IJCTA, 10(02), 2017, pp. 305-320

A Novel Switching Strategy for Realization of Single Phase Matrix Converter As a Universal Power Electronic Converter

Senthil Kumar Rasappan* and Vivekanandan Chenniappan**

Abstract : This paper presents the realization of a single phase matrix converter as a universal power electronic converter.The Matrix converter can act as rectifier, controlled rectifier (converter), inverter, chopper, cycloconverter and cyclo inverter by a novel switching strategy logic. Induction motorload is connected and the harmonics are verified for Direct Matrix converter. The single structure matrix converter eliminates the rectifier and dc link due to direct AC-AC conversion. Normal sinusoidal PWM and square wave signal generation have been used here, which describes a simple algorithm for multiple purposes. Simulation is performed using MATLAB/Simulink and the results obtained heredemonstrate a high performance, low THD matrix converter.

Keywords: Single phase Matrix converter, Rectifier, Converter, Inverter, Chopper, Cyclo converter, THD, Induction Motor, MATLAB.

1. INTRODUCTION

The matrix converter is an advanced circuit topology capable of converting AC to AC. Many benefits are encompassed by this topology such as; the matrix converter fulfills the requirements to provide a sinusoidal voltage at the load side and it is also possible to get variable frequency at the load side.It offers bi-directional power flow, sinusoidal input and output. Since there is no DC link as like in common converters, the matrix converter can be built as a full-silicon structure as per Venturini and Alesina[1]. The controlled output waveform can be obtained on varying the modulation technique with minimum number of switches as comparedwith AC-DC-AC converters [2]. Unity displacement factor can be seenin supply side irrespective of the load type.The use of aMatrix Converter in the future reduces the need forlearning many varying converter topologies and that isnow the subject of current active research [3].

The singlephase matrix converter (SPMC) was first realized by Zuckerberger [4]. It has been shown that the SPMC could be used to operate 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 supply AC from battery, thus two conversions are required. Also in traction different types of motors are employed such as DC series, DC shunt and AC series which require probable conversion of supply. A number of conversion kits are required in laboratories. This increases the total cost and also the space requirement [9, 10].

This paper describesa single-phase matrix converter (SPMC) may be conceived and designed with four bi-directional switches and simple switching logic.An algorithm is developed torealize asingle-

* Assitant Professor (SG), Department of EEE, SNS College of Technology, Coimbatore, Affliated to Anna University Chennai, *E-mail: senkumarme@gmail.com*

** Vice Principal, SNS College of Engineering, Coimbatore, Affliated to Anna University Chennai, *E-mail: cv.snsce@gmail.com*

phase matrix converter (SPMC) as a universal power electronicconverter by suitableswitching strategy. The input is based on either an AC or a DCsupply.Normal sinusoidal PWM and square wave signal generation are used to synthesize these converters. The switchingalgorithm is then executed in computer simulationmodels to elucidate its basic behavior. Results of thesimulations are presented to verify that the proposedtechnique is feasible. 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. A single structure matrix converter performs all power converter modules and hence it diminishes the need to design new hardware for a particularconverter.

2. SINGLE PHASE MATRIX CONVERTER AND REALIZATION

The Basic circuit of single-phase matrix converter is shown in figure 1. It consist of matrix input and output lines with four bi-directional switch connecting single phase input (either AC or DC) to the single phase output (load) at the intersections. The four ideal switches are S1,S2,S3 and S4 capable of conducting in both directions, blocking forward and reverse voltages, switching between states without any delays. Each switch is bi-directional consisting of two diodes and two IGBTs connected back to back [4]. 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.

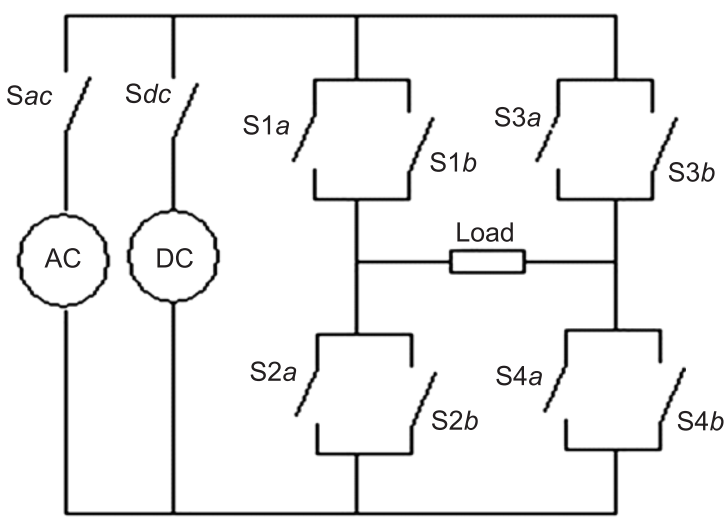


Figure 1: Basic circuit of a Matrix Converter

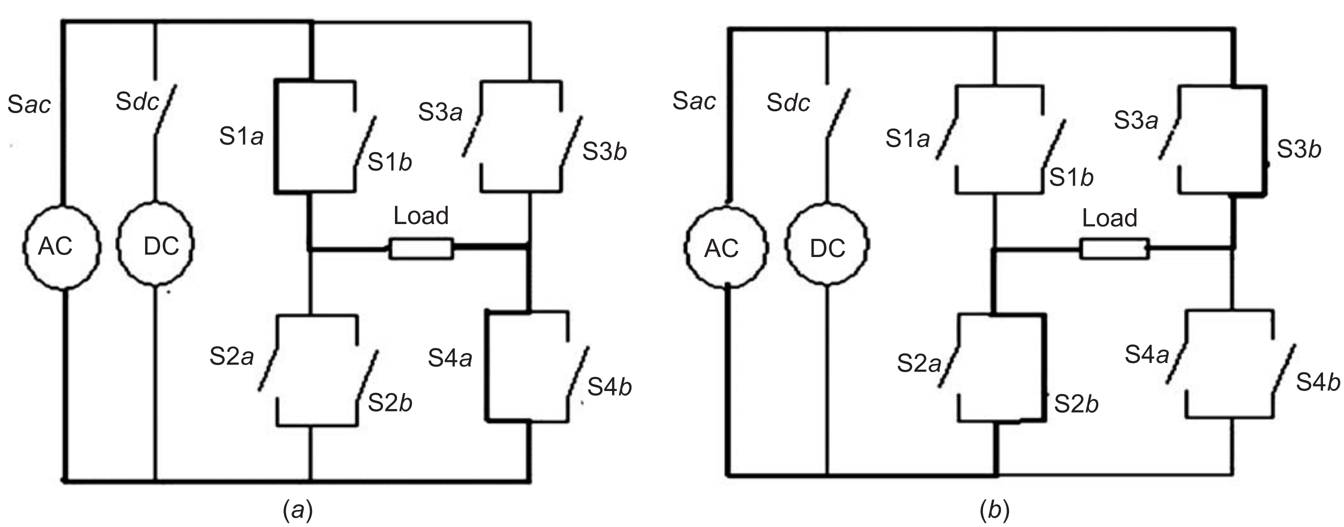


Figure 2: (*a*) and (*b*) Switching states as Rectifier

Realizations of Matrix Converter as universal power electronic converters are explained here. A Matrix Converter is capable to convert fixed AC to variable (controlled) AC. The output AC may be of variable voltage or variable frequency.

Realization as rectifier and controlled rectifier (converter) is shown in figure 2, 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 2(*a*) represents for positive half cycle and 2 (*b*) for negative half cycle. The bold line signifies the current conduction.

Realization as inverter is shown in figure 3, 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.

