# A NOVEL SWITCHING STRATEGY FOR SINGLE PHASE UNIVERSAL MATRIX CONVERTER WITH HARDWARE IMPLEMENTATION


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## ABSTRACT

*This paper presents the execution of a single phase matrix converter as a universal power electronic converter. The Matrix converter can act as rectifier, controlled rectifier (converter), inverter, chopper, cyclo converter and cyclo inverter by a novel switching logic. Normal sinusoidal PWM and square wave signal generation have been used here, which describes a simple algorithm for multiple purposes. Induction motor load is connected to Direct Matrix converter and its harmonics are verified. Simulation and hardware model is developed and the results obtained here demonstrate a high performance, low THD universal matrix converter.*



**Key words:** *Single phase Matrix converter, Rectifier, Converter, Inverter, Chopper, Cyclo converter, Induction Motor, Harmonic Analysis, Hardware*


## I. INTRODUCTION

The matrix converter is the most general converter type in the family of AC to AC direct converter. On the one hand, the matrix converter fulfills the requirements to provide a sinusoidal voltage at the load side. On the other hand, it is possible to adjust the unity power factor on the main side as per Venturini and Alesina [1]. The advantage of matrix converter is that, it does not require intermediate energy storage and have lower switching losses, thus delivering low harmonics in the load side as per sunter [2]. The controlled output waveform can be obtained on varying the modulation technique with minimum number of switches as compared with AC-DC-AC converter [3].

The Single Phase Matrix Converter (SPMC) was first realized by Zuckerberger [4]. It has been shown that the SPMC could be operated as a direct AC-AC single-phase converter [5], DC chopper [6], rectifier [7] and inverter [8].

For AC-DC and DC-AC conversion different converters are used. But in certain applications like uninterruptable power supply, rectifiers are used to convert AC into DC for charging the batteries and inverters are used to convert DC into AC, thus two conversions are required [9]. So, a number of conversion kits are required, which increases the total cost and also the space requirement [10].

This paper describes a Single Phase Matrix Converter (SPMC) designed with four bi-directional switches and a simple switching logic. An appropriate switching strategy is developed to realize a SPMC as a universal power electronic converter, which is named as universal matrix converter [11]. The input is either an AC or a DC supply. Normal sinusoidal PWM and a square wave signal generation are used to synthesize these converters [12]. The switching scheme is then executed in computer simulation models to expose its basic behavior. A simple resistive load is used to reduce the complexities of the circuit. Later, an induction motor load has been introduced to evaluate the harmonic analysis of the converter. Results of the simulation are presented to verify that the proposed technique is feasible.

The laboratory hardware setup of SPMC, consist of four bi-directional IGBT switches and a PIC 16F877 micro controller as a driver circuit. This matrix converter model performs all power converter modules and hence it diminishes the need to design new hardware for a particular converter [13]. The use of a Matrix Converter in the future reduces the need for learning many varying converter topologies and that is now the subject of current active research [14].

## II. SINGLE PHASE MATRIX CONVERTER

The Topology of single-phase matrix converter is shown in figure 1. It consist of matrix input and output lines with four bi-directional switches connecting single phase input to the single phase output at the intersections. Four ideal switches $S_1$, $S_2$, $S_3$ and $S_4$ consist of two IGBTs connected back to back as a and b, and is capable of conducting current in both directions.

Bi-directional switches have two basic rules: (i) do not connect two different input lines to the same output lines to avoid short circuit and (ii) do not disconnect the output lines to avoid open circuit.

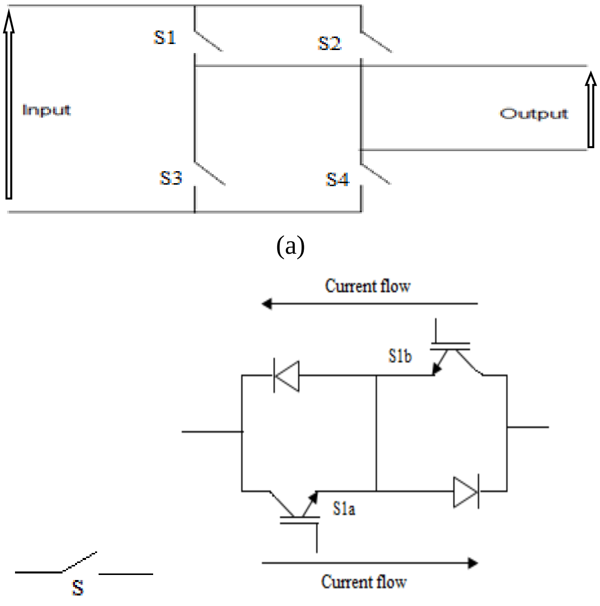


FIG.1 (a) Topology of SPMC ; (b) single switch; (c) expansion of each switch – bidirectional switches

## III. CIRCUIT REALIZATION

Realization of Matrix Converter as universal power electronic converter is explained here. The basic circuit of a Matrix Converter [4] is shown in figure 2. A Matrix Converter is capable to convert fixed AC to variable (controlled) AC. The output AC may be of variable voltage or variable frequency.

