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Simulation Model of a new Single-phase toSingle-phase Cycloconverter based on Single-phaseMatnx Converter Topology with Sinusoidal PulseWidth Modulation

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ABSTRACT

In this project, single phase to single phase Cyclo converter and three phase six step Cyclo converter using different frequency conversions implementation is simplified by the use of the well known SPWM technique with R, RL- Load. This thesis presents work on modeling and simulation Cyclo converter using MATLAB / Simulink incorporating Sim Power system Single-phase and Three-phase Block. Matrix converter is very simple in structure and has powerful controllability. However, commutation problem and complicated PWM method keep it from being utilized in industry. The problem of commutation in SPMC occurs when inductive load is used. A systematic switching sequence is required that lengthens the dead time between conduction of each IGBT's in SPMC to protect it from malfunction and damaged as a result of existence of voltage and current spike due to short circuit.

Keywords - **Power Electronics, Single-Phase Matrix Converter (SPMC), Cyclo converter, Sinusoidal Pulse Width Modulation (SPWM), MATLab Simulation & Computer Modelling.**

I. INTRODUCTION

The introduction of power transistors for implementing the bidirectional switches made the matrix converter topology more attractive. However, the real development of matrix converters starts with the work of Venturini and Alesina published in 1980. They presented the power circuit of the converter as a matrix of bidirectional power switches and they introduced the name “Matrix Converter.” In this project, common emitter anti-parallel interconnected IGBT’s-diode pair is used as the bidirectional switch. Diodes are in place to provide reverse blocking capability to the switch module. The IGBT’s were used due its high switching capabilities and high current carrying capacities. To give the triggering pulses to the bidirectional switch there are various control methods. By using these control methods we can control of output voltage of Cyclo converters. PWM Techniques are the efficient control methods as it contains no peripheral devices. In this project, a well know Sinusoidal Pulse Width Modulation Technique (SPWM) is used for controlling the gate pulses that are given to the switches. In the SPWM control, a sinusoidal reference signal is compared with the high frequency triangular signal to generate the gate pulses and a controlled A.C. output voltage is obtained by adjusting the pulse width by varying the modulation index.

As Cyclo converter is a power frequency changer, the most desirable features in power frequency changers are

1) Simple and compact power circuit;

2) Generation of load voltage with arbitrary amplitude and frequency;

3) Sinusoidal input and output currents;

4) Operation with unity power factor for any load;

5) Regeneration capability.

Moreover, these characteristics are not fulfilled by the conventional frequency changers. This is the reason for the tremendous interest in matrix converter topology as the ideal features can be fulfilled. The matrix converter (MC) offers possible "all silicon" solution for AC-AC conversion removing the need for reactive energy storage components used in conventional rectifier-inverter based system. Gyugyi first described the topology in 1976. Obviously all published studies dealt with mainly the three-phase circuit topologies. The Single-phase matrix converter variant on the same philosophy denoted as SPMC was first realised by Zuckerberger.

II. CYCLO CONVERTER

In Industrial applications, two forms of electrical energy are used: direct current (DC) and alternating current (AC). Usually constant voltage constant frequency single -phase or three-phase ac is readily available. However, for different applications, different forms, magnitudes and/or frequencies are required. There are four different conversions between DC and AC power sources. These conversions are done by circuits called power converters. The converters are classified as

1. Rectifiers: from Single-phase or Three-phase AC to variable voltage DC
2. Choppers: from DC to variable voltage DC
3. Inverters: from DC to variable magnitude and variable frequency, single-phase or three phase AC
4. Cyclo converter: from Single-phase or Three-phase AC to variable magnitude and variable frequency, single-phase or three-phase AC

This chapter explains about the Cyclo converter, their types, step-up and step-down operation and their applications. Traditionally, the AC-AC converters using semiconductor switches are commonly classified into indirect converter which utilizes a DC link between the two AC systems and direct converter that provides direct conversion. Indirect converter consists of two converter stages and energy storage element, which convert input AC to DC and then reconverting DC back to output ac with variable amplitude and frequency as shown in Fig. 1(a). In direct converter there is no need of DC link as shown in Fig 1(b)

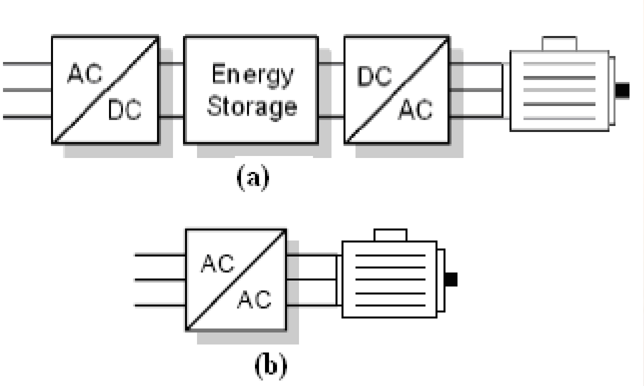


Fig 1: AC/AC converter (a) Indirect converter (b) Direct converter

Cyclo converters are the direct type converters used in high power applications driving induction and synchronous motors. They are usually phase-controlled and they traditionally use thyristors due to their ease of phase commutation. The basic block diagram of Cyclo converter is shown in Fig 2.

