

Simulation modal for SPMC as Single Phase Cycloconverter with SPWM

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Abstract— Modern power electronics revolutionized the idea of Matrix converter, which is the universal in its nature and provide all Silicon solution to the developer. Electric drive system (EDS) provides flawless control to the electrical machine and it is important to have a converter that can fulfill the demand of the particular industry. The ac-ac controller is of the two types 1) Indirect converter 2) Direct converter. Matrix converter is often used for the three phase applications but the popularity of the matrix converter is much more in single phase system because of its universal nature. Single phase Matrix converter (SPMC) is consists of the four bi-directional switches (IGBT-diode pairs) and all the switches are capable of the reverse blocking and bidirectional current flow. Controlling of bidirectional switches is made in the driver circuit. Sinusoidal Pulse width Modulation Technique is used for the controlling of switches. All the work is done with the help of Matlab/Simulink software.

Index Terms— Driver circuit, Electric Drive System, Indirect Converter, Direct Converter, IGBT, SPMC, SPWM.

1 INTRODUCTION

Modern power electronics have a large application in the field of controlling of machines. Electrical machines either ac or dc both need speed variation for the specific work. Controlling of electrical machine is done before with the conventional methods but these methods contain large quantity of losses. And minimization of these losses is also necessary for smooth operation of electrical machine. Losses of electrical rotating machine are classified into two category- 1) Core losses or constant losses or iron losses 2) Copper losses or Ohmic losses. Core loss in electrical machine is classified into two categories – 1) Eddy current loss and 2) Hysteresis loss. Copper loss, coupling field loss and friction and windage losses are irreversible in nature and these are therefore dissipated as heat. Core losses in electrical machine are proportional to the frequency of the input ac supply. And so we can minimize the core loss and get the large range of speed variation with the changes in supply frequency. For that work we are using cycloconverter. Cycloconverter is used to get ac voltage of variable amplitude and variable frequency from ac voltage of fixed amplitude and fixed frequency. Majority of cycloconverter [1] uses naturally commutated SCRs for their operation when the maximum output frequency is restricted to a portion of the input frequency. With the rapid advancement in technology of fast-acting fully controlled switches, force commutated cycloconverters or recently developed matrix converters with bidirectional on and off control switches provide independent control of the magnitude and frequency of the produced output voltage as well as sinusoidal modulation of output voltage and current. Conventional cycloconversion process is a indirect method which uses rectifier-inverter type converter. Indirect method involves the AC-DC-AC conversion which uses dc link capacitor. The dc link capacitor increases the weight of converter, reduces the reliability of converter and increases the volume. Because of all these drawbacks we are using direct conversion process without the dc link capacitor [2]. Maximum active power transfer to the load is decided by nature of the control algorithm. MC has a maximum input-output voltage transfer ratio limited to approximately 87 % for sinusoidal input and output waveforms, which can be improved. Additionally, matrix converter requires more silicon devices than a conventional AC-DC-AC indirect power frequency converter. Since monolithic bi-directional controls exist they are used for switching purpose.

2 MATRIX CONVERTER

2.1 Historical Background

Matrix converter is proposed almost four decades ago but this converter is still struggling for a significant share in power electronics market. The matrix converter (MC) first appeared in the literature in a book by Gyugi and Pelly in 1976 and also in a journal publication by Daniels and Slattery in 1978 and these both published for ac-ac conversion process. In these journals, it was also defined as a “force commutated cycloconverter.” [3] Since then, as with many power converter topologies, effort has focused on the origin of modulation and control strategies. In contrast to a dc-link voltage source inverter (VSI), the modulation of the switches in the matrix converter is harder since three changing voltages can be used for the modulation. Methods similar to VSI modulation strategies which use only the most positive and negative accessible voltages are presented in [2]. Matrix converter is good solution for VSDs and it provides all solution to the electrical system. We can get input to output power ration approximately 87 percent with the suitable modulation technique. The popular modulation techniques used in Matrix Converter are PWM, Space Vector Pulse width modulation, Space vector modulation. Out of all these technique the most popular technique is space vector modulation but it is complex in nature and it makes the circuit more complex. So instead of SVM technique we are using a simple SPWM technique which is easier to understand and this technique is simple to apply on single phase matrix converter circuit. In that techniques the major concern is to eliminate the lower order harmonics both at input and output. MC

contains bidirectional switches capable of blocking reverse voltage and current flow in both directions. It uses fast switching power electronics devices like IGBTs and MOSFETs.