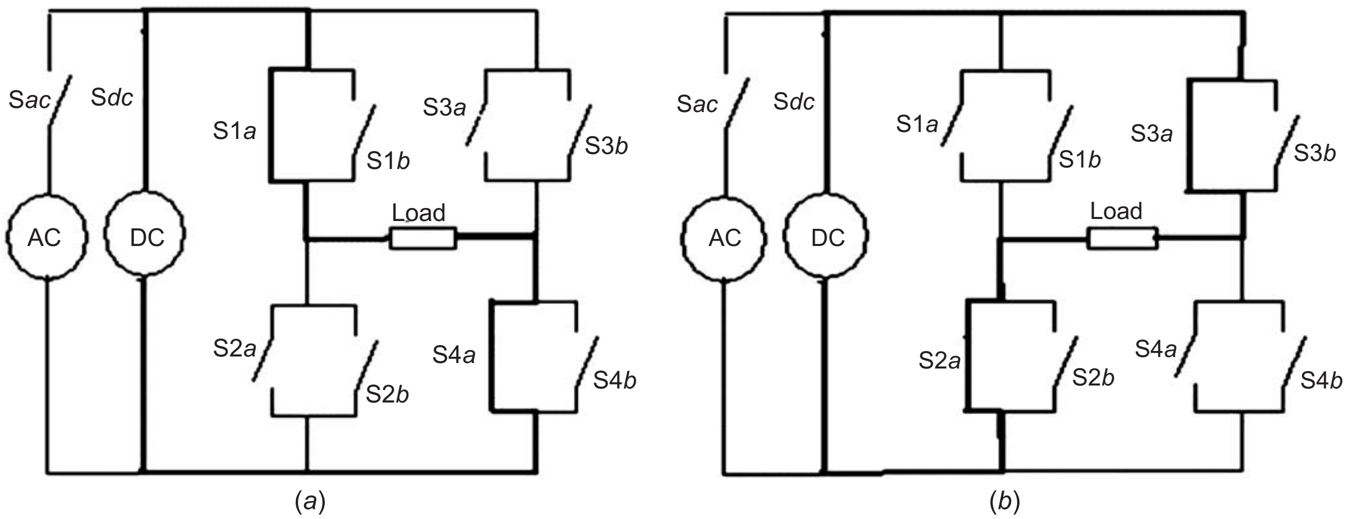


Figure 3: (*a*) and (*b*) Switching states as Inverter

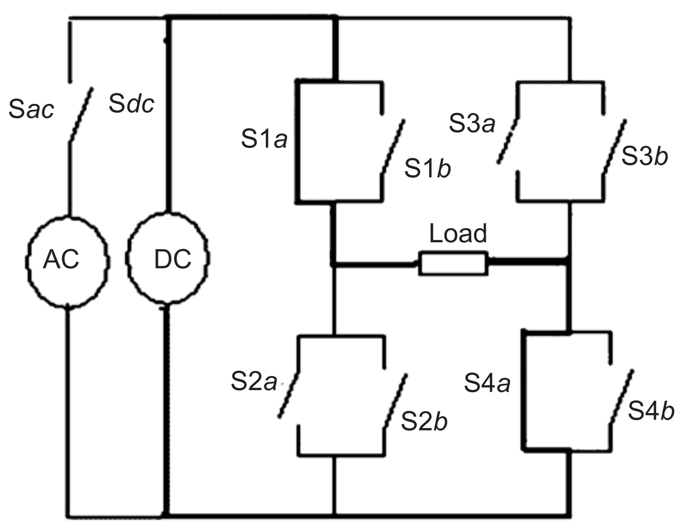


Figure 4: Switching states as Chopper

Realization as chopper is shown in figure 4, where input is DC and the output is variable DC. First quadrant chopper is shown here. It is also conceivable for four quadrant operation.

Realization as cyclo-converter and cyclo-inverter is shown in figure 5, where input is fixed AC and the output is AC with variable frequency. Figure 5 (*a*) and (*b*) represents for positive half cycle; Figure 5 (*c*) and (*d*) for negative half cycle. The output frequency can be varied by altering the modulating frequency. In Matrix converter both frequency and magnitude can be varied.

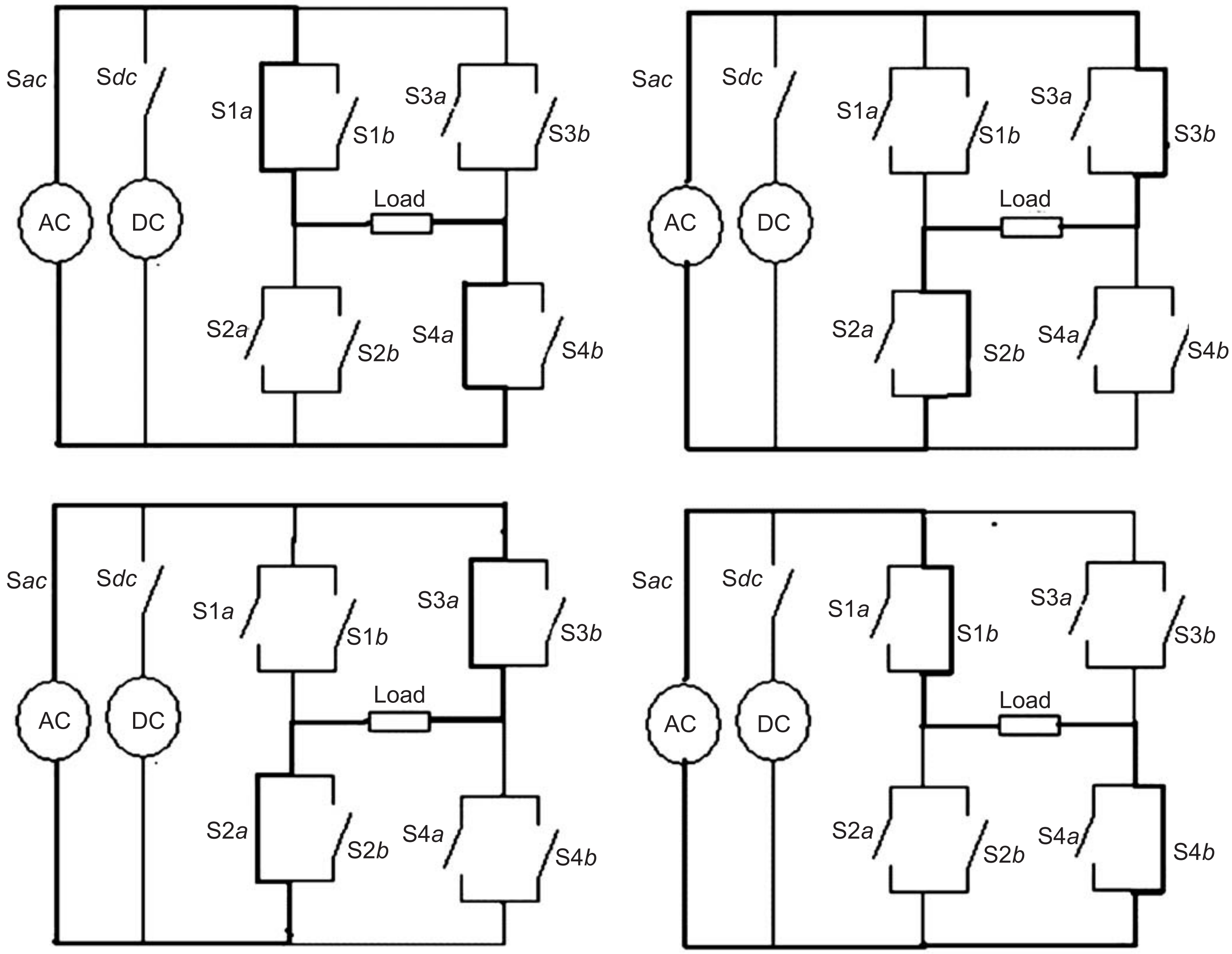


Figure 5: Switching states as Cyclo-converter and cyclo-inverter

3. SWITCHING ALGORITHMS

Two different modulation schemes have been used to demonstrate the effects of the sinusoidal and square wave modulation signals at the output from the point of harmonic content and input voltage utilization [4]. Its instantaneous input voltage is $Vi(t)$ and its output voltage is $Vo(t)$. This topology converts the input voltage, $Vi(t)$ into variable amplitude or frequency as the output voltage $Vo(t)$ by changing the modulating frequency.

If the input signal is

$$Vi(t) = Vim \cos \omega i\, t \quad (1)$$

Then, the fundamental output voltage will be

$$Vo(t) = Vom \cos \omega o\, t \quad (2)$$

With a fundamental frequency $fo = fm - fi$ (3)

where, fo = Output Frequency,

fm = Modulation Frequency,

fi = Input Frequency.

The four power switching devices are switched at high frequency, fs,($fs \gg fi$ and fo, $fi = wi/2pi$ and $fo = wo/2pi$).

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)

Table 1
Switching Algorithm

Converter	*Input Supply*	*Switching Strategy*	*Output Nature*
Rectifier	AC	S1*a*, S4*a* (positive half cycle)	DC (un-controlled)
		S2*b*, S3*b* (negative half cycle)	
Converter	AC	S1*a*, S4*a* (positive half cycle)	DC (controlled)
		S2*b*, S3*b* (negative half cycle)	
Inverter	DC	S1*a*, S4*a*	AC (controlled)
		S3*a*, S2*a*	
Chopper	DC	S1*a*, S4*a*	DC (controlled)
Cyclo-converter	AC	S1*a*, S4*a* S3*b*, S2*b*	AC (controlled)
		S2*a*, S3*a* S4*b*, S1*b*	
Cyclo-inverter	AC	S1*a*, S4a S3*b*, S2*b*	AC (controlled)
		S2*a*, S3*a* S4*b*, S1*b*	
Matrix Converter	AC	S1*a*, S4*a* S3*b*, S2*b*	AC (controlled)
		S2*a*, S3*a* S4*b*, S1*b*	

Normal sinusoidal pulse width modulation and square wave signal generation have been used here. The standard SPWM technique is illustrated [9] in figure 6. This switching algorithm (states) is clearly mentioned in the Table 1 for a universal matrix converter. [9]

4. SIMULATION

Matrix converter is a single stage converter which converts fixed ACinput into variable voltage / variable frequency AC output. Simulation is executed in MATLAB/Simulink [11] platform.

The Simulink models presented in figure 7 and 8. 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 inductive load. Sinusoidal pulse width modulation techniques are adopted for drive the switches.