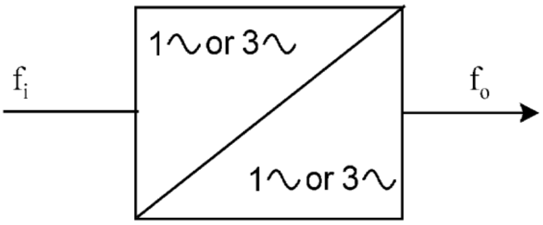


Fig 2: Block diagram of Cycloconverter

A Cyclo converter is a type of power controller in which an alternating voltage at supply frequency is converted directly to an alternating voltage at load frequency without any intermediate DC stage. In a line commutated Cyclo converter, the supply frequency is greater than the load frequency. The operating principles were developed in the 1930s when the grid controlled mercury arc rectifier became available. The techniques were applied in Germany, where the three phase 50 Hz supply was converted to a single phase AC supply at 16⅔ Hz for railway traction. In the United States, a 400 HP scheme in which a synchronous motor was supplied from a Cyclo converter comprising 18 thyratrons was in operation for several years as a power station auxiliary drive. However, because these early schemes were not sufficiently attractive technically or economically, they were discontinued. A Cyclo converter is controlled through the timings of its firing pulses, so that it produces an alternating output voltage. By controlling the frequency and depth of phase modulation of the firing angles of the converters, it is possible to control the frequency and amplitude of the output voltage. Thus, a Cyclo converter has the facility for continuous and independent control over both its output frequency and voltage. This frequency is normally less than 1/3 of the input frequency. The quality of the output voltage wave and its harmonic distortion also impose the restriction on this frequency. The distortion is very low at low output frequencies. The Cyclo converters are normally used to provide either a variable frequency from a fixed input frequency or a fixed frequency from a variable input frequency.

A Cyclo converter can handle load of any power factor and allows power flow in both the directions. The output voltage wave shape inevitably contains harmonic distortion components in addition to the required sinusoidal component. These distortion terms are produced as a necessary outcome of the basic mechanism of the Cyclo converter, whereby the output voltage is fabricated from segments of the input voltage waves. These distortions can be minimized by adequate filters at the output. The distortion of the output voltage increases if the ratio of the output and input frequency increases.

III. SINGLE-PHASE MATRIX CONVERTAER

The Single-Phase Matrix Converter (SPMC) consists of a matrix of input and output lines with four bi-directional switches connecting the single-phase input to the single-phase output at the intersection. The SPMC is presented schematically in Fig 3. Its instantaneous input voltage $vi(t)$ and its output voltage $vo(t)$. It comprises of four ideal switches S1, S2, S3, and S4 capable of blocking forward and reverse voltages (symmetrical devices) and switching between states without any delays.

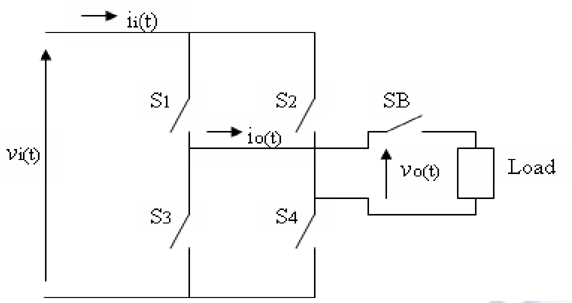
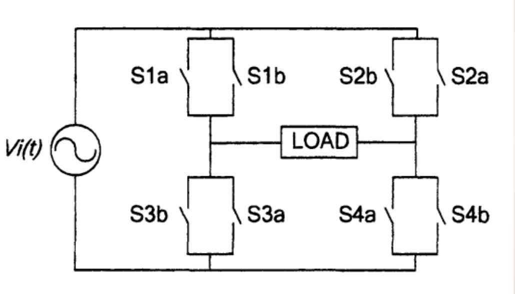


Fig 3: Single-phase matrix converter circuit configuration a) at no load

SPMC operating at no-load: With the SB open the SPMC is unloaded as shown in Fig 4.2(a). This topology converts the input voltage *vi*(t), with constant amplitude and frequency, through the four ideal switches to the output terminals in accordance with pre-calculated switching angles. The input voltage of the matrix converter presented in Fig 4.2 is given by



(b)

Fig 3: Single-phase matrix converter circuit configuration b) at load

$$V_i(t) = \sqrt{2}V_i(t)\cos\omega_i t \qquad \text{……. (1)}$$

The matrix converter will be designed and controlled in such a manner that the fundamental of the output voltage is

$$V_o(t) = \sqrt{2}V_o(t)\cos\omega_o t \qquad \text{……. (2)}$$

The problem at hand may be defined as follows: with input voltage from equation 3.1, the matrix converter switching angles will be calculated so that the fundamental of the output voltage will be given in equation 3.2, keeping with the degrees of freedom specified by

$$V_o(t) = \begin{cases} v_i(t) & \text{where S1 and S2 are in on state – mode 1} \\ -v_i(t) & \text{where S2 and S3 are in on state – mode 2} \\ & \text{where (S1 \& S2) or (S2 \& S3) are in on state – mode 3} \end{cases} \qquad \text{………. (3)}$$