The matrix converter substitutes the numerous conversion stages and the intermediate energy storage element (dc link capacitor) by a single power conversion stage, and uses a matrix of semiconductor bidirectional switches connecting input and output terminals [10]. With this overall arrangement of switches, the power flow through the converter can inverse. Because of the lack of any energy storage element, the immediate power input must be equal to the power output, assuming perfect zero-loss switches. However, the reactive power input does not have to equivalent power output. It can be said once more that the phase angle amongst the voltages and currents at the input can be precise and does not have to be the same as at the output. These days power electronics converters are used in numerous applications such as Industrial, Medical and Railways etc. [11]. Optimization of power electronic system design and operation is vital to hold the rising need for energy efficiency in portable electric devices and respond to their increasing useful features. These features require extra electric power while the devices must be reduced in size and weight. Power electronics converters like Rectifier and Inverters are castoff in various commercial and industrial applications. Inverters are used widely in many applications in which the essential voltage is AC in nature. An improved control structure for single phase Matrix Converter (SPMC) such that it can be used for different applications, is projected in this dissertation. Improvement of control signals through Sinusoidal Pulse Width Modulation (SPWM) is presented and the Matrix Converter is evaluated for its operation based on switching sequence.

2.2 Fundamentals

Matrix converter is a kind of universal converter which is used for the all type of conversion process possible by conventional methods. These methods employed silicon switches which can be either uncontrolled or controlled. In conventional methods, conversion processes are classified into mainly four categories:-

- AC to DC conversion: - In that conversion process we convert the ac supply to dc supply. This process is also known as rectification. Rectifier circuits are also categorized as 1) Single phase rectifiers and 2) Three phase rectifier. Single phase rectifier are also categorized as half wave converter, full wave converter (either center tapped or bridge type) and semi converter (Symmetrical or asymmetrical).
- DC to DC conversion: - In that conversion process we convert input dc of some level to output dc of other level. Choppers are used for dc to dc conversion process. It is classified into different classes. But out of all these the BUCK and BOOST converter are mainly used.
- AC to AC conversion: - In that conversion process we convert AC input of some amplitude and frequency to ac output of other amplitude and frequency. For only change in amplitude of input supply voltage we are using ac controllers or regulators. For four quadrant operation we are using dual converter. For change in both the amplitude and frequency of input ac supply we are using cycloconverter. In this dissertation we will see the work related to the cycloconverter.
- DC to AC conversion: - In this conversion process we changes the DC input supply to AC output. This conversion is made possible using inverters.

3 MATRIX CONVERTER AS CYCLOCONVERTER

Matrix converter is used for all these possible conversion processes. In matrix converter the input and output phases are in the form of matrix with the help of bidirectional switches. These switches allow any output phase to be connected to any input phase. It also provides sinusoidal input and output waveform with the minimal amount of higher order harmonics and sub harmonics are absent. Bidirectional switches allow flow of energy in both the direction i.e. from source to load terminals and load to source terminals. But the commutation problem arises when we are using inductive load and for that we have to increase the deal time interval. Matrix converter doesn't need any kind of energy storage element which is used for the conventional rectifier-inverter topology [5]. Reactive energy storage elements are bulky in size and are expensive too. Bidirectional switches are capable of blocking reverse voltage and allow flow of current in both directions. Single phase Matrix converter consists of four bidirectional switches. Input of the SPMC is connected to the 110 RMS ac supply voltage of 50Hz frequency. Output is connected to load. Fig 1 shows the circuit diagram of the SPMC with R and RL load respectively.

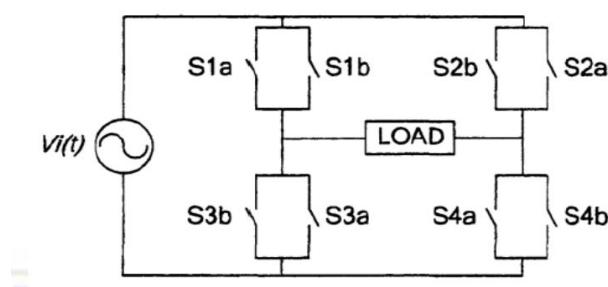


Fig 1: Circuit Diagram of SPMC

Bidirectional switches are formed by using the common emitter configuration of antiparallel connected IGBT-Diode pair. IGBT is used in this configuration for flow of current in both direction and diodes are used for blocking reverse voltage. The bidirectional switch is shown in fig 2.