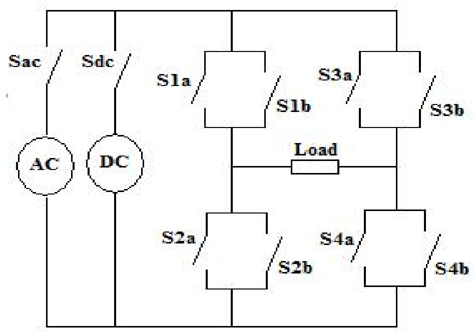


FIG.2: Basic circuit of a Matrix Converter

Realization as rectifier and controlled rectifier (converter) is shown in figure 3, where input is AC and the output is either uncontrolled DC or variable DC. Variable output is obtained by applying triggering pulse at a delay. Figure 3(a) represents for positive half cycle and 3(b) for negative half cycle. The bold line signifies the current conduction.

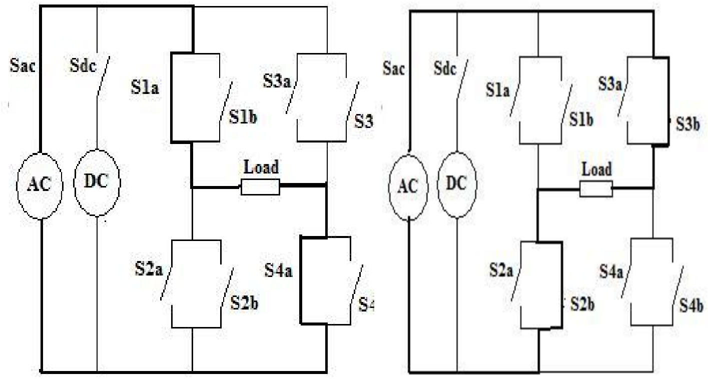


FIG.3: Switching states as Rectifier

Realization as inverter is shown in figure 4, where input is DC and the output is variable AC. The magnitude of voltage is controlled by SPWM and the frequency is controlled by modulating frequency.

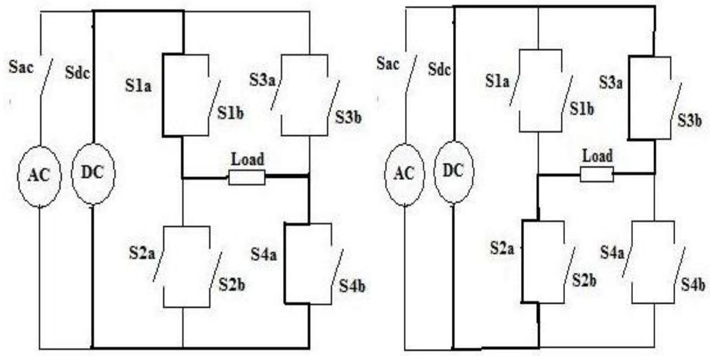


FIG.4: Switching states as Inverter

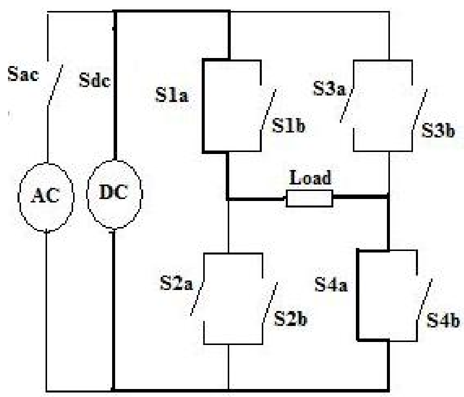


FIG.5: Switching states as Chopper

Realization as chopper is shown in figure 5, where input is DC and the output is variable DC. First quadrant chopper is shown here. It is also conceivable for four quadrant operation.

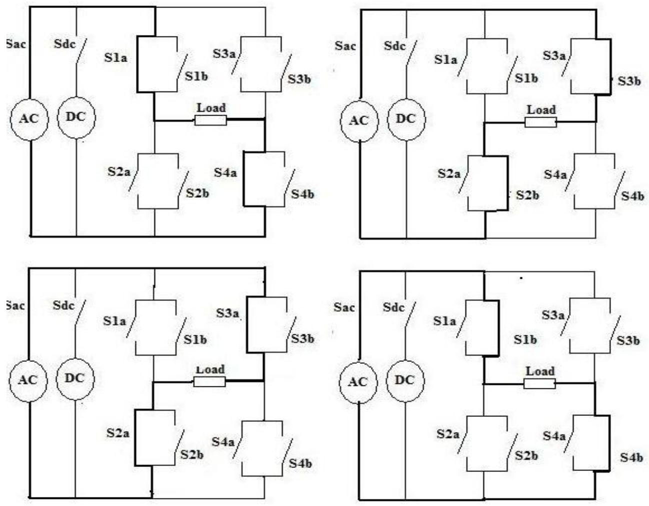


FIG.6: Switching states as Cyclo-converter and cyclo-inverter

Realization as cyclo-converter and cyclo-inverter is shown in figure 6, where input is fixed AC and the output is AC with variable frequency. Figure 6 (a) and 6 (b) represents for positive half cycle; 6 (c) and 6 (d) for negative half cycle. The output frequency can be varied by altering the modulating frequency.