The additional states (S1 &S2 – on) and (S2 &S3- on) are forbidden states (they create a short circuit of the mains). The instantaneous value of the output voltage, *vo*(t), has the following characteristics:

1. Its maximum value is identical to the maximum value of the input voltage.
2. It contains fundamental and additional high order harmonics located at well defined sampled frequencies.
3. Its main harmonic has a stepped-up frequency and a stepped –down amplitude.

The SPMC may operate

1. In modes 1 and 2 (operation without load shorting)
2. In modes 1, 2 and 3 (operation with load shorting)

In this project, we will see the operation without load shorting i.e. (modes 1 and 2).The four power switching devices are switched at high frequency, fs (fs >>fi and fo where fi = ωi / 2Π and fo = ωo /2Π). The normalized switching time (or duty cycles of every switch) during any switching cycle (Ts = 1/fs), is defined by

$$m_j^k = \frac{\text{the time interval when the circuit is in mode j, during the kth cycle}}{Ts} = \frac{\Delta_j^k}{Ts} \qquad \text{……….(4)}$$

Where j = 1, 2 is the operation mode, k= 1, 2… n… is the cycle number.

It is obvious that

$$\left\{ \sum_{j=1}^{2}\Delta_j = T_s \qquad \text{or} \qquad m_1^k + m_2^k = 1 \right. \qquad \text{…. (5)}$$

As a result of high frequency of the converter, the average output voltage during any *k*th switching cycle Ts is given by

$$V^{k}_{o,av} = \left(m^{k}_{1} - m^{k}_{2} \right) v^{k}_{i}(t) \quad \text{……….} \ (6)$$

Where vi(t) is the input voltage during the *K*th cycle and is practically constant. Keeping with equation 6 one can write that the fundamental of output voltage is given by

$$Vo\cos(\omega ot) = (m_1 - m_2) Vi\cos(\omega it) \quad \text{….} \ (7)$$

Fig 3 shown below interprets equations 4-7. It presents the input voltage (fig.3(a)), the instantaneous output voltage(fig.3(b)),the desired fundamental of the output voltage (Fig.3(c)) and the averaged output voltage (Fig.3(d)) during one input switching cycle (1ms @ fs = 1KHz);

From the Fig 3, it can be seen that. The input voltage is almost constant within one switching cycle (fi << fs)

1. During the nth switching cycle Ts, the instantaneous output voltage oscillates between two values +vi^n(to) and –vi^n(to) (with nTs < to <= (n+1)Ts)
2. The averaged output voltage follows the required voltage given in equation 3.2
3. When m1~m2 with Ts the fundamental of output voltage approaches to zero

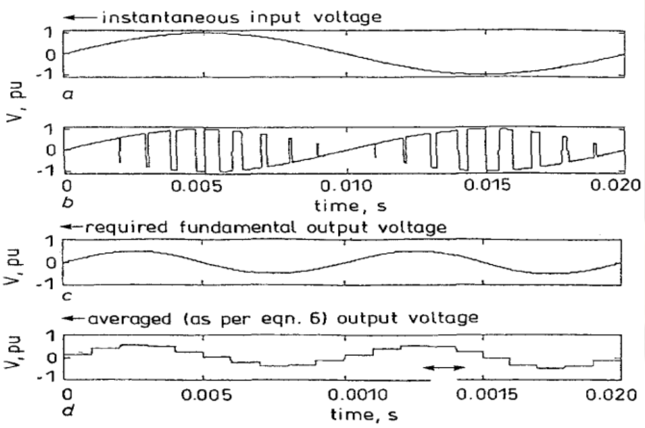


Fig 4: Input, Output, required output and averaged output wave forms

From equations 3.5 and 3.7, we obtain

$$m_1 = \frac{1 + \frac{Vo\cos(\omega ot)}{Vi\cos(\omega ot)}}{2}$$

$$m_2 = \frac{1 - \frac{Vo\cos(\omega ot)}{Vi\cos(\omega ot)}}{2} \quad \text{……….} \ (8)$$

It is obvious that

$$0 \le mj \le 1 \quad \text{……….} \ (9)$$

From equations 3.8 and 3.9 is evident that

$$\left| \frac{Vo\cos(\omega o\, t)}{Vi\cos(\omega o\, t)} \right| \le 1 \quad \text{……….}(10)$$