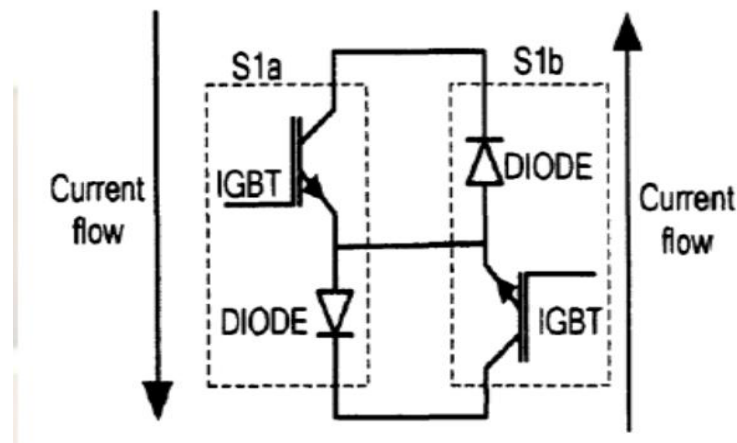


Fig 2: Bidirectional Switch

IGBT is used because of its high switching capability and high current carrying capabilities which is desirable among all the power electronics researchers. In addition to that IGBT can be switched with supersonic frequencies i.e. frequency > 20 kHz which can be ideal for modern power converter circuits.

4 WORKING PRINCIPLE

SPMC can be worked both as step down and step up cycloconverter with the help of proper switching pulses provided on the bidirectional switches connected to SPMC circuit. The general circuit diagram and working of step down and step up process are explained in the next sections.

4.1 Step Down Process

The switching instances are considered with the following rules for the bidirectional switches let's suppose to be S_{ij} , where $i=1, 2, 3, 4$ and $j=a$ and b . Here a and b represent the driver circuit for the respective combination. The circuit diagram and the switching states are provided for step down frequency of 25Hz. So let's see some general rule of switching angles for the cycloconverter switches in the below points [1]:

- For the positive half cycle of the input voltage, switches S_{1a} , S_{4a} , S_{2b} , S_{3b} are forward biased. To get the positive cycle at the load switches S_{1a} and S_{4a} are triggered. And similarly switches S_{2b} and S_{3b} are triggered for the next half cycle. So with these switching instances we can get the two positive cycles simultaneously.

- For the negative half cycle of the input voltage, switches S_{1b} , S_{4b} , S_{2a} , S_{3a} are forward biased. To get the negative cycle at the load switches S_{2a} and S_{3a} are triggered and similarly switches S_{1b} and S_{4b} are triggered to get next negative cycle. All these states are shown in below fig no fig 3 and fig 4:

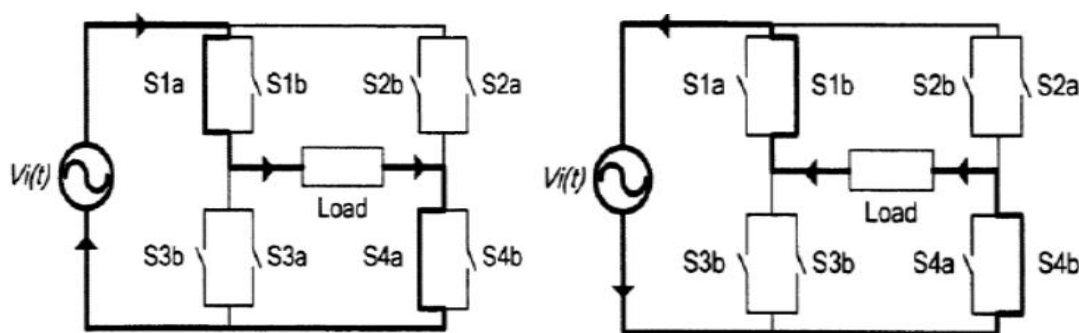


Fig 3 a) State 1 (Positive Cycle) b) State 2 (Negative Cycle)