## IV. SWITCHING STRATEGY

Two different modulations have been used viz., sinusoidal and square wave modulation signals, in order to demonstrate the output from the point of harmonic content and input voltage utilization [14, 15].

Its instantaneous input voltage is $V_i\ (t)$ and its output voltage is $V_o\ (t)$ . This topology converts the input voltage, $V_i\ (t)$ with constant amplitude and frequency.
If the input signal is

$$V_i\ (t) = V_{im} \cos \omega_i\ t \qquad (1)$$

Then, the fundamental output voltage will be

$$V_o(t) = V_{om} \cos \omega_o t \qquad (2)$$

With a fundamental frequency

$$f_o = f_m - f_i \qquad (3)$$

where, $f_o$ =Output Frequency, $f_m$ =Modulation Frequency, $f_i$ =Input Frequency. The four power switching devices are switched at high frequency, $f_s$, ($f_s \gg f_i$ and $f_o$, $f_i = \omega_i / 2$ pi and $f_o = \omega_o/2$ pi) [4].

The switching combinations for a matrix converter are explained as, the state of the 4 bi-directional switches *Sij* (*i* = 1,2,3,4 and *j* = a,b) where 'a' and 'b' represent driver one and two respectively following the rules [4] below;
At any time ' *t*', any two switches *Sij* below will be ON;

- (*i* = 1, 4 and *j* = a) will conduct the current flow during positive cycle of input source. (state 1)
- (*i* = 1, 4 and *j* = b) will conduct the current flow during negative cycle of input source. (state 2)
- (*i* = 2, 3 and *j* = b) will conduct the current flow during positive cycle of input source. (state 3)
- (*i* = 2, 3 and *j* = a) will conduct the current flow during negative cycle of input source. (state 4)

| CONVE-RTER | INPUT SUPPLY | SWITCHING SCHEME | OUTPUT NATURE |
|---|---|---|---|
| Rectifier | AC | S1a, S4a (positive half cycle) | DC (un-controlled) |
| | | S2b, S3b (negative half cycle) | |
| Converter | AC | S1a, S4a (positive half cycle) | DC (controlled) |
| | | S2b, S3b (negative half cycle) | |
| Inverter | DC | S1a, S4a | AC (controlled) |
| | | S3a, S2a | |
| Chopper | DC | S1a, S4a | DC (controlled) |
| Cyclo-converter | AC | S1a, S4a S3b, S2b | AC (controlled) |
| | | S2a, S3a S4b, S1b | |
| Cyclo-inverter | AC | S1a, S4a S3b, S2b | AC (controlled) |
| | | S2a, S3a S4b, S1b | |
| Matrix Converter | AC | S1a, S4a S3b, S2b | AC (controlled) |
| | | S2a, S3a S4b, S1b | |

TABLE 1: Switching Strategy

This switching strategy is clearly mentioned in the Table 1 for a universal matrix converter [11]. The standard SPWM technique is illustrated [9] in figure 7.

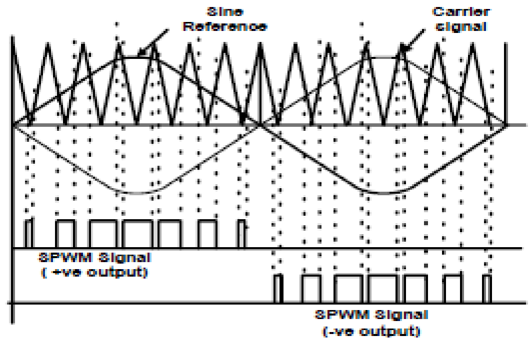


FIG.7: SPWM modulation technique

## V. SIMULATION

Matrix converter is a single stage converter which converts fixed AC input into variable voltage / variable frequency AC output. Simulation is executed in MATLAB/Simulink [16] platform.

The Simulink models are presented in figure 8, 9 and 10. It consists of four bi-directional switches, a pulse generation block and a clamp circuit. For simplicity, a resistive load is connected. A clamp circuit does not restrict the peak-to-peak expedition of the signal, but moves it up or down by a fixed value. Diodes are used for clamping and a capacitor is used to maintain an altered dc level at the clamper output. Hence the clamp circuit acts a protective device for converter. A snubber circuit consists of diodes that connected in anti-parallel arrangement with IGBT bi-directional switches. It facilitates a free-wheeling path for the switch, in case of an inductive load. Sinusoidal pulse width modulation techniques are adopted for driving the switches [14].