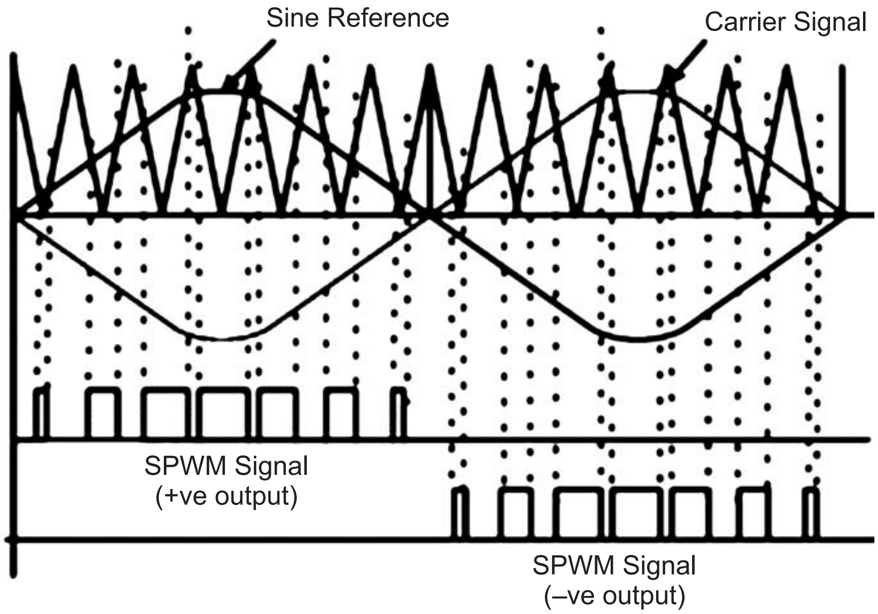
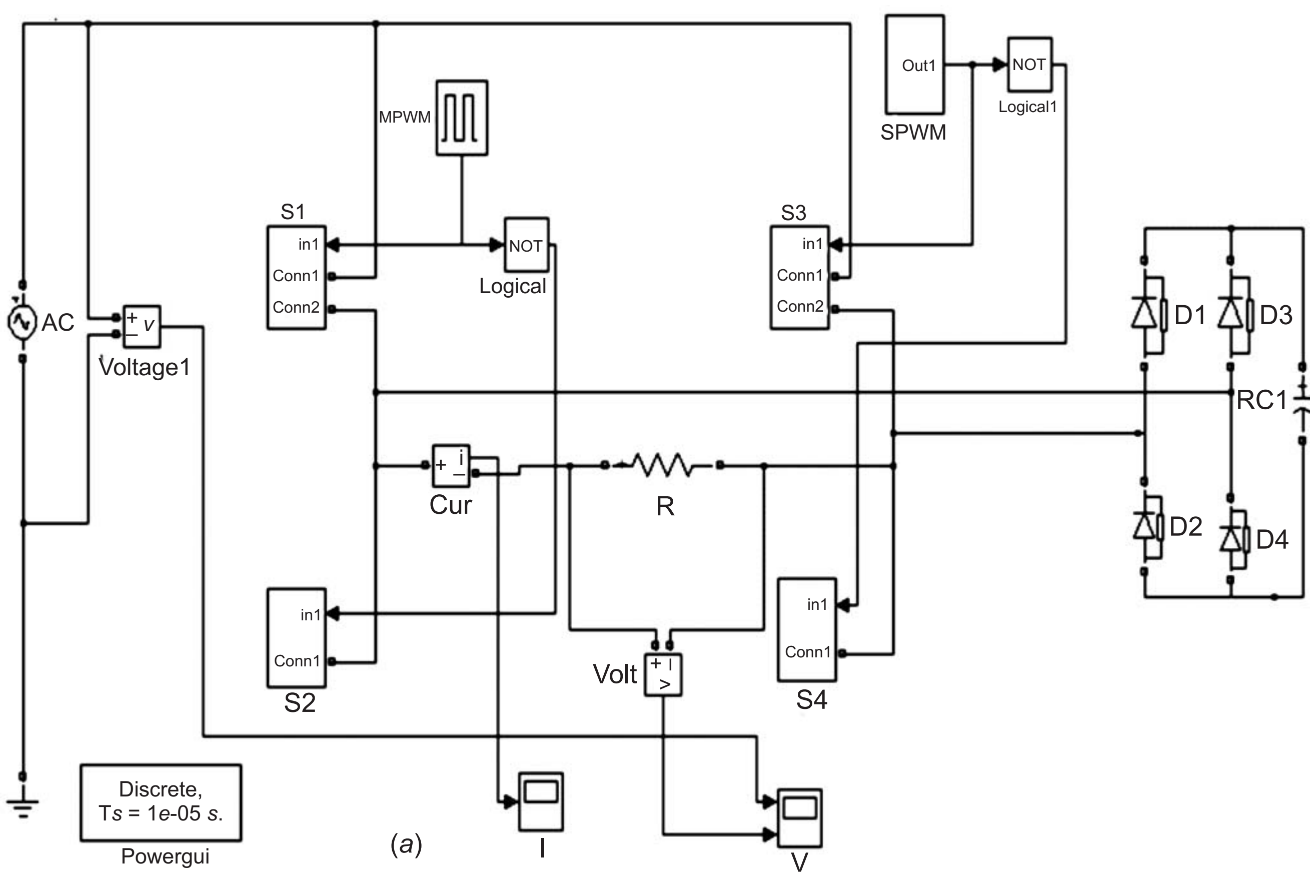


Figure 6: SPWM modulation technique

Matrix converter performing as converter (controlled rectifier) is shown in figure 7(*a*) and Matrix converter performing as inverter is shown in figure 7(*b*). Simulation model of Matrix converter with induction motor load is shown in figure 8.



(*a*)