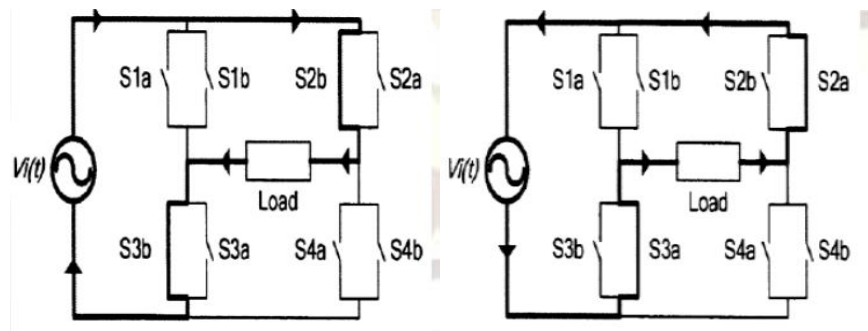


Fig 4 a) State 3 (Positive cycle) b) State 4 (Negative Cycle)

Similarly the other two step down frequencies 16.67 Hz and 12.50 Hz are also done in the same manner.

4.2 Step up Process

For step up process circuit arrangement will be same and the changes in the switching sequence are applied for the step up frequency operation. The fig no 2.6 and fig 2.7 shows the working of step up cycloconverter for the frequency of 50 Hz. The working of step up cycloconverter can be understood with the following points explained below [9] :

- The dotted line in the diagram represents the safe commutation switch during each particular state. Let's say the output frequency is 50 Hz.
- To achieve this, when the supply voltage is positive the switch is in state 1. Here, S4a is the controlling switch to produce the SPWM pattern S1a and S2a are kept as continuously ON during this cycle; S1a to complete the loop for SPWM return and acts in conjunction with S2a to provide free-wheel operation whenever S4a is turned OFF.
- Due to the nature of operation the commutation period has to spread over the dead-time period to allow for energy to dissipate and hence current reverses due to inductive loads are eliminated.
- Similarly switching state 2 are used during negative cycle to produce the next half cycle. The time delay during 'td' between each switch commutation is around 97μs. This will allow for the current to decay until zero prior to the next switching sequence.
- There are a total of four (4) different switching states capable of being used in various combinations to produce the desired effect. This method allows commutation between switching states without producing those damping spikes.

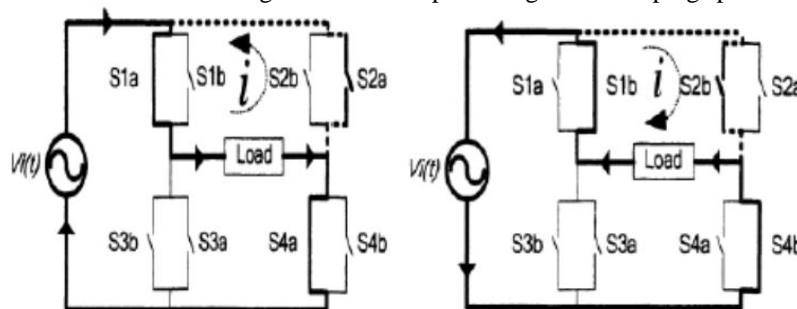


Fig 5 a) State 1 (Positive cycle), b) State 2 (Negative cycle)

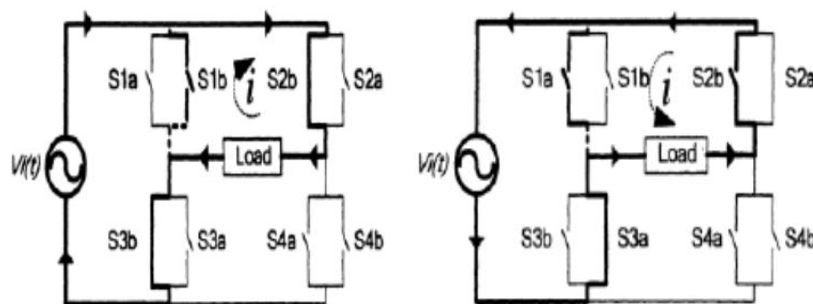


Fig 6 a) State 3 (Positive Cycle), b) State 4 (Negative cycle)

5 MERITS AND DEMERITS OF MATRIX CONVERTER

Matrix Converters is a direct converter and it has so many advantages. Some of the merits of MC are listed below in some points:

- It has sinusoidal input and output waveforms.
- Power flow in a matrix converter is bi-directional.
- Its input power factor can be controlled fully.
- Its energy storage requirement is also very low.