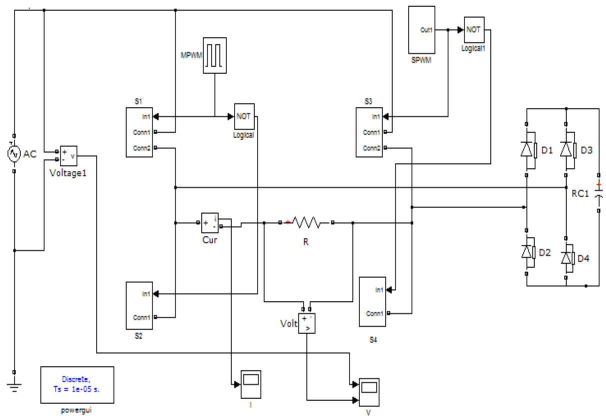

FIG.8: Simulation model of Converter

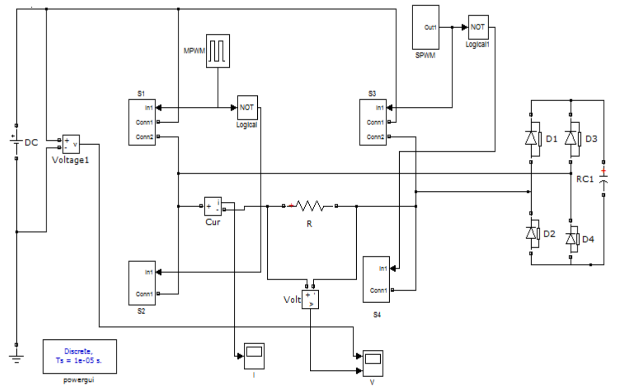

FIG.9: Simulation model of Inverter

Matrix converter performing as converter (controlled rectifier) is shown in figure 8, where input source is AC. and Matrix converter performing as inverter is shown in figure 9, where input source is DC. Simulation model of Matrix converter with induction motor load is shown in figure 10.

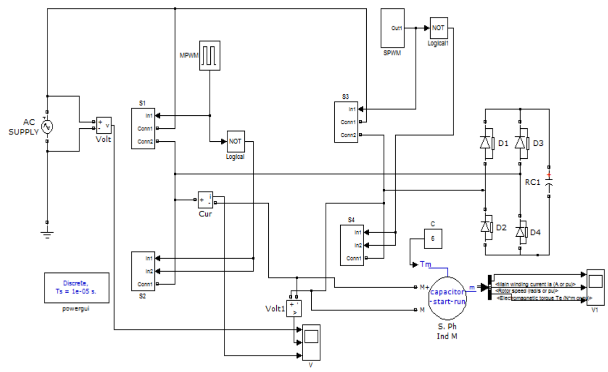

FIG.10: Matrix converter model with IM load

## VI. HARDWARE IMPLEMENTATION

The Functional block diagram of the hardware circuit is shown in the figure 11.

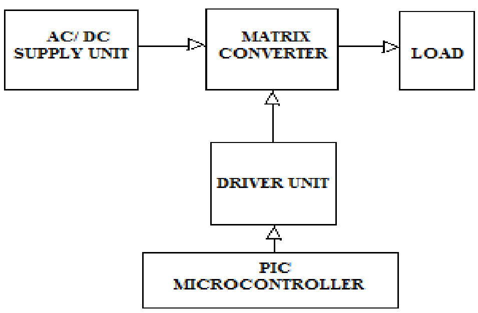


FIG. 11 Functional block diagram of SPMC

It consists of four bi-directional switching arrangements as matrix converter, a driver unit, an AC and DC supply unit, PIC micro controller and resistive load unit. The microcontroller [17] used here is PIC 16F877. The microcontroller which produces the pulse and delay signal according to the coding feed. These signals trigger the IGBT switches accordingly through the driver unit. Two push button switches are provided to change the converter performances as rectifier or inverter or converter [18]. Thus the fixed supply voltage can be converted to the required output. The Proto type model of SPMC is assembled and is shown in figure 12.

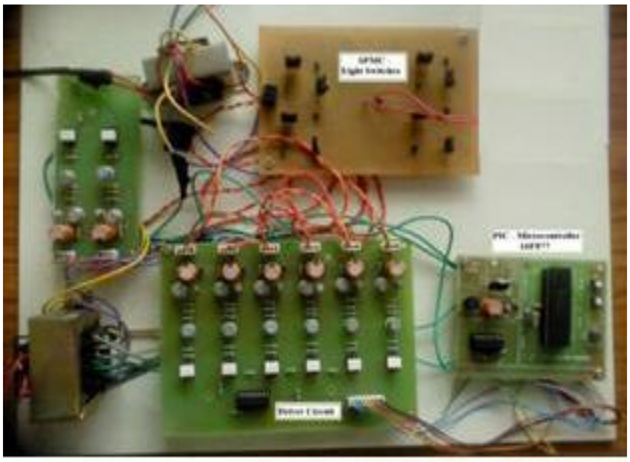

FIG 12: Single phase Matrix Converter Model

The experimental arrangement of SPMC is shown in figure 13. An IGBT power module (Driver Unit) is used to produce PWM pulses for eight IGBT power switches. The signals for these pulses are established through PIC micro controller (PIC MC). A separate regulated DC power supply is used for Inverter/ Chopper operation. The output waveform and values are evaluated using Digital Storage Oscilloscope (DSO).