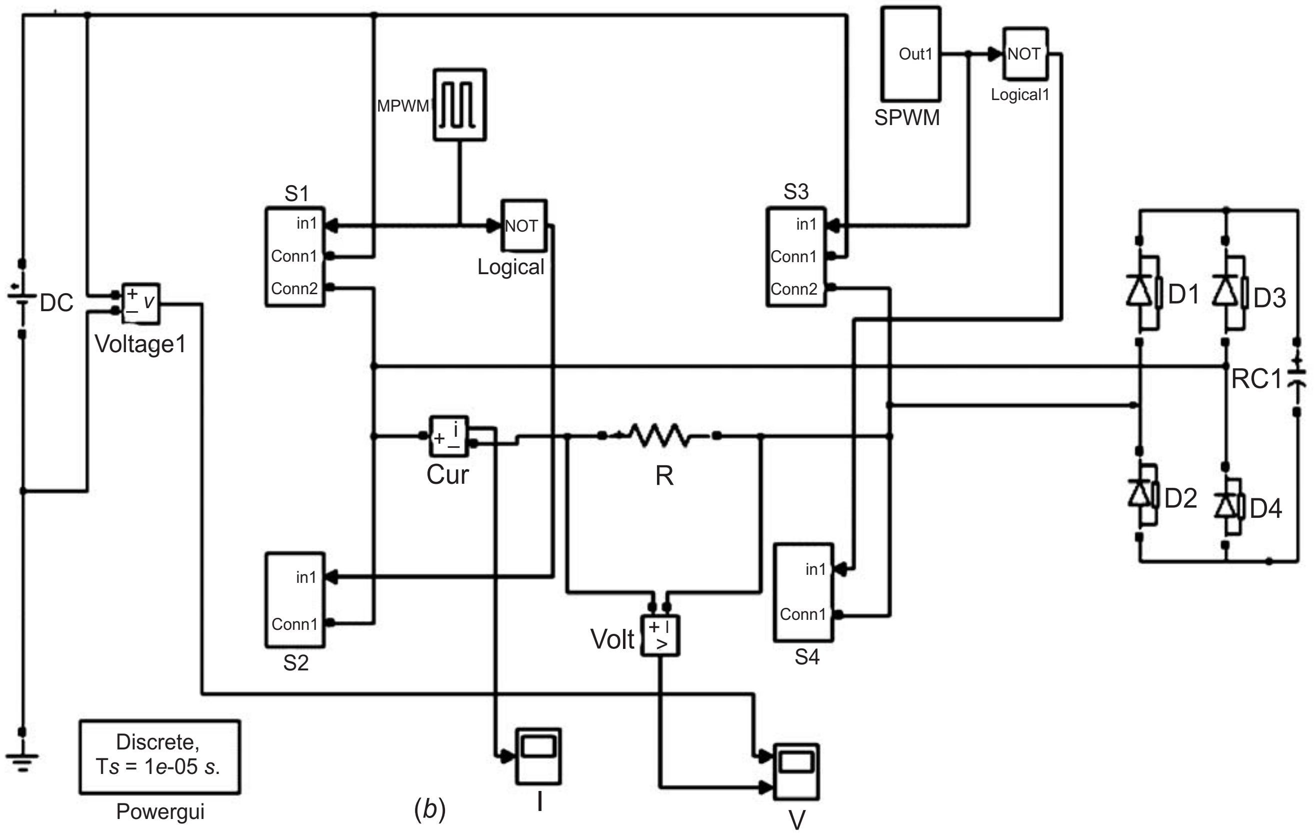


Figure 7: (*a*) Simulation model of Converter (*b*) Simulation model of Inverter

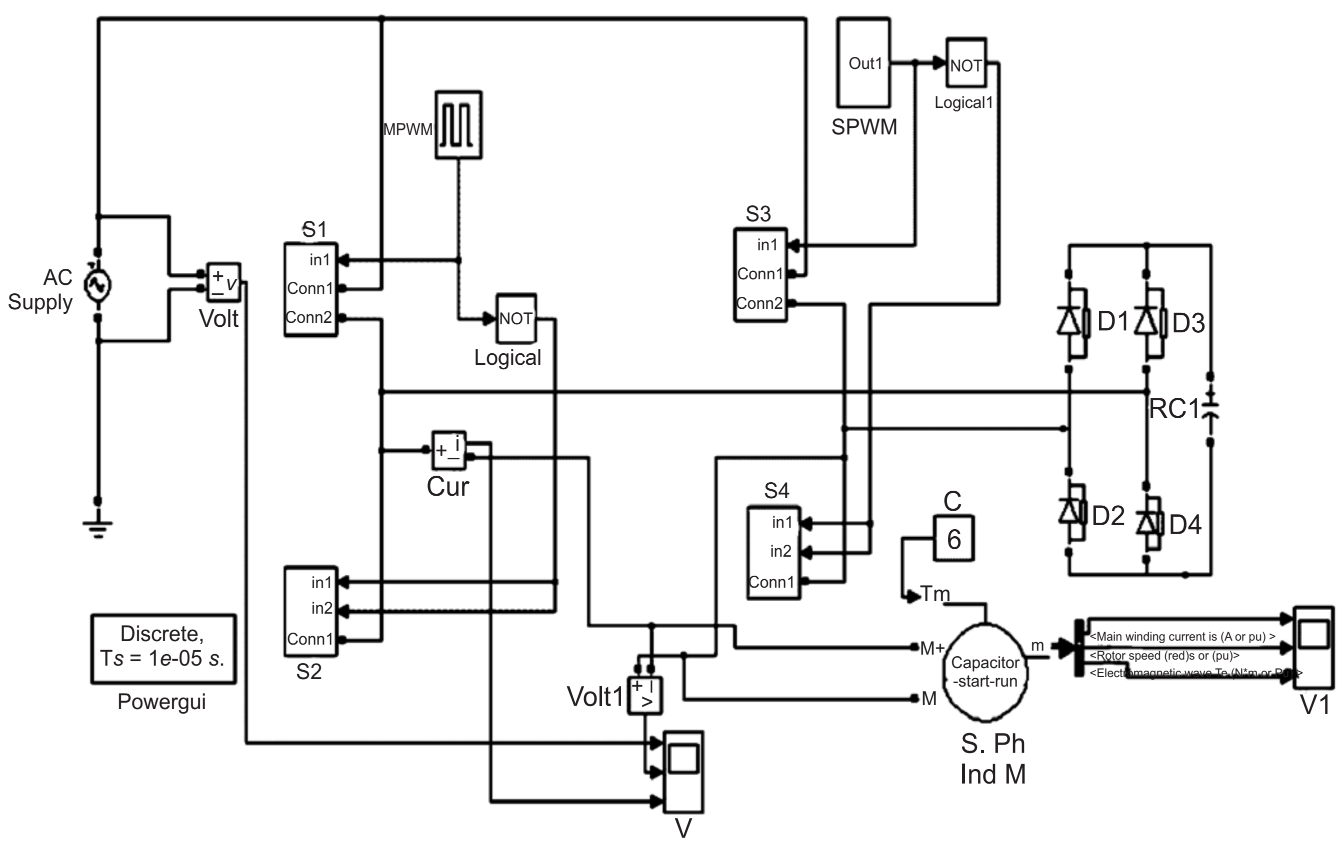


Figure 8: Matrix converter model with IM load

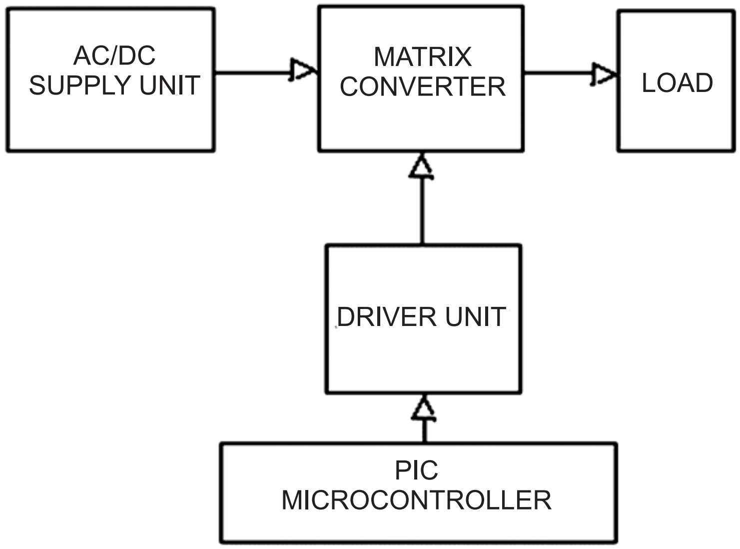


Figure 9: Functional block diagram of SPMC

5. HARDWARE IMPLEMENTATION

The Functional block diagram of the hardware circuit is shown in the figure 9. It consists of four bi-directional switching arrangement as matrix converter, a driver block, an AC and DC supply units, PIC micro controller and resistive / IM load unit.

The microcontroller [12] used here is PIC 16F877. The microcontroller which produces the pulse and delay signal according to the coding feed. These signals trigger the IGBT switchesaccordingly through the driver unit. Two push button switches are provided to change the converter performances as rectifier or inverter or converter. 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 10. It consists of Power supply unit, SPMC with four IGBT bi-directional switches,a Microcontroller circuit and a resistive load fabricated [13].

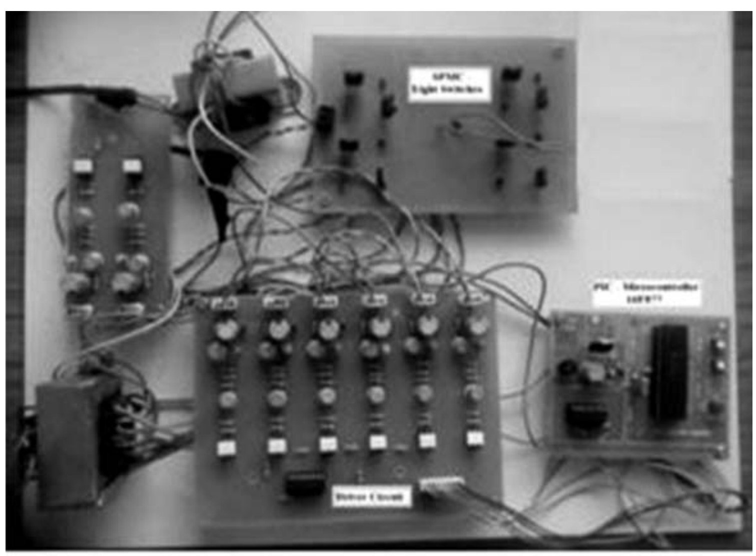


Figure 10: Single phase Matrix Converter Model

The experimental arrangement of SPMC is shown in figure 11. An IGBT power module (Driver Unit) from Vi- Microsystem 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 determined using Digital Storage Oscilloscope (DSO).

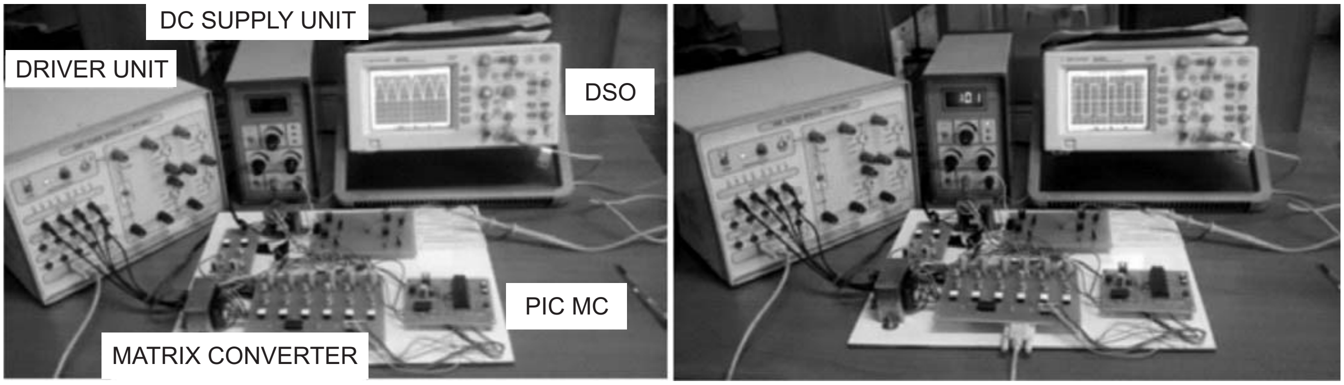


Figure 11: Experimental arrangement of SPMC (*a*) as rectifier, (*b*) as inverter

6. RESULT AND DISCUSSION

The simulation model of the single phase matrix converter (SPMC) is shown in figure 7 and figure 8.A single structure of matrix converter performing all power converter modules are presented with the input voltage, output voltage and output current waveforms respectively.

