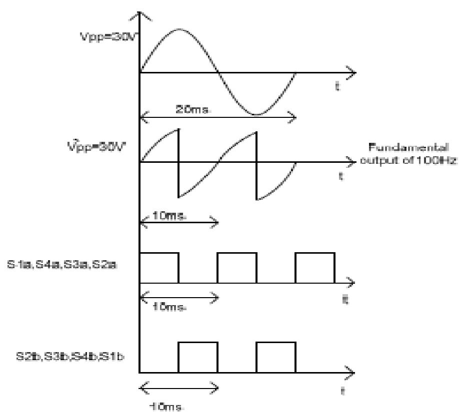

Figure 18: Theoretical waveform of SPMC as a Cycloconverter.

Table 4: Simulation parameters

Parameters	As a Cycloconverter	As an Inverter	As a Rectifier
Input voltage	34V (AC)	30V (DC)	34V (AC)
Input frequency	50Hz	-	50Hz
Resistive load	100Ω	100Ω	100Ω
Output voltage	34V	30V	34V
Output frequency	100Hz	50Hz	-
Output current	0.34A	0.34A	0.34A

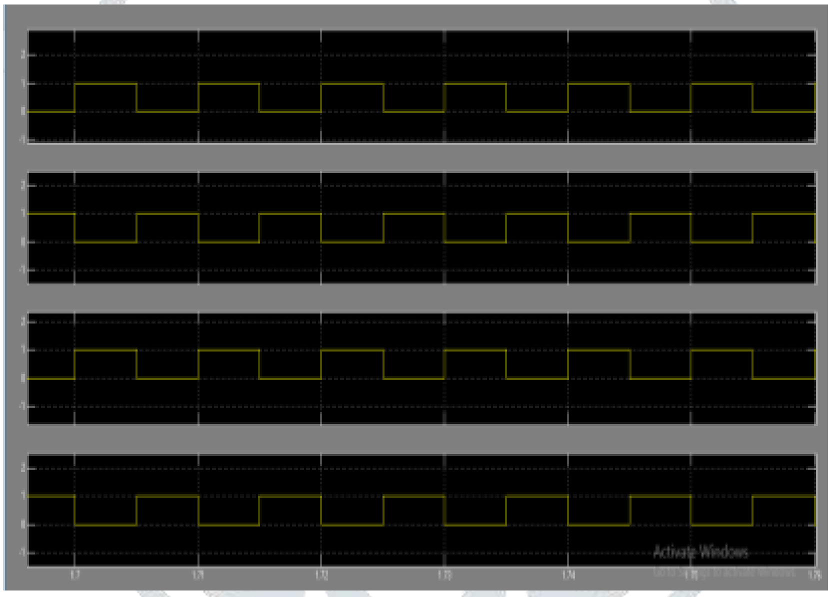

Figure 19: Simulation result for switching pattern generator.

Input voltage (f=50Hz)

Output voltage (f=100Hz)

Output current

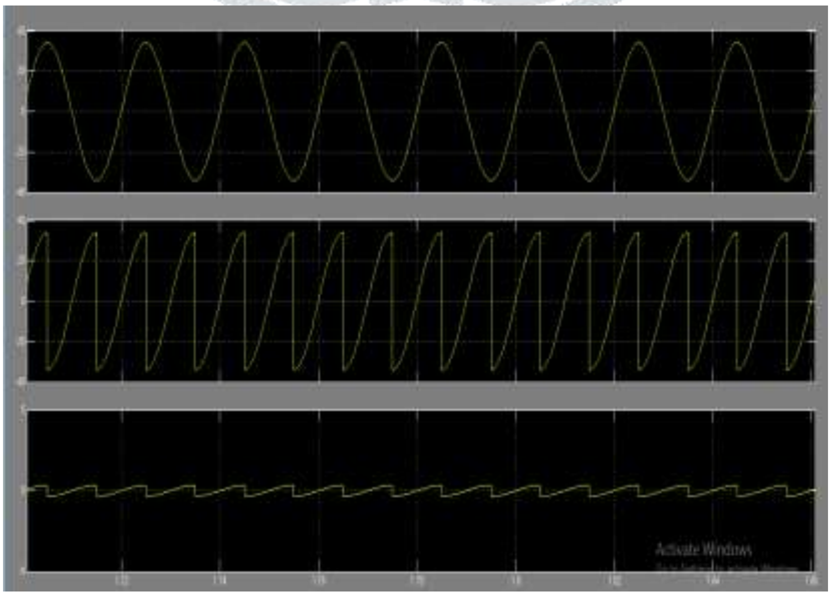

Figure 20: Simulation result of SPMC as a Cycloconverter. Output of 100Hz obtained for an input of 50Hz.

Input voltage (f=50Hz)

Output voltage (f=50Hz)

Output current

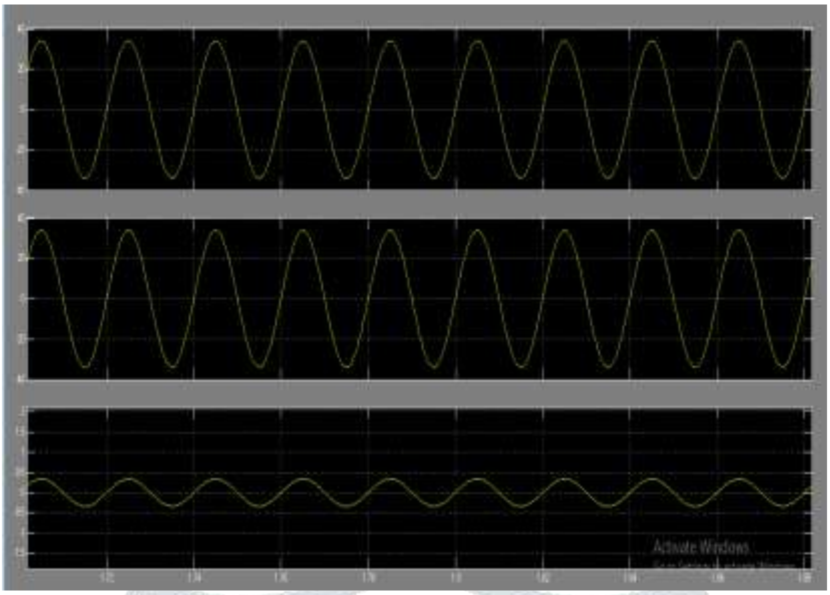

Figure 21: Output of 50Hz obtained for an input of 50Hz.