(a)

(b)

FIG 13: Experimental arrangement of SPMC
(a) as rectifier, (b) as inverter

## VII. RESULT AND DISCUSSION

The simulation model of the single phase matrix converter (SPMC) is shown in figure 8 and figure 9. A single structure of matrix converter performing all power converter modules are presented with the input voltage, output voltage and output current waveforms respectively.

**SPECIFICATIONS:**

Amplitude of the triangular wave, Vc =1v.
Amplitude of the sine wave, Vref = 0.75v.
Modulation index, Mi = Vc/Vref = 1/0.75 = 0.75.
Switching frequency, fs =1.8 KHz.
Resistive load, R = 10 Ohms
Induction Motor = 0.25 kW, 100V, Capacitor start motor with Torque input of 6 N-m

**(1) SPMC as Rectifier:**
Input Voltage, Vin =100 V (peak to peak), AC
Input Frequency, fi=50 Hz.
Output Voltage, Vo = 100 V, DC
Output Current, Io=Vo/R=100/10 =10 A, DC

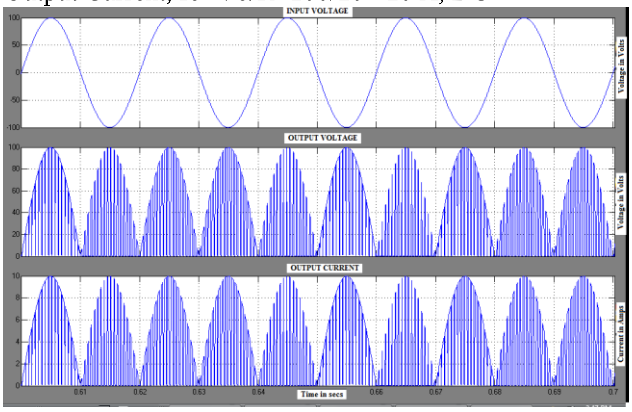


FIG. 14: Simulated results of Rectifier operation

From the figure 14, it is evident that the matrix converter can act as an uncontrolled rectifier. The input is AC and the output is uncontrolled DC.

**(2) SPMC as Converter:**
Input Voltage, Vin =100 V p-p, AC
Input Frequency, fi=50 Hz.
Output Voltage, Vo = 100 V, DC, at $90^0$ pulse triggering ($\pi/2$ rad)
Output Current, Io=Vo/R=100/10 =10 A, DC at $90^0$ pulse triggering ($\pi/2$ rad)

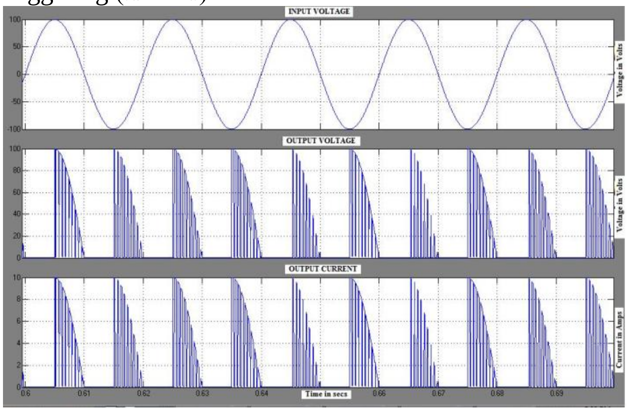

FIG. 15: Simulated results of Converter operation

From the figure 15, it is evident that the matrix converter can act as a controlled rectifier (converter). The input is AC and the output is controlled DC, where the output magnitude (DC) can be altered with the help of triggering pulses. Here $90^0$ pulse triggering is applied.

**(3) SPMC as Inverter:**
Input Voltage, Vin =100 V p-p, DC
Output Voltage, Vo = 100 V, AC
Output Current, Io=Vo/R=100/10 =10 A, AC
Output Frequency, fo=50 Hz.