7. SPECIFICATIONS

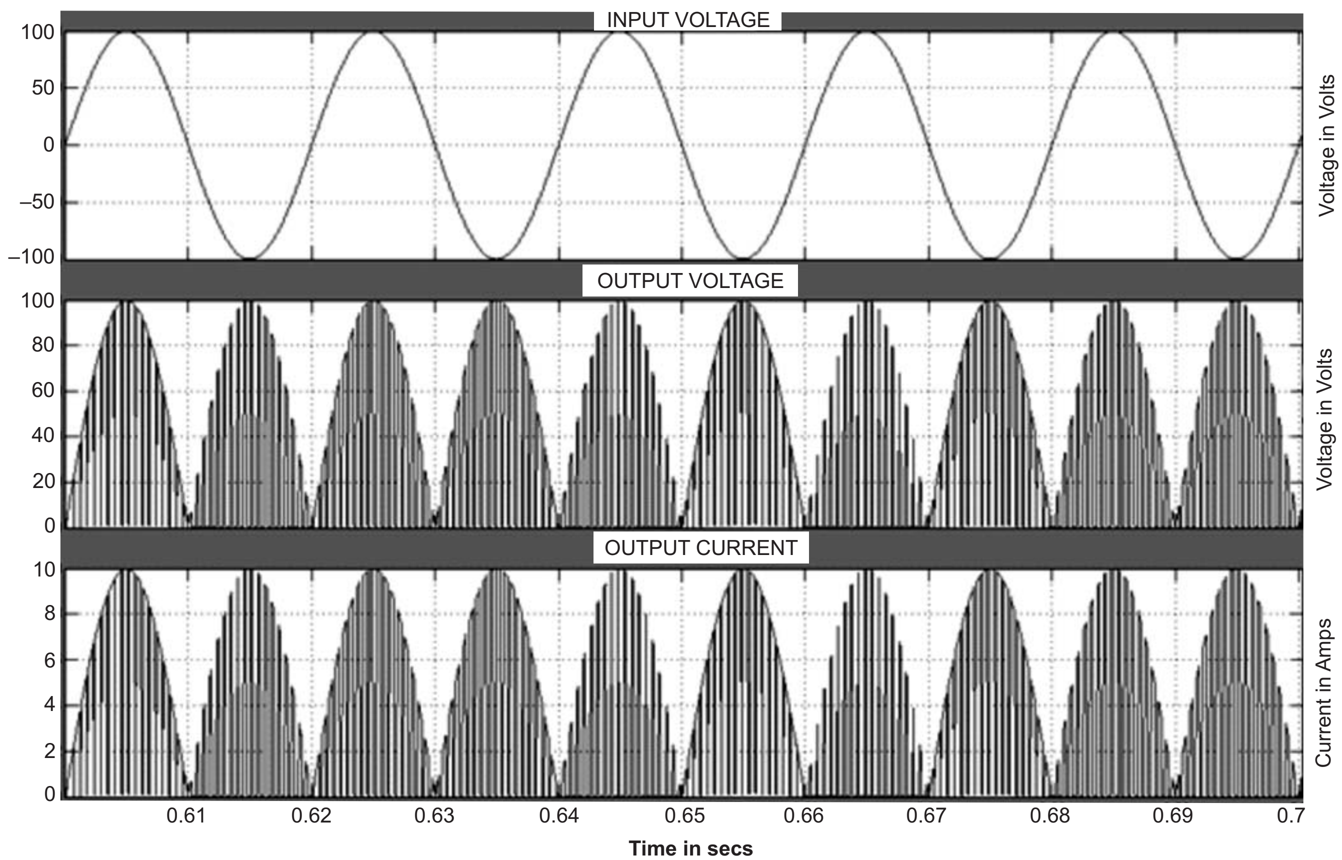


Figure 12: Simulated results of Rectifier operation

Amplitude of the triangular wave,	V_c = 1*v*.
Amplitude of the sine wave,	V_{ref} = 0.75*v*.
Modulation index,	M*i* = V*c*/Vref =1/0.75 = 0.75.
Switching frequency,	*fs* = 1.8KHz.
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

(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° pulse triggering (π/2 rad)
Output Current,	Io	=	Vo/R=100/10 =10 A, DC at 90° pulse triggering(π/2 rad)

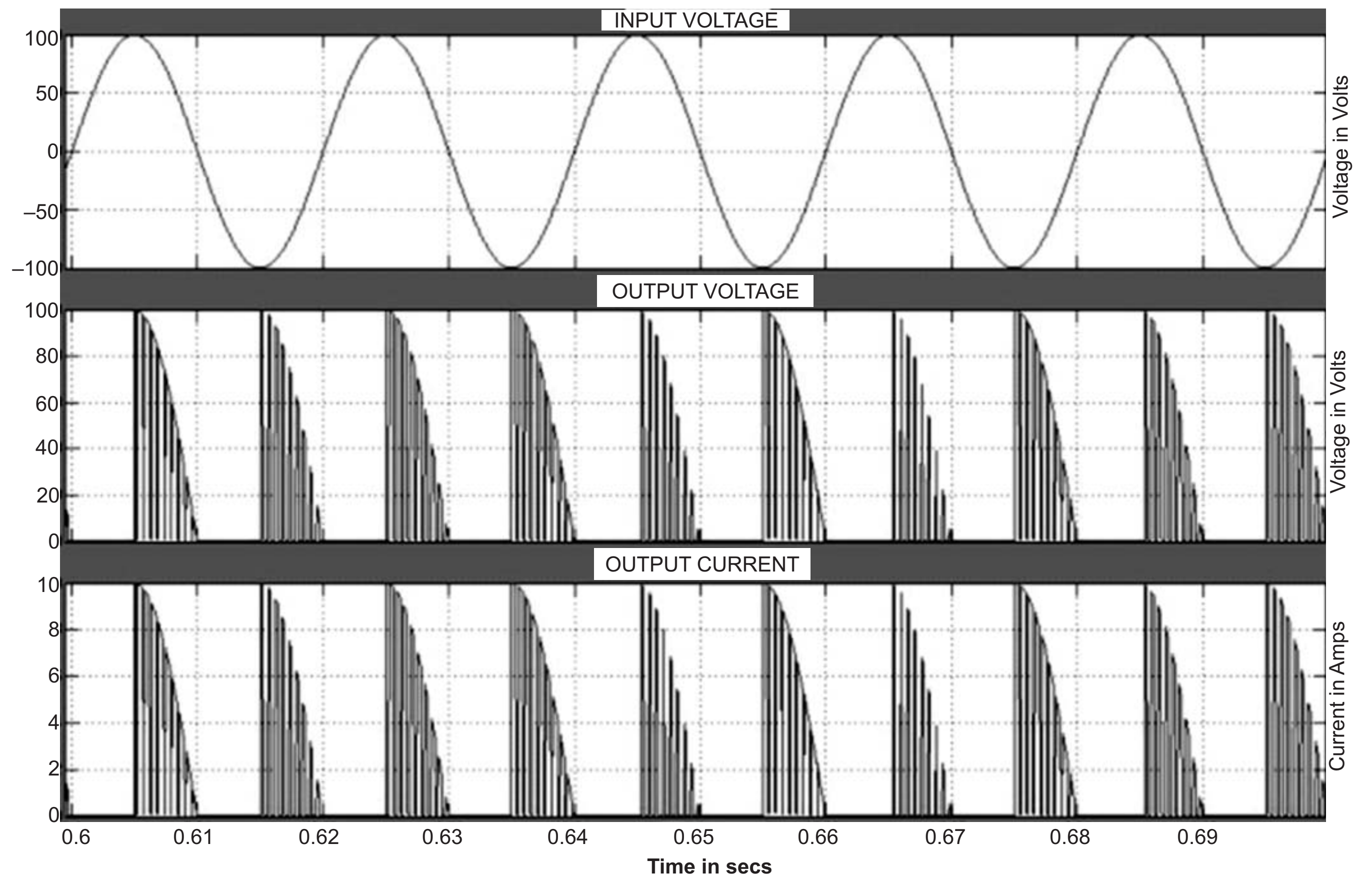


Figure 13: Simulated results of Converter operation

(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.

(4) SPMC as Chopper:

Input Voltage,	Vin	=	00 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

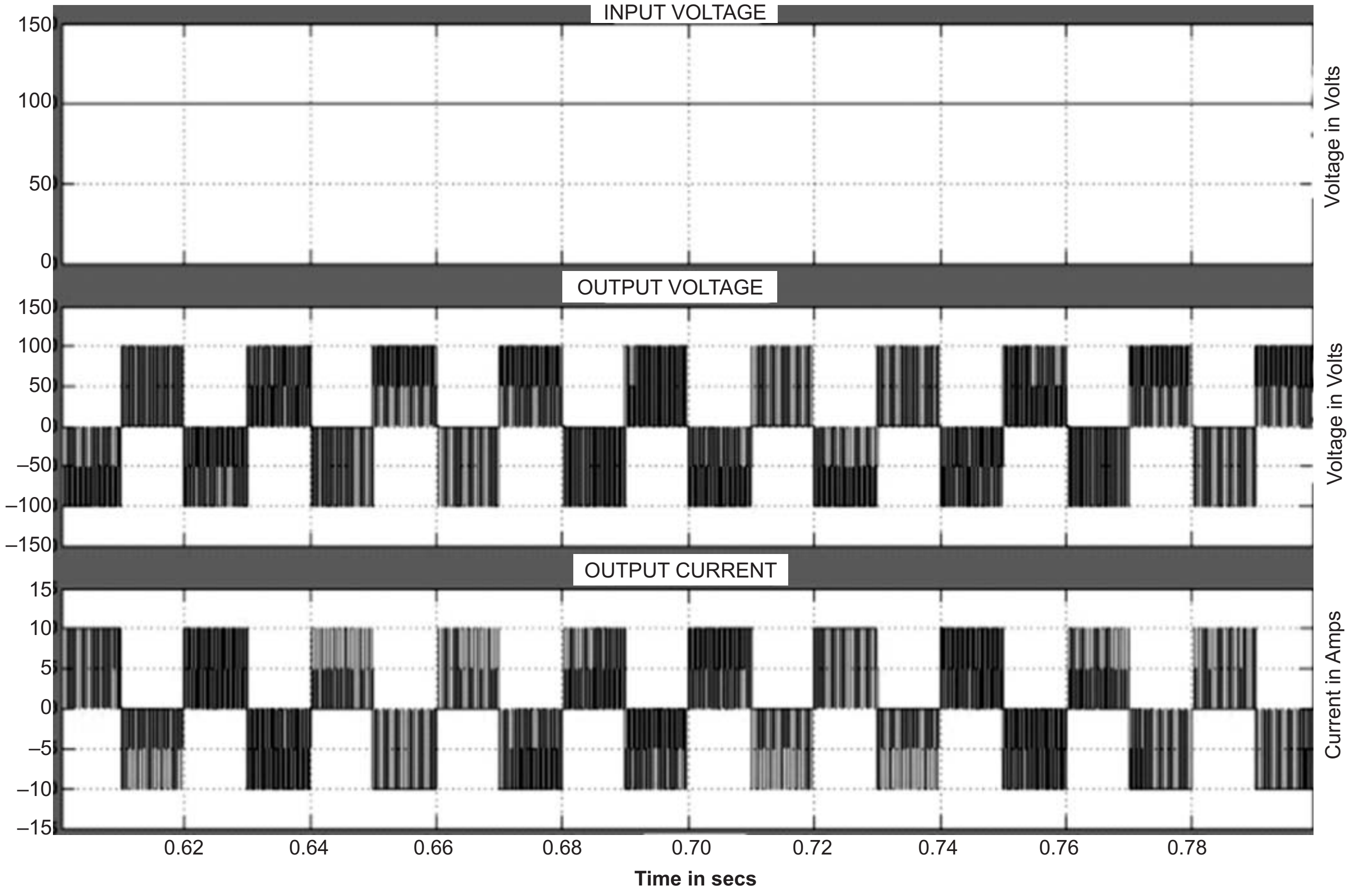


Figure 14: Simulated results of Inverter operation

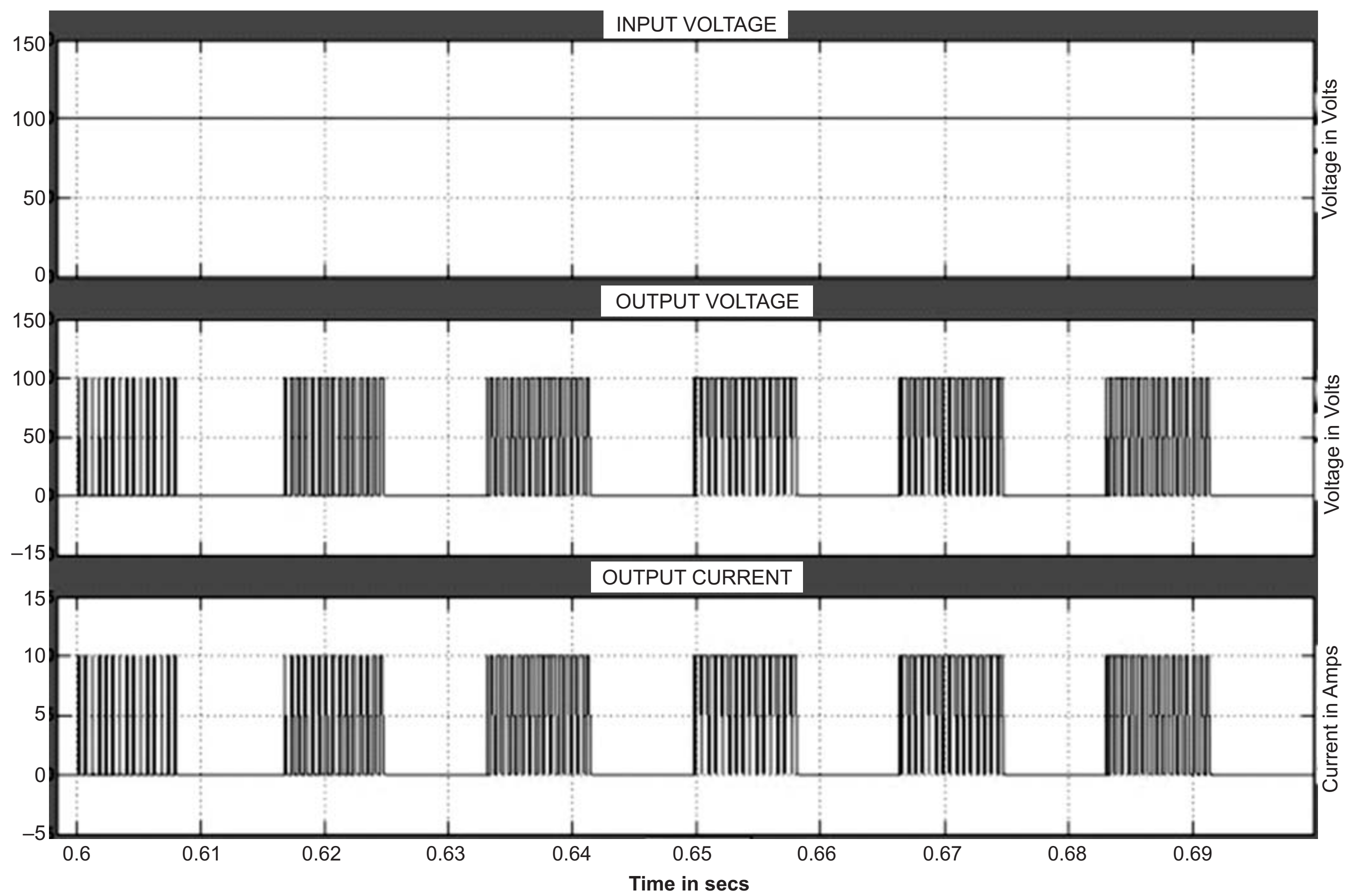


Figure 15: Simulated results of Chopper operation

(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.

(6) SPMC as Cyclo- inverter :

Input Voltage,	Vin	=	00 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.

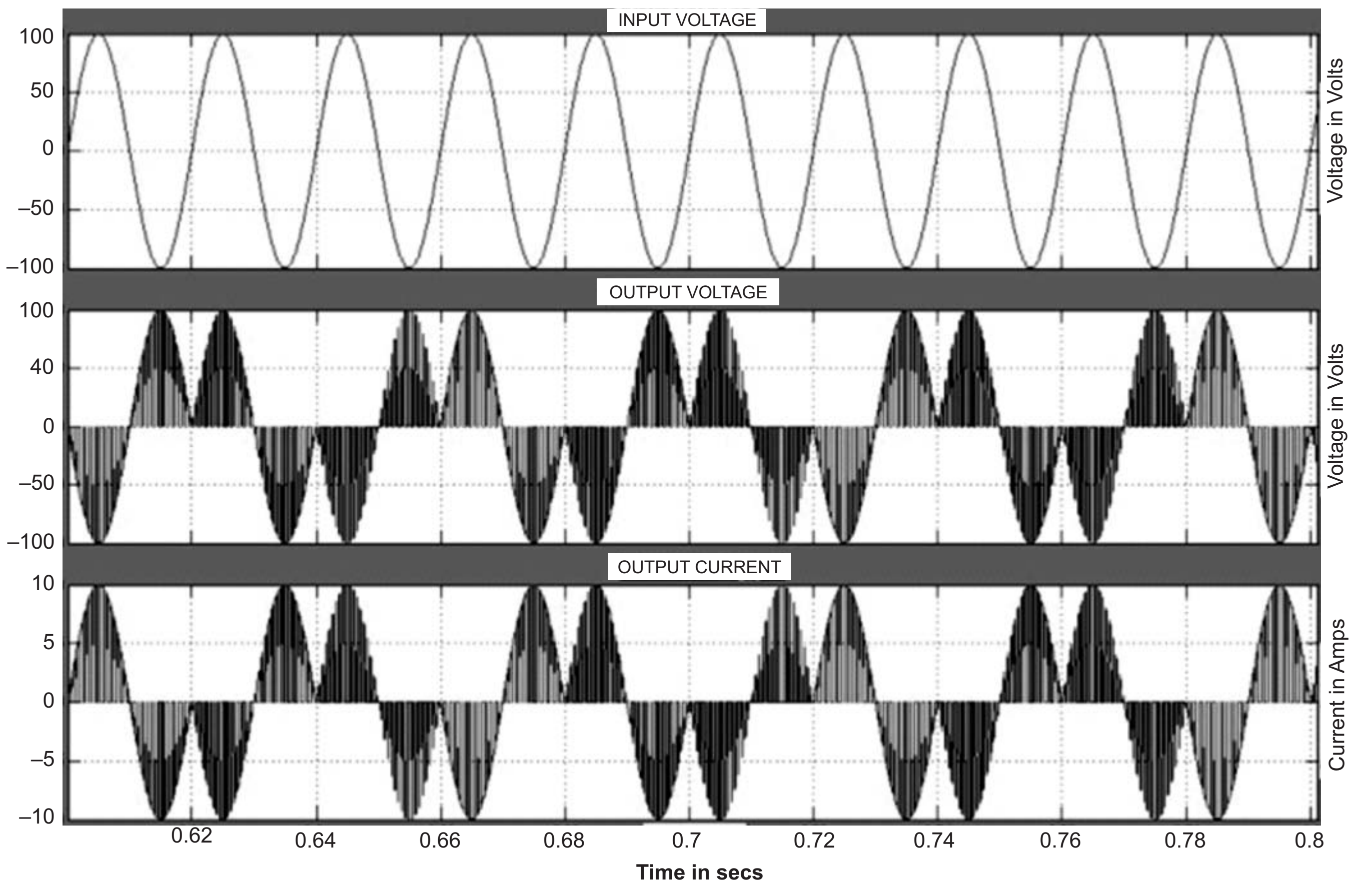


Figure 16: Simulated results of Cyclo-converter operation

(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.