Equation 3.10 must exist for any time, t, and this imply that when cos (ωi(t)) vanishes (this function => 0) also cos (ωo(t)) must vanish (=> 0). Therefore, input and the output waveforms must be synchronized and the fundamental of output voltage must cross zero more frequently than the input voltage. Hence, the single-phase matrix converter is a frequency step-up circuit capable of converting an input waveform with an angular frequency given by

$$\omega_o = r \times \omega_i \quad \text{……….} \ (11)$$

Where r = 1, 2, 3…

When cos (ωi(t)) = 0, the m1 and m2 are calculated in accordance with equation 3.8 and L' Hospital rule. The result is

$$m_1 = \frac{1 + \frac{Vo\cos(\omega ot)}{Vi\cos(\omega ot)}}{2}$$

$$m_2 = \frac{1 - \frac{Vo\cos(\omega ot)}{Vi\cos(\omega ot)}}{2} \quad (12)$$

Keeping with equation 3.12 we obtain

$$Vo \le \frac{\omega i}{\omega o} Vi \quad \text{……….} \ (13)$$

The above equation means that single-phase matrix converter is stepping down the output voltage fundamental. Based on the equations 3.8-3.13, one can conclude that the switching pattern, the ms might be calculated. The four switching power devices S1, S2, S3, and S4 will be controlled according to the switching pattern. The above discussed matrix converter topics can be summarizes as

1. The matrix converter will be controlled according to a switching pattern and the purpose is to obtain an output main harmonics as per equation 3.2.
2. Its input, *vi*(t) is a sinusoidal waveform and its output, *vo*(t) comprises a number of high order harmonics.
3. Both waveforms have identical maximum values and total RMS values.
4. The matrix converter is a frequency step-up and fundamental voltage step-down converter. Up to this point the SPMC is unloaded.

SPMC operating with passive load: When the SB is closed, the SPMC supplies current to its load. The relation between the output voltage and the output current for the passive, R, L load is

$$Vo(t) = \mathrm{Rio(t)} + \mathrm{L}\frac{\mathrm{dio(t)}}{\mathrm{dt}} \quad \ldots\ldots\ldots. (14)$$

Considering Fig 4.2 and the operation modes of this topology, the input current, i(t), is given by

$$i_i(t) = \begin{cases} i_o(t) & -\ \text{Mode 1} \\ -i_o(t) & -\ \text{Mode 2} \end{cases} \qquad (15)$$

Where mode 1 and mode 2 were defined in above section.

Keeping in mind that the load of the converter is almost always a low pass filter (R, L load) the output current waveform contains less high order harmonics than the output voltage.

IV. WORKING OF SPMC AS CYCLOCONVERTER

We know that the Single-phase matrix converter consists of forced commutated bidirectional switches. By controlling these bi-directional switches Cycloconverter operation is done. The schematic view of the SPMC circuit configuration for the Cycloconverter operation is given the Fig 3.1

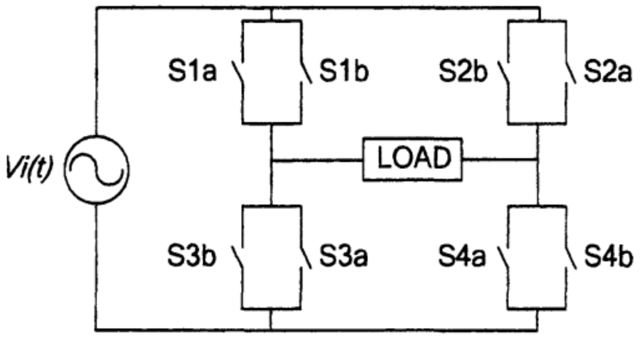


Fig 5: Schematic diagram of SPMC circuit configuration

The SPMC circuit as shown in Fig 4.1 uses four bi-directional switches for the Cyclo converter implementation. It requires the use of bi-directional switches capable of blocking voltage and conducting current in both directions. Unfortunately there is no discrete semiconductor device. Currently that could be fulfilling the needs and hence the use of common-emitter anti-parallel IGBT, diode pair as shown in Fig 4.2. Diodes are in place to provide reverse blocking capability to the switching module. The IGBT were used due to its high switching capabilities and high current carrying capabilities desirable amongst researchers for high power applications.

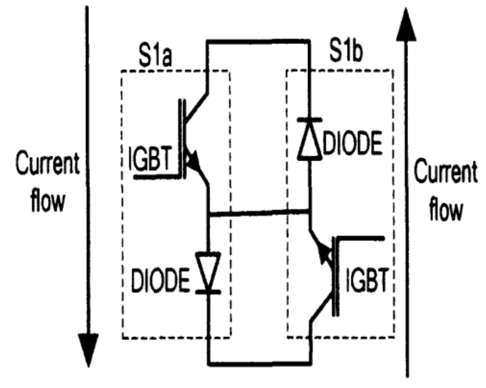


Fig 6: Schematic view of Bi-directional switch (common -emitter)

SWITCHING STRATEGY FOR STEP-DOWN CYCLOCONVERTER: The implementation of the SPMC as a Cycloconverter requires different bi-directional switching arrangements depending on the desired output frequency. The output voltage of the converter is controlled by Sinusoidal Pulse Width Modulation (SPWM), but the frequency of the converter is changed by controlling the duration of operation of the switch. In this project the input frequency used is set at 50Hz and the desired output frequency synthesized at the 25 and 12½ Hz for step down Cycloconverter as shown in Fig 6. The SPWM helps to give the gate triggering pulses in sequence as required to the get the desired frequency at the output voltage.