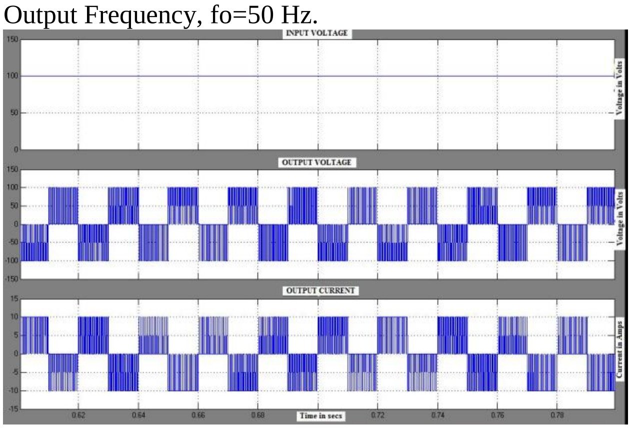

FIG. 16: Simulated results of Inverter operation

From the figure 16, it is evident that the matrix converter can act as an inverter, where the input is DC and the output is variable AC. The output voltage can be altered with the help of triggering pulses.

**(4) SPMC as Chopper:**
Input Voltage, Vin =100 V p-p, DC
Resistive load , R=10 Ω.
Output Voltage, Vo = 100 V, DC,
Output Current, Io=Vo/R=100/10 =10 A, DC

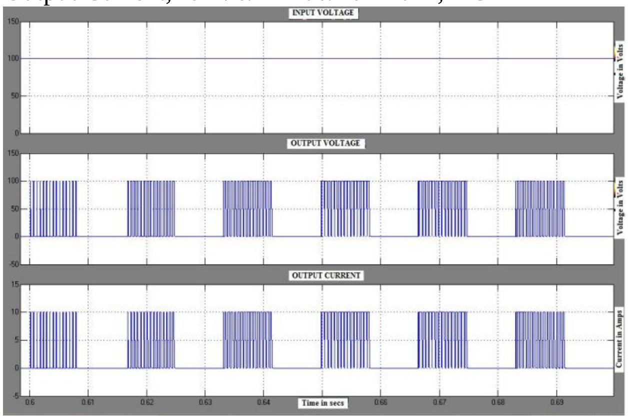

FIG. 17: Simulated results of Chopper operation

From the figure 17, it is evident that the matrix converter can act as a chopper, where the input is DC and the output is variable DC. The output voltage can be altered with the help of triggering pulses.

**(5) SPMC as Cyclo-converter:**
Input Voltage, Vin =100 V p-p, AC
Input Frequency, fi=50 Hz.
Output Voltage, Vo = 100 V, AC
Output Current, Io=Vo/R=100/10 =10 A, AC
Output Frequency, fo=25 Hz.

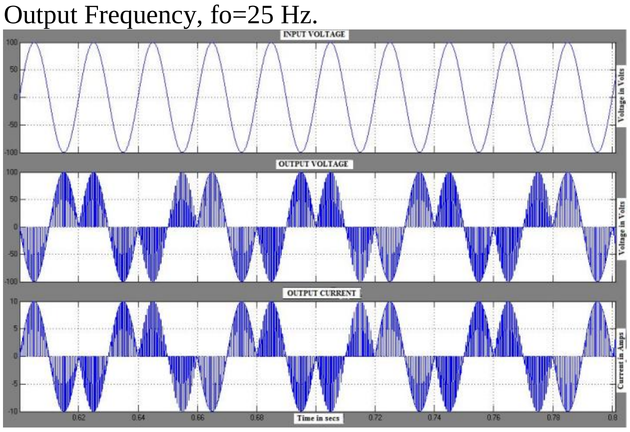

FIG. 18: Simulated results of Cyclo-converter operation

Figure 18 represents, the matrix converter can act as a cyclo-converter, where the input is AC and the output is variable frequency AC. The output frequency can be altered with the help of triggering pulses. Here the output frequency obtained is 25 Hz.

**(6) SPMC as Cyclo- inverter:**
Input Voltage, Vin =100 V p-p, AC
Input Frequency, fi=50 Hz.
Output Voltage, Vo = 100 V, AC
Output Current, Io=Vo/R=100/10 =10 A, AC
Output Frequency, fo=100 Hz.

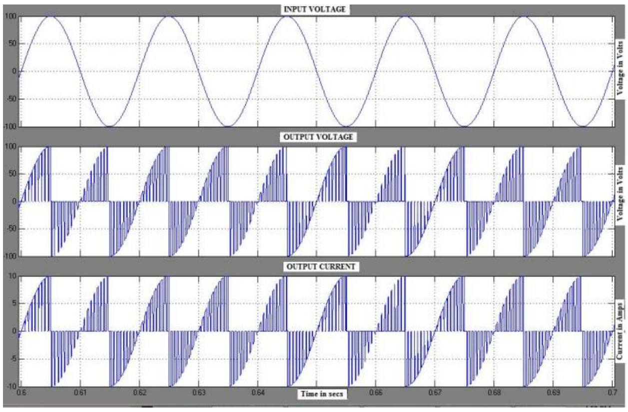


FIG. 19: Simulated results of Cyclo-inverter operation

Figure 19 represents, the matrix converter can act as a cyclo-inverter, where the input is AC and the output is variable frequency AC. The output frequency can be altered with the help of triggering pulses. Here the output frequency obtained is 100 Hz.