Input voltage (30V)

Output voltage

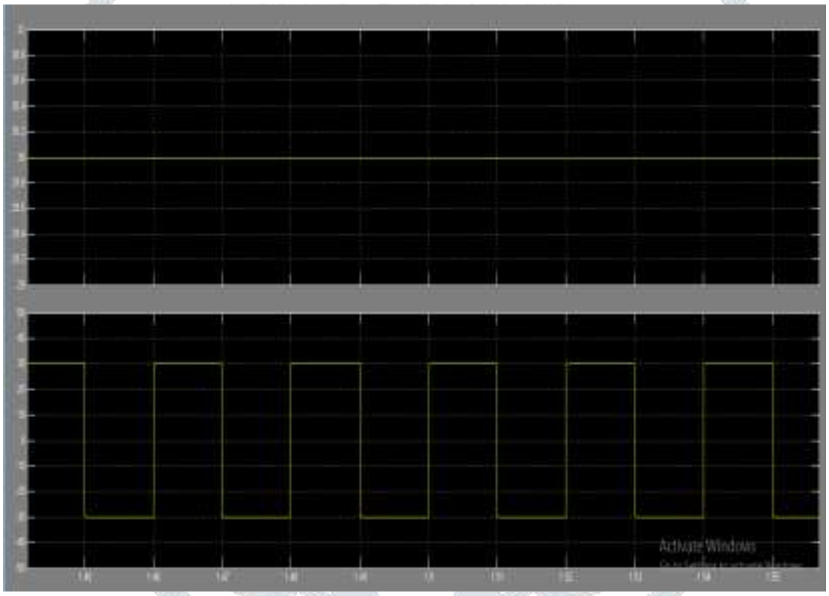

Figure 22: Simulation waveforms of output voltage of SPMC as an inverter.

Input voltage (f=50Hz)

Output voltage

Output current

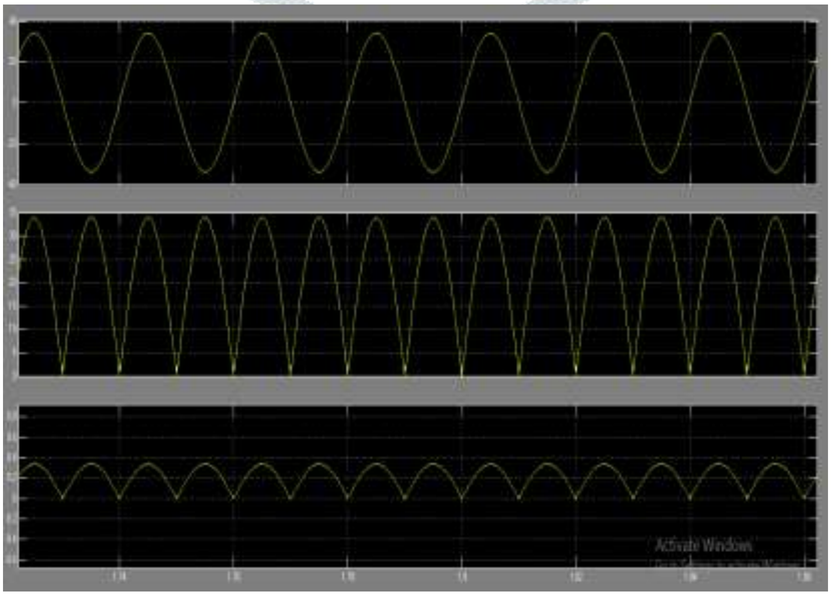

Figure 23: Simulation waveforms of output voltage and output current of SPMC as a rectifier.

VII. CONCLUSION

In this paper, operation and simulation of SPMC as a cycloconverter, an inverter and as a rectifier has been elucidated. This topology replaces two stage classical converter (AC-DC-AC) for generation of high frequency directly without need of energy storage element. Thus lack of energy storage element will enhance the efficiency level. When fed from the mains at constant frequency and amplitude, the converter is capable of synthesizing a constant output voltage with variable frequency. Using MATLAB/Simulink (MLS), simulation outputs were observed to confirm the predicted performance of the proposed topology.

To date, all published studies dealt with the use of Sinusoidal pulse width modulation (SPWM) or other modulation techniques as the switching algorithm in this SPMC, there exists possible reversal current if inductive loads are used during switch turn off. A systematic switching sequence is required in order to avoid output voltage and current spikes as given in tables 1, 2 and 3. So, in this work logic gates are used to generate control pulses for the matrix converter switches to produce output without any spikes. Simple resistive load has been used to reduce complexities of the circuit. Under this loading condition, the converter's performance has been tested for an output frequency of 50Hz and 100Hz. The MOSFETs are used as the main power switching device due its high power applications and fast switching frequency for fine control.

One Matrix Converter can be used for different power circuit for various converters like Rectifier, Inverter, Cycloconverter and AC voltage controller etc.

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