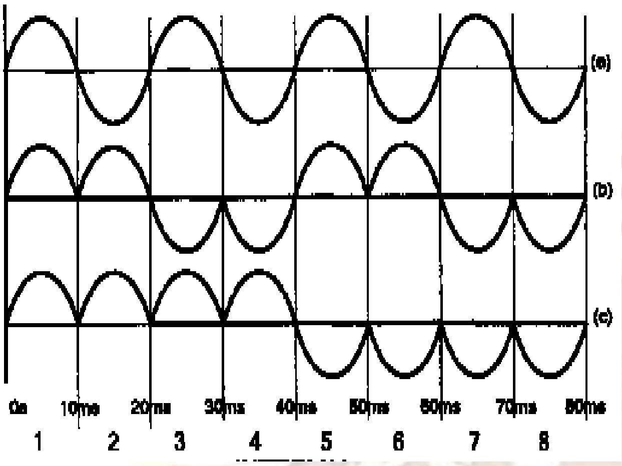
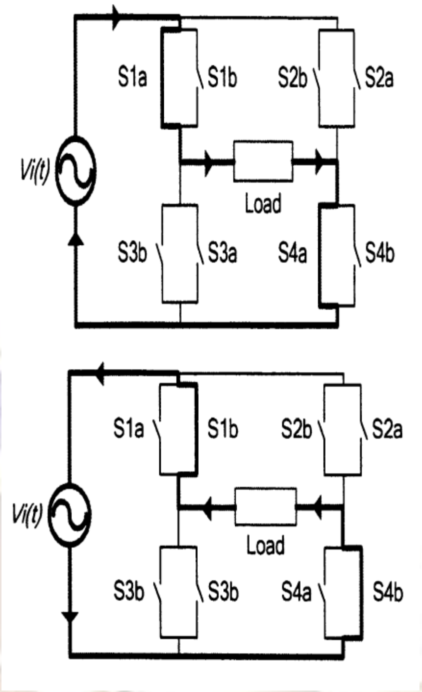


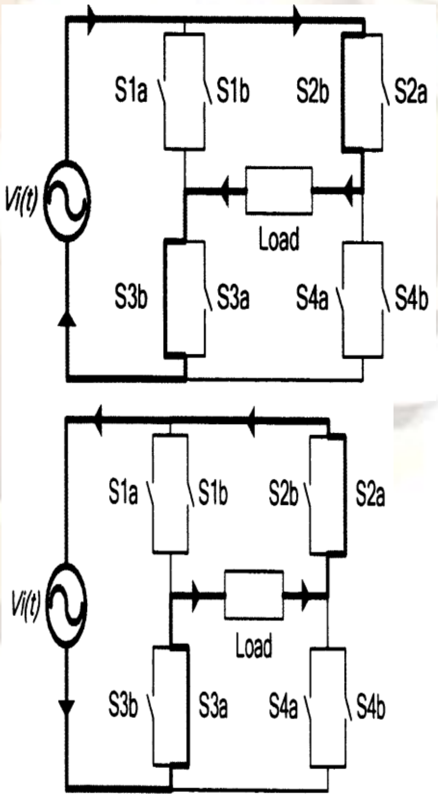
Fig 7: Wave forms of a) I/P at 50 HZ b) O/P at 25 HZ c) O/P at 12 ½ HZ

During the positive half-cycle of the input voltage, the switches S1a, S2b, S3b and S4a are forward biased and during the negative half cycle of the input voltage, the switches S1b, S2a, S3a and S4b are forward biased. To get the positive half-cycle at the load, the switches S1a and S4a are triggered during the positive half-half cycle of the input and are shown in Fig 8(a). And to get the negative half-cycle at the load the switches S2b and S3b are triggered and are shown in Fig 8(c).More over during negative half cycle of the input voltage, switches S4b and S1b are triggered to get the negative half-cycle at the load and are shown in Fig 8(b). To get the positive half-cycle at the load switches S3a and S2a are triggered and are shown in Fig 8(d).

Table 1 shows the different states of switching in sequence to get the desired frequency of the output voltage. The switching sequences are dependent on the time interval and the state of the driver circuit following table 1 as shown below (for one cycle).



a) State 1(positive cycle) b) State 2(negative cycle)



c) State 3(positive cycle) d) State 4(negative cycle)

Fig 8: Different states for the operation of the Cycloconverter

The switching angles, of the four bi-directional switches Sij (i = 1, 2, 3, 4 and j = a, b) where ‘a’ and ‘b’ represent as driver one and driver two respectively will be considered by the following rules below.