**(7) SPMC as Matrix converter:**
Input Voltage, Vin =100 V p-p, AC
Input Frequency, fi=50 Hz.
Output Voltage, Vo = 100 V, AC
Output Current, Io=Vo/R=100/10 =10 A, AC
Output Frequency, fo=50 Hz.

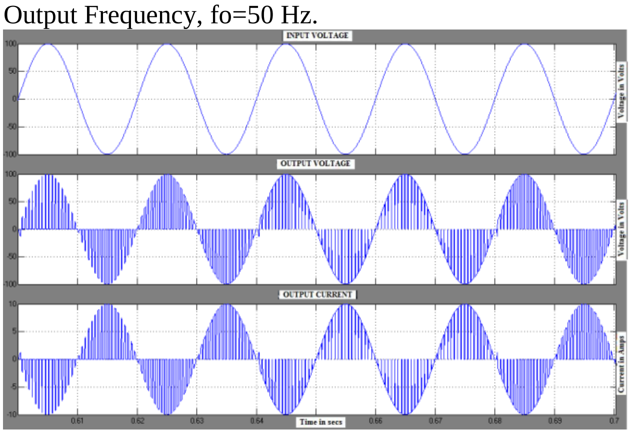


FIG. 20: Simulated results of Matrix converter operation

Figure 20 represents, the operation of matrix converter, where the input is AC and the output is variable frequency AC.

**(8) SPMC as Matrix converter with IM:**
Input Voltage, Vin =100 V p-p, AC
Input Frequency, fi=50 Hz.
Output Voltage, Vo = 100 V, AC
Output Current, Io= 10 A, (approx.) AC
Output Frequency, fo=50 Hz.
IM = Induction Motor load

The simulation result of SPMC with induction motor load is satisfactory as shown in figure 21 (a) and (b) where the THD obtained is 4.07%, which is below IEEE specifications. It has been inferred that the harmonic content obtained here is less than the referred base paper [2].

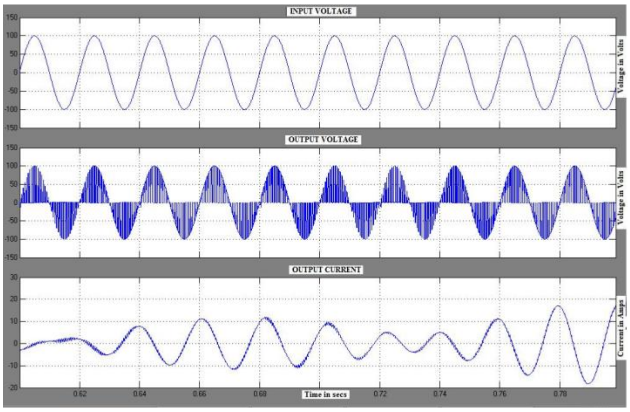


FIG. 21(a): Simulated results of Matrix converter with IM

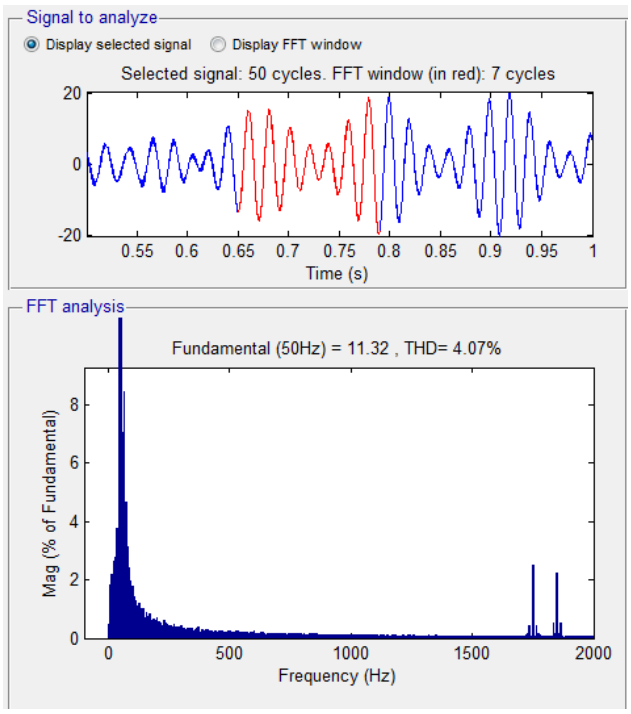


FIG. 21(b): THD analysis of Matrix converter with IM

**(9) Hardware Results:**

The outputs of hardware implementation of SPMC are obtained through DSO. The input waveform represents 50 Hz (Time period of 20 ms) AC supply which is shown in Figure 22. The magnitude (1 Volt / division) and time in seconds (5 ms / division) are clearly mentioned here.