Although MC has so many advantages but in some area it has to improve little bit. Some of the demerits are given in following points:

- Its input to output voltage transfer ratio is limited to a particular value approx. 87%.
- Semiconductor switches used in matrix converters are more than Cycloconverters.
- Sensitive to disturbances.

6 MODULATION TECHNIQUES

Modulation is the process of superimposing low frequency reference signal on high frequency carrier signal. With the advances in silicon based power devices PWM converters are suitable most widely used in drives. PWM converters make it possible to control both the frequency and magnitude of the voltage and current applied to drive motor [4]. The energy that a PWM converter connected to a motor is controlled by PWM signals applied to the gates of the power switches. Different PWM techniques are existing, that are Sinusoidal PWM, Hysteresis PWM and the relatively new Space-Vector PWM [5]. Different modulation and control methods for the power electronics converters are shown in fig 3.1. The pulses are generated with the sinusoidal pulse with modulation technique (SPWM) and the controlling of pulses are done with the help of pulse generator. Here in this driver circuit SPWM is generated with the help of two waves – 1) Carrier signal whose frequency must be greater than the frequency of the input supply frequency and 2) Reference signal whose frequency is similar to the frequency of the input supply frequency. In this SPWM technique, the modulation index is used for the variation in the width of pulses and with resultant of that the output voltage is also controlled.

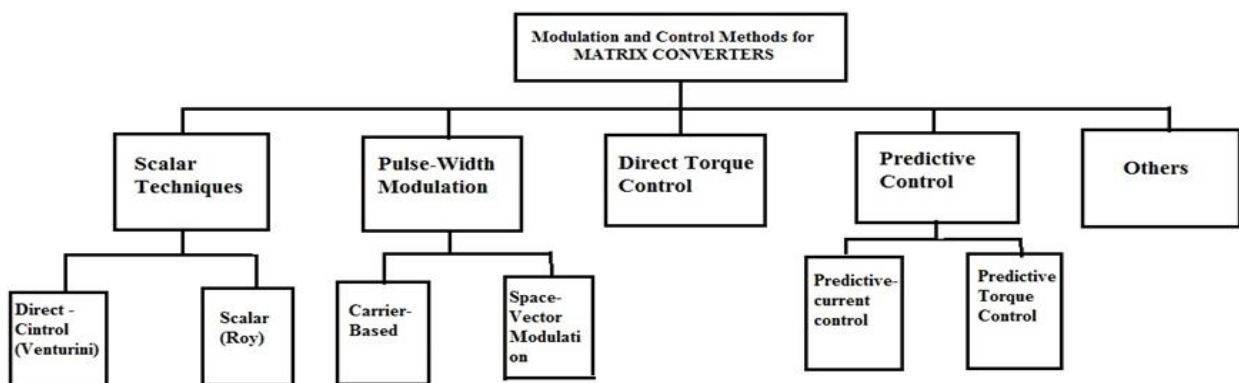


Fig 7: Different Modulation Techniques used for Power Electronics Converters

Sinusoidal Pulse Width Modulation (SPWM) technique is one of the modest carrier-based modulation methods for the controlling of Matrix Converters [7]. The SPWM is a familiar shaping technique in the field of Power Electronics where a high frequency triangular carrier signal is compared with a sinusoidal reference signal. The main benefit of carrier based SPWM is that the complexity is very low and the dynamic response is also good for Matrix Converters [1].

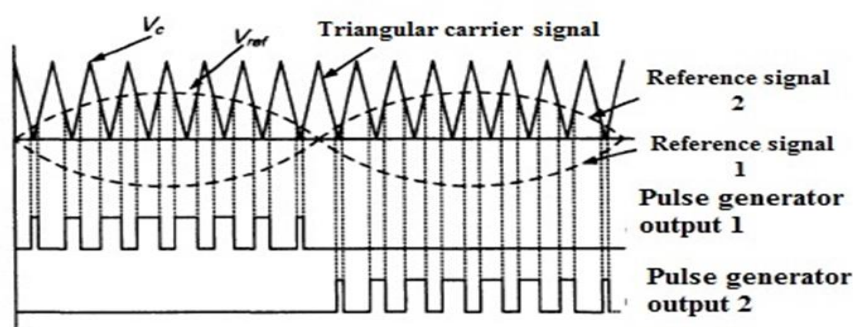


Fig 8: Sinusoidal Pulse width Modulation

In the above figure 3.1, the two reference signals are used with the phase opposition. The reference signal has frequency same as the frequency of the input supply i.e. 50 Hz. A high frequency carrier signal is used in this driver circuit. Its frequency is 5 kHz and it is triangular in nature. When the signals are compared with the comparison block in simulation we get the pulses and these pulses are then multiply with the Pulse generator output. Pulse generator producing control pulses for the fixed duration of time for the bidirectional switches used in SPMC. So that's how we are producing the pulses for different frequency operations.