- At any time ‘t’, only two switches Sij(i= 1, 4 and j =a) will be in ‘ON’ state and conduct the current flow during positive cycle of input source.(state 1)
- At any time ‘t’, only two switches Sij(i= 1, 4 and j = b) will be in ‘ON’ state and conduct the current flow during negative cycle of input source.(state 2)
- At any time ‘t’, only two switches Sij(i= 2, 3 and j = b) will be in ‘ON’ state and conduct the current flow during positive cycle of input source.(state 3)
- At any time ‘t’, only two switches Sij(i= 2, 3 and j =a) will be in ‘ON’ state and conduct the current flow during negative cycle of input source.(state 4)

Input frequency	Target output frequency	Time interval	State	Switch “modulated”
50 Hz	25Hz	1	1	S1a and S4a
		2	4	S2a and S3a
		3	3	S2b and S3b
		4	2	S1b and S4b
	12½ Hz	1	1	S1a and S4a
		2	4	S2a and S3a
		3	1	S1a and S4a
		4	4	S2a and S3a
		5	3	S2b and S3b
		6	2	S1b and S4b
		7	3	S2b and S3b
		8	2	S1b and S4b

Table 1: Switching Sequence of step down Cycloconverter

PULSE WIDTH MODULATION CONTROL: The most efficient method of controlling the output voltage is to incorporate pulse width modulation control (PWM control). In this method, a fixed AC input voltage is supplied to the Cycloconverter and a controlled AC output voltage is obtained by adjusting the on and off periods of the gate pulses. There are many possible PWM Techniques proposed in the literature. The choice of a particular PWM Technique depends on the permissible harmonic content in the inverter output voltage, machine type, power level and semiconductor switching devices employed for a particular application The PWM control has the following advantages.

1. The output voltage control can be obtained without any additional components.
2. The output voltage is controlled by varying the modulation index instead of varying the amplitude of the carrier signal.

With this type of control, lower order harmonics can be eliminated or minimized along with its output voltage control. The filtering requirements are minimized as higher order harmonics can be filtered easily.

V. MAIN MODEL

Basic schematic view of the single-phase matrix converter configuration working as Cycloconverter is seen in Fig. The MLS implementation of the SPMC configuration is as shown below Fig 9.

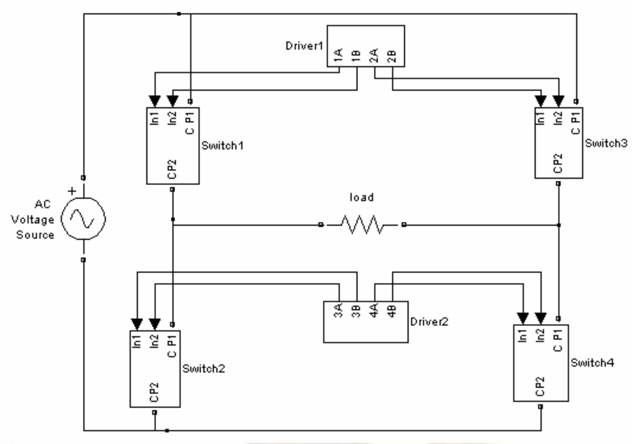


Fig 9: Top level main model of SPMC in MLS

Switches used are the bi-directional switches used to block the voltage and conduct the current in both directions. The Matlab design of the bi-directional is shown as shown in Fig 10.

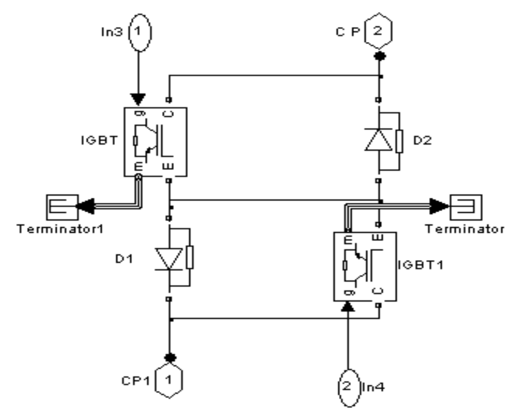
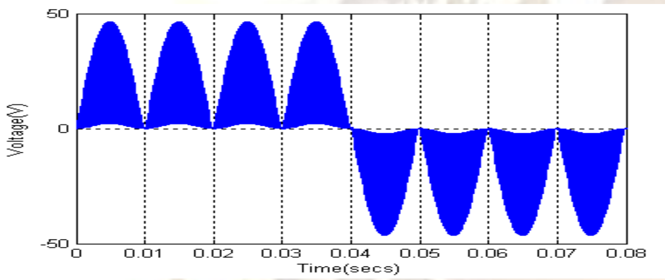


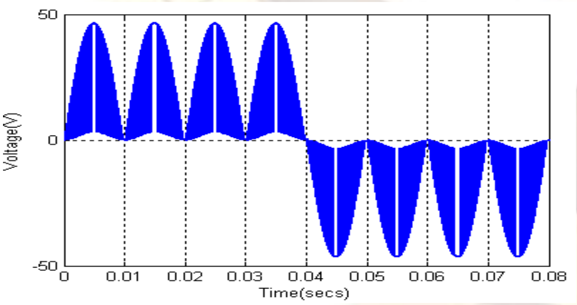
Fig 10: Bi-directional switch module in MLS

DRIVER CIRCUIT MODEL: Driver circuits were designed to generate the SPWM pattern that is controlled using the switching states as in tables 1. The driver circuit algorithm are designed by using MLS is shown in Fig, comprising SPWM generator portion and state portion. A two "sine wave" blocks are used to generate two sinusoidal references signal 'Vref1' and 'Vref2'. Output from the "sine wave" block is multiplied using a "multiply" block with the output from the constant block that represents the modulation index, thus magnitude could be varying changing this "constant" value. The "repeating sequence" block is used to generate the triangular carrier signal 'Vc'. To produce the SPWM the "relational operation" block are used as a comparator that triggers an output switching function between "0" and "1" that represents the PWM train.