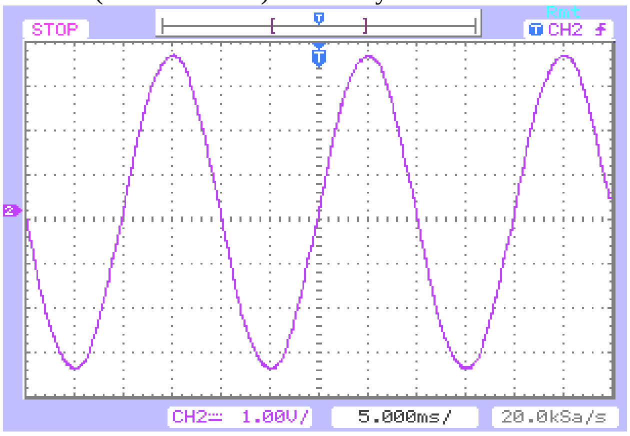


FIG 22: Input AC waveform

The output waveforms are represented in figure 23, 24 and 25. Figure 23 represents 50 Hz uncontrolled DC output for an AC input, thus it is evident that the matrix converter can act as a controlled rectifier (converter) or uncontrolled rectifier. Figure 24 represents an inverter operation, where the input is DC and the output is variable AC of 100 Hz frequency.

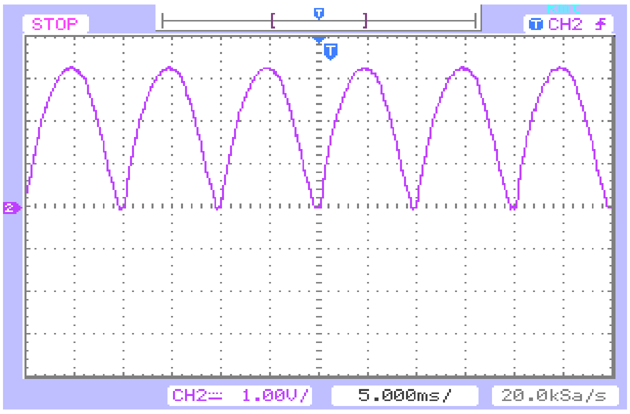


FIG 23: Hardware output of controlled rectifier

Figure 25 represents the output waveform of SPMC, performing as a cyclo-converter, it is evident that the matrix converter can act as a cyclo-converter, where the input is AC and the output is variable AC. The output frequency (AC) can be altered with the help of triggering pulses. Here the output frequency is 25Hz (Time period is 40 ms) which is clearly mentioned.

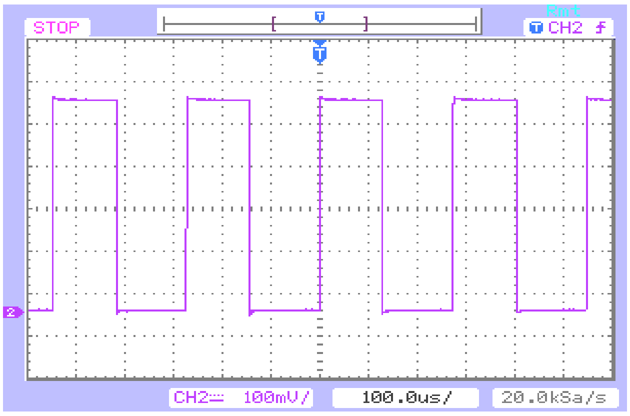


FIG 24: Hardware output of Inverter

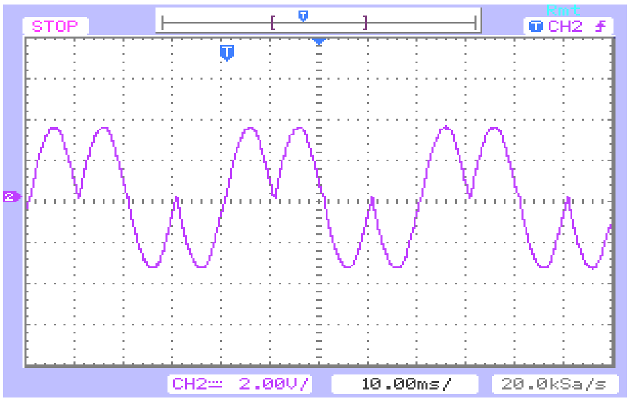


FIG 25: Hardware output of cyclo converter

It is concluded that, SPMC is acted as controlled rectifier (converter), inverter, cyclo-converter and cyclo-inverter operations in hardware approach and that too with reasonable performance.

## VII. CONCLUSION

A Single Phase Matrix Converter has been designed and executed as universal power electronic converter with a simple resistive load. With appropriate novel switching combination of IGBT bi-directional switches, SPMC is acted as controlled rectifier (converter), inverter, chopper, cyclo-converter and cyclo-inverter operations in both simulated and hardware approach. Hence, it is clear that the single phase matrix converter is perfectly operated as a universal matrix converter. Further, matrix converter is tested with an induction motor load and the harmonics level acquired is almost 4% which exhibit a low THD.

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