7 SWITCHING SEQUENCES FOR CYCLOCONVERSION

7.1 for step down

Some of the Lower frequencies applied to the SPMC are 25 Hz, 16.67 Hz, 12.50 Hz. In this process we have to take the different time intervals for the different frequencies. For the 25 Hz frequency operation we get two pulses in positive cycle and another two pulses in negative cycle. The resultant from this waveform has the frequency of half the frequency of the input supply. Similarly we get the resultant waveforms for other two frequencies [1].

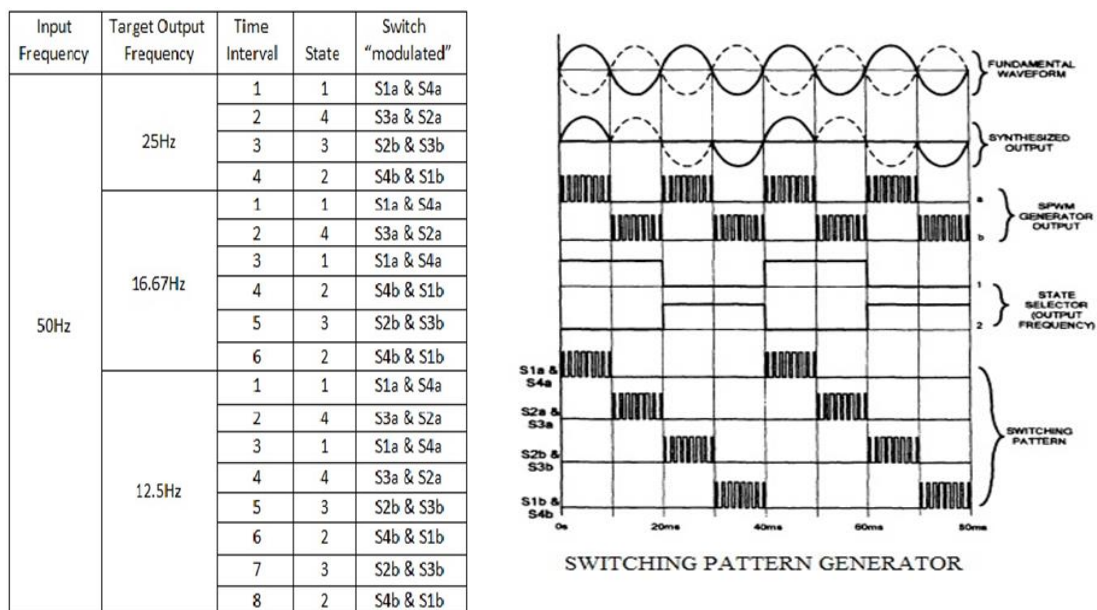


Fig 9: Switching sequence and its waveform for step down frequency
a) Table and b) Waveform from driver circuit for 25 Hz

7.2 for step up

Some of the higher frequencies applied to the SPMC are 50 Hz, 100 Hz, 150 Hz. In this process we have to take the different time intervals for the different frequencies. For the 100 Hz frequency operation we get a complete cycle in half cycle of input supply. Similarly we get the resultant waveforms for other two frequencies [9].