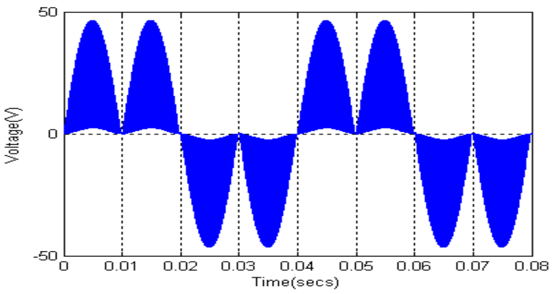
SIMULATION RESULTS OF R LOAD



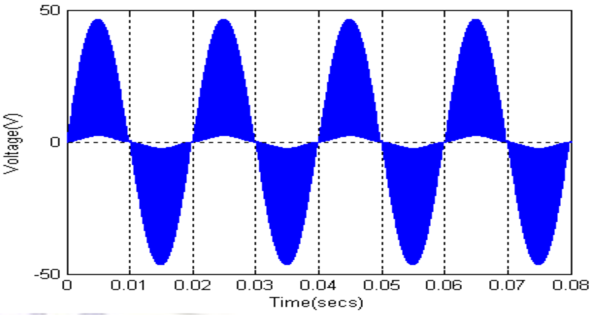
O/P voltage wave form of 12½Hz of modulation index of 0.7



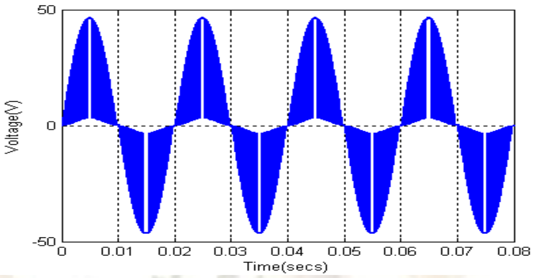
O/P voltage wave form of 12½Hz of modulation index of 1.0



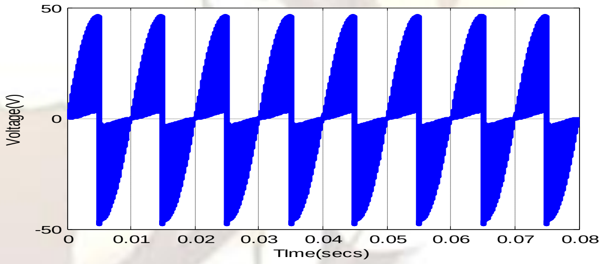
O/P voltage wave form of 25Hz of modulation index of 0.7



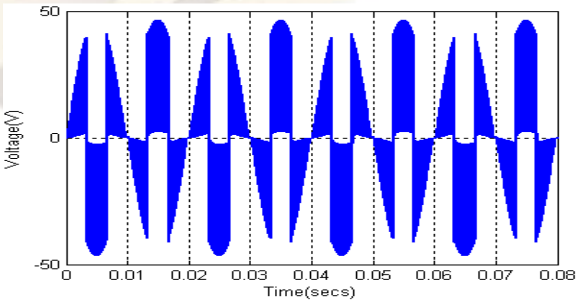
O/P voltage wave form of 50HZ of Modulation Index 0.7