(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

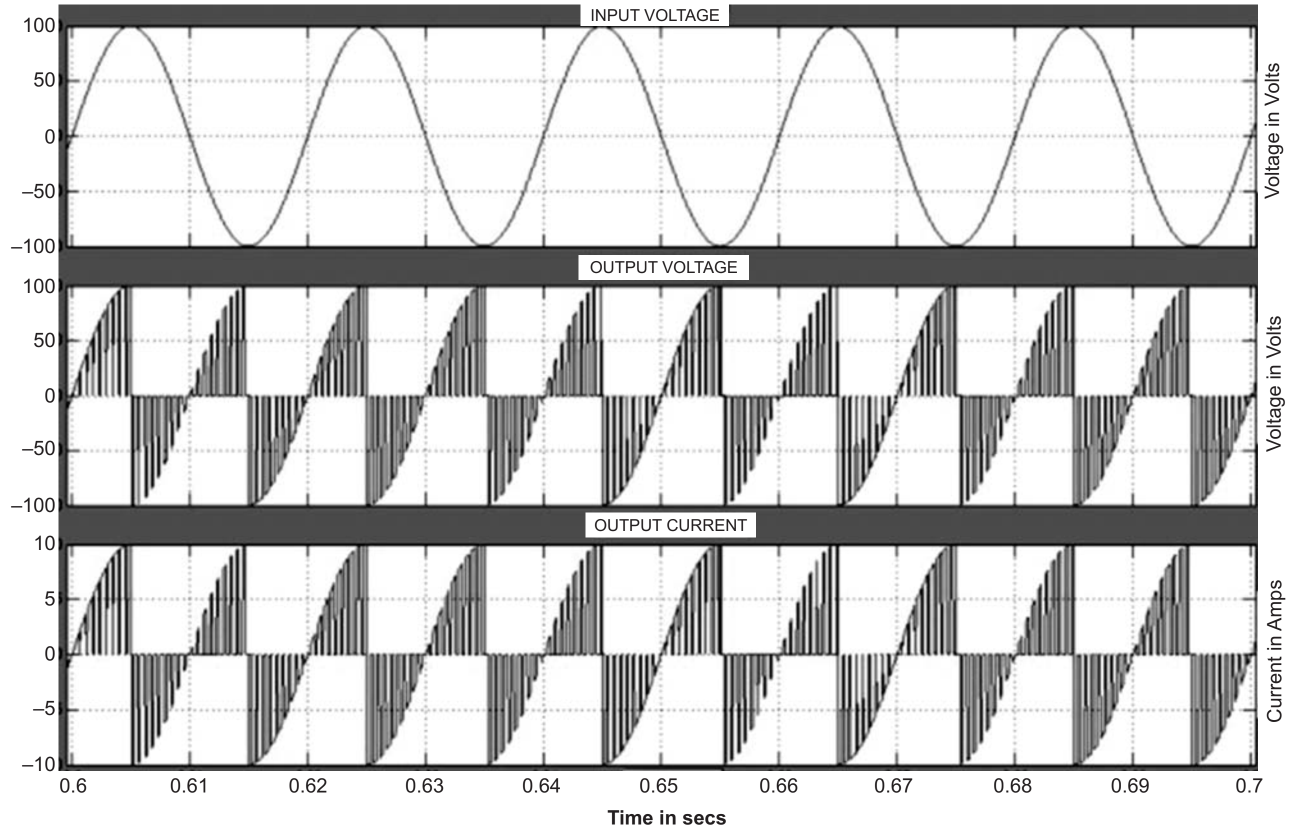


Figure 17: Simulated results of Cyclo-inverter operation

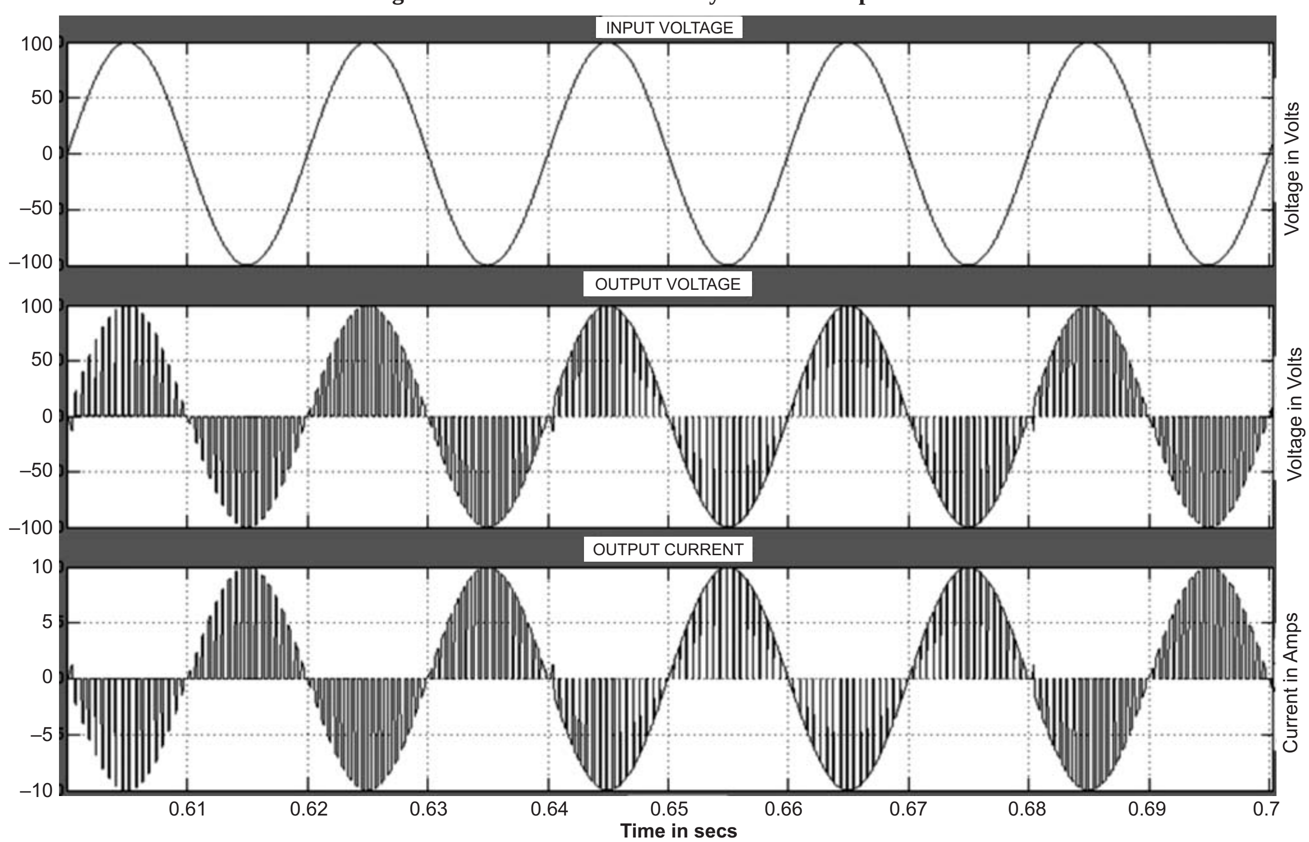


Figure 18: Simulated results of Matrix converter operation

Simulated results and THD analysis are shown in figure 19.The THD obtained is 4.07% for 10 cycles, which is lowerthan the mentioned reference[2]