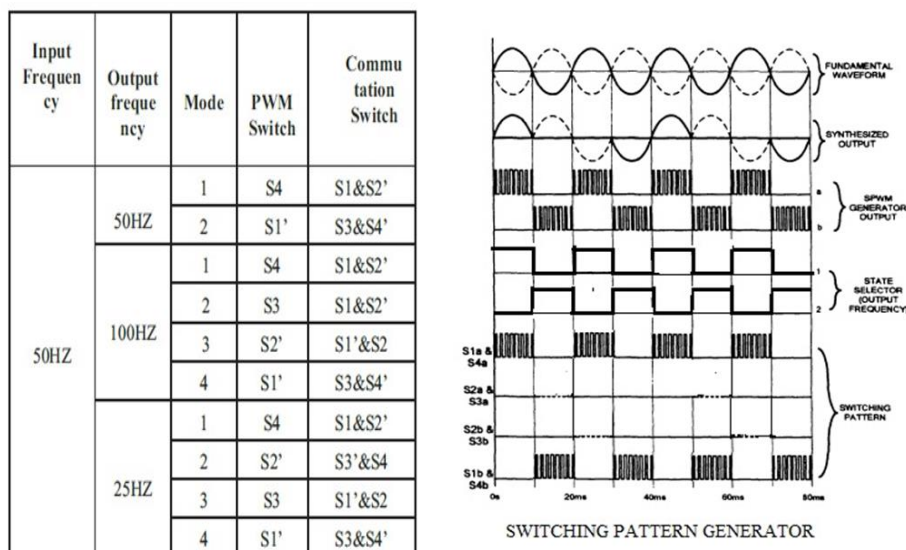


Fig 10: Switching Sequence and Its waveform for the step up frequency
a) Table and b) Waveform from driver circuit for 50 Hz

8 SIMULATION MODEL AND RESULTS

8.1 Proposed Model

The simulation model of the SPMC shown in below diagram as :

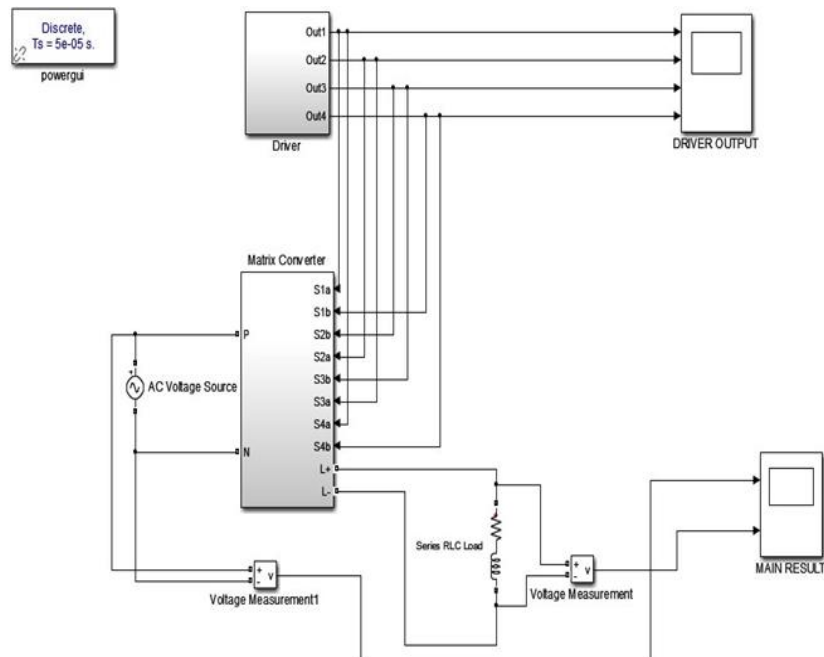


Fig 11: Simulation Model of SPMC

8.2 SPMC AND BIDIRECTIONAL SWITCH SIMULINK

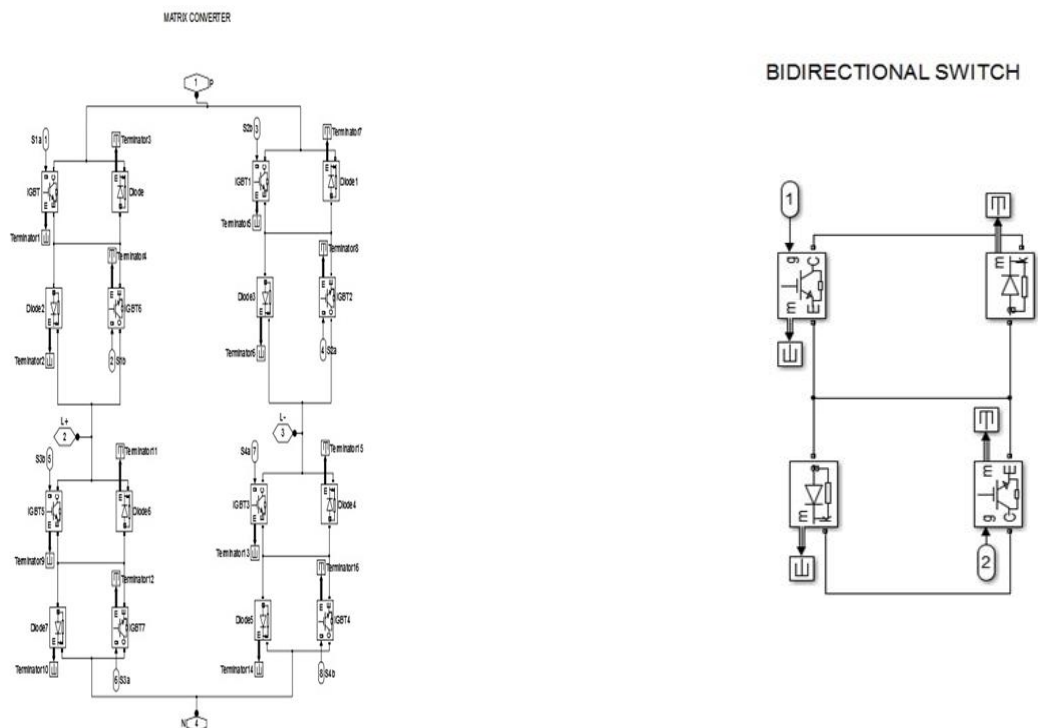


Fig 12: SPMC circuit arrangement and Bidirectional Silicon switch IGBT-diode pair

8.3 Driver Circuit

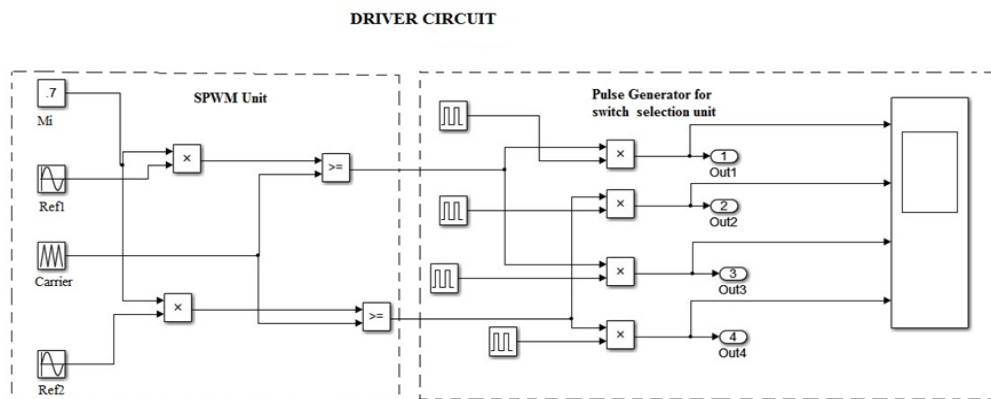


Fig 14: Driver Circuit using SPWM

8.4 Results

8.4.1 For step down frequencies

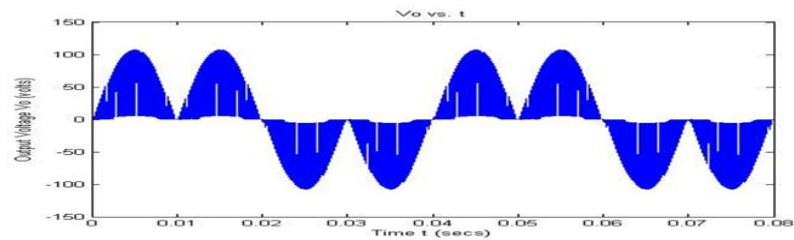


Fig 15: output waveform for the 25 Hz frequency

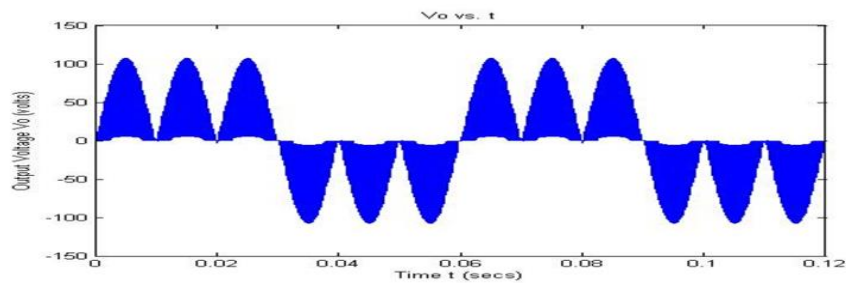


Fig 16: for 16.67 Hz Frequency