O/P voltage wave form of 50HZ of Modulation Index 1.0

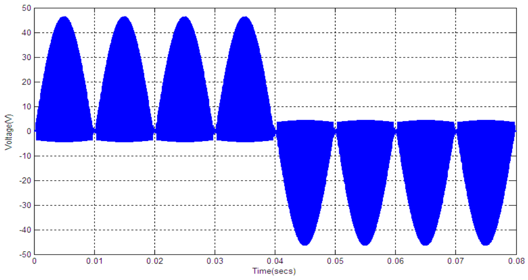


O/P Voltage wave form of 100 HZ of modulation index 1

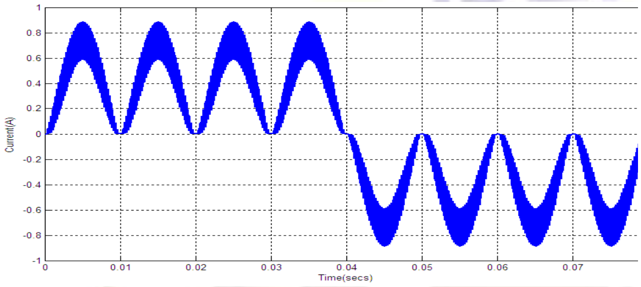


O/P Voltage waveform of 150 Hz of modulation index 0.7

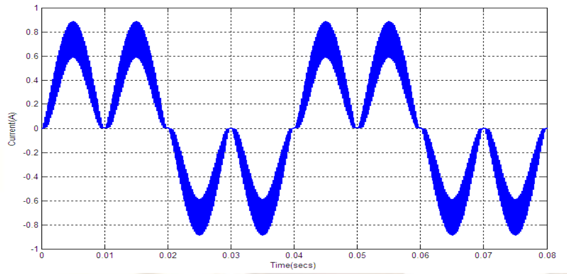
SIMULATION RESULTS OF R-L LOAD



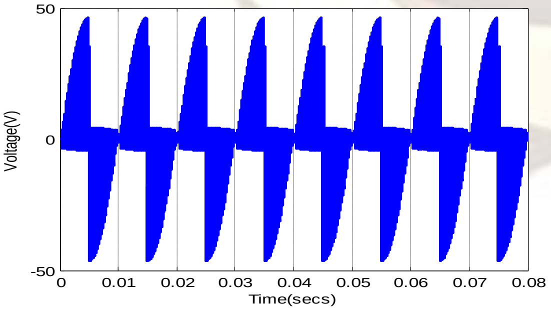
O/P Voltage waveform of 12½ Hz of modulation index 0.7



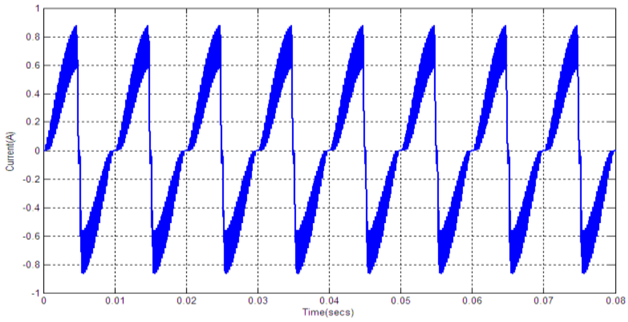
O/P Current waveform of 12½ Hz of modulation index 0.7



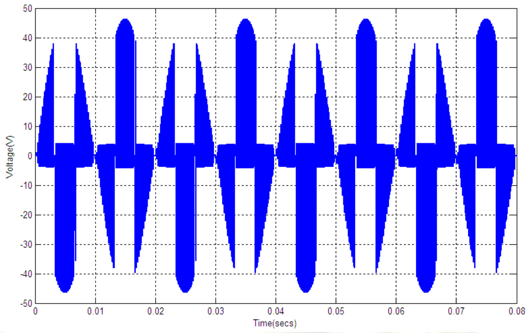
O/P Current waveform of 25 Hz of modulation index 0.7



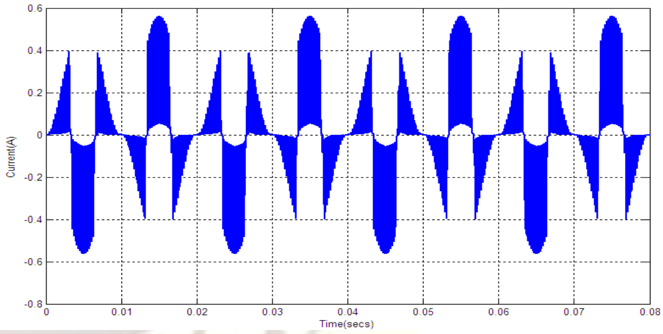
O/P Voltage waveform of 100 Hz of modulation index 0.7



O/P Current waveform of 100 Hz of modulation index 0.7



O/P Voltage waveform of 150 Hz of modulation index 0.7



O/P Current waveform of 150 Hz of modulation index 0.7

PARAMETERERS FOR SIMULATION

Input source	**50Vrms**
Reference Frequency Signal	**50 Hz**
Carrier Signal	**5KHz**
Sample Modulation Index	**0.7&1.0**
Load	**R= 50Ω and** **L= 4mH**

Table2 Parameters

VI. CONCLUSION

In this project, the computer simulation model on SPMC for Cycloconverter operation using MATLAB/Simulink (MLS) software package has been presented.

- It includes the implementation of SPWM to synthesize the AC output supply for a given AC input. Matrix converter has many advantages like simple and compact circuit.
- Operation at unity power factor.
- Regeneration capabilities.
- Simulation results of SPMC illustrates that it is feasible to realise the converter in the various basic AC-AC converters that includes; AC controller, Step-up and Step-down frequency changer.
- A safe commutation technique is implemented to avoid current spikes by allowing the dead time.
- Matrix converter technology has potential benefits especially for applications where size, weight, and long term reliability are the important factors.
- Having these advantages, MC has very limited applications due to non-availability of full controlled bi-directional switch, complex control system.

In the near future, MC places a vital role by developing suitable control strategies.

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