8. HARDWARE RESULTS

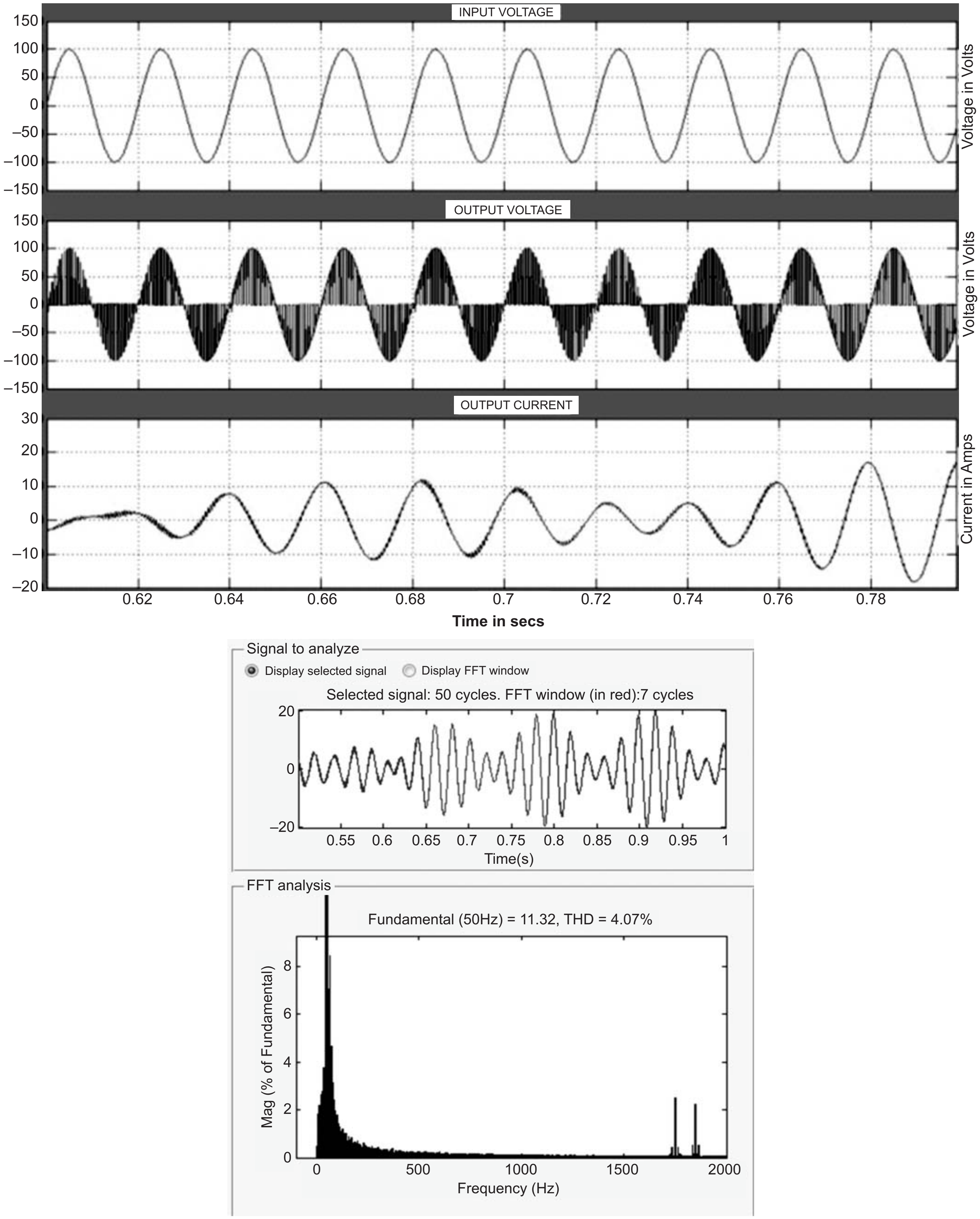


Figure 19: (*a*) Simulated results of Matrix converter with IM (*b*) THD analysis of Matrix converter with IM

The outputs of hardware implementation of SPMC are obtained through DSO and are shown in figure 20. The input waveform represents 50 Hz AC input supply is in figure 20 (*a*). The figure 20 (*b*) represents 50 Hz uncontrolled DC output, figure 20 (*c*) represents 100 Hz AC output and figure 20 (*d*) represents 25 Hz controlled AC cyclo-converter output.

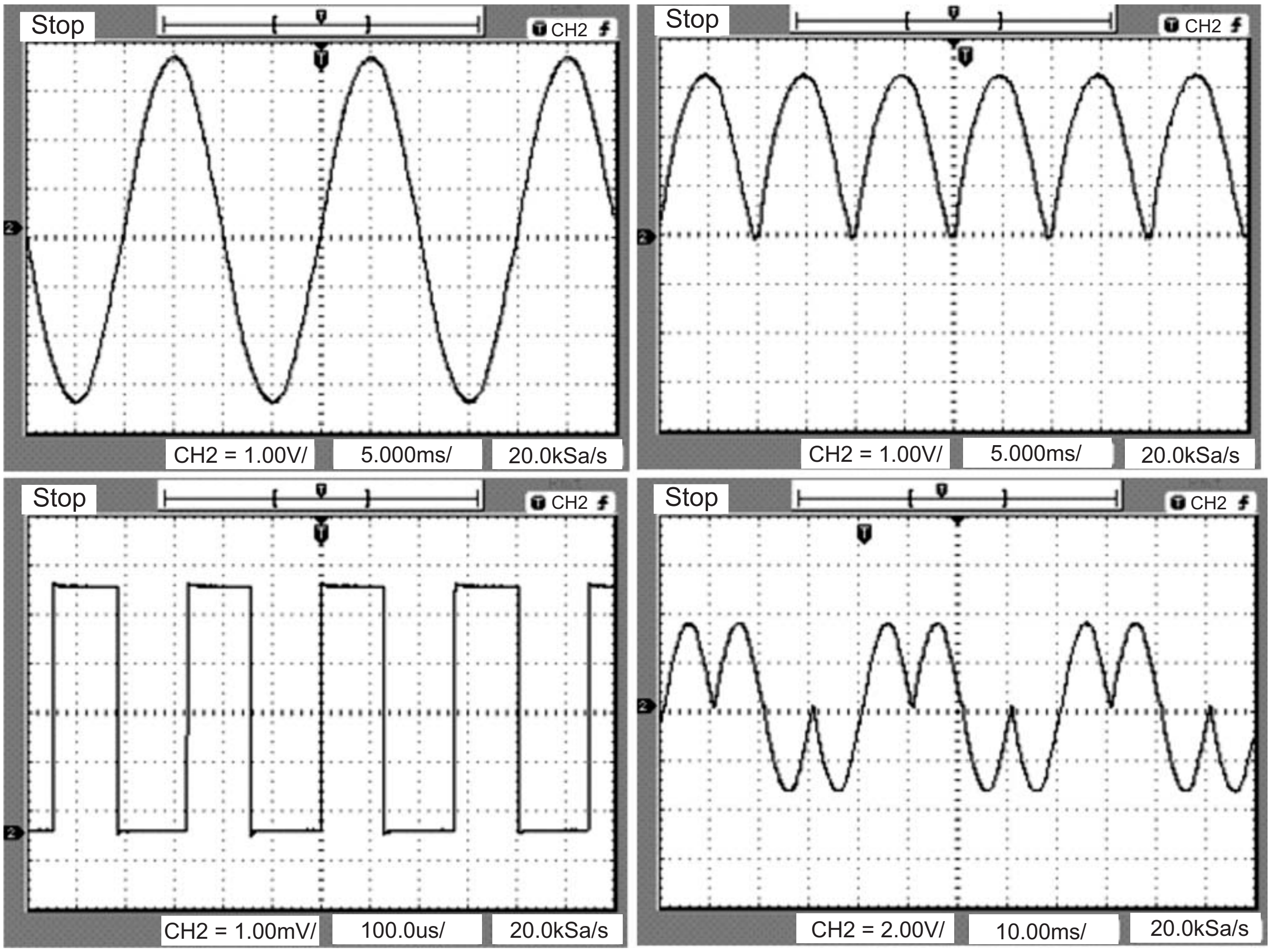


Figure 20: Hardware input and outputs

The hardware results of SPMC performing as (*a*) Input waveform (*b*) Rectifier, (*c*) Inverter and (*d*) Cyclo converter.

9. CONCLUSION

A single phase matrix converter has been designed, realized and implemented as a universal power electronic converter with a simple resistive load. A logical switching combination of IGBT bi-directional switches is implemented to achieve this realization. Sinusoidal PWM and square wave signal generation are used to synthesize the output waveforms. The output results obtained demonstrate a high performance universal converter, where any possible conversions (AC-AC, DC-DC, AC-DC, DC-AC) of electrical supply can be implemented. Further, matrix converter is tested with an induction motor load and the harmonics level acquired is almost 4% which exhibit this converter with a switching strategy is satisfactory.

10. REFERENCES

1. M.Venturini, et.al.:"*The generalized transformer: A newBi-directional wave form frequency converter with continuouslyadjustable input power factor*", IEEE PESC, pp242–252, (1980).
2. SedatSunter, et.al.: "*Implementation of a single-phase Matrix converter induction motor drive*" Electrical Engg , 90:425-433,Springer-Verlag, (2008).
3. Noor S.Z.M,et.al.: "*Modellingand simulation of a DC chopper using single phase Matrixconverter topology*", Proc. of IEEE Sixth InternationalConference PEDS, Malaysia, pp 827-832, (2005).

4. A. Zuckerberger, et. al.:"*Single phase Matrix converter*". IEEE proceeding of Electrical Power Application, 144:235–240, (1997).

5. Idris Z,et. al.: "*Implementation of single-phase Matrix converter as a direct AC-AC converter with commutation strategies*", Proc. of 37th IEEE Power Electronics Specialists Conference, PESC 06, pp.1 – 7, 18-22,(2006).

6. Idris Z,et. al.: "*Safe commutation strategy in Single-phase Matrix Converter*", Proc. of IEEE Sixth International Conference PEDS 2005, Malaysia, pp. 886-891, (2005).

7. Baharom R.,et. al.: "*A new single-phase controlled Rectifier using single-phase Matrix converter*", Proc. of first International Power and Energy Conference PECon, Malaysia, pp. 453-459, (2006).

8. Hamzah M.K.,et. al.: "*A new single-phase Inverter using single- phase Matrix converter topology*", Proc. of first International Power and Energy Conference PECon, Malaysia, pp. 459-464, (2006).

9. Ajay Kumar Gola, et. al., "*Implementation of an Efficient Algorithm for a single phase Matrix converter*", Journal of Power Electronics, Vol. 9, No. 2, (2009).

10. Mayurappriyan. P.S, et.al.: "*Simulation and Analysis of Matrix Converter used in Wind Turbine Generators*",Journal of the Institution of Engineers (India), Vol. 90, May 18, (2009**).**

11. Math Works MATLAB® (V-7.0), R2012a for Microsoft Windows.

12. PICF877 handbook.

13. Muhammed H. Rashid, "*Power Electronics - circuits, devices and applications*",3rd edition, PHI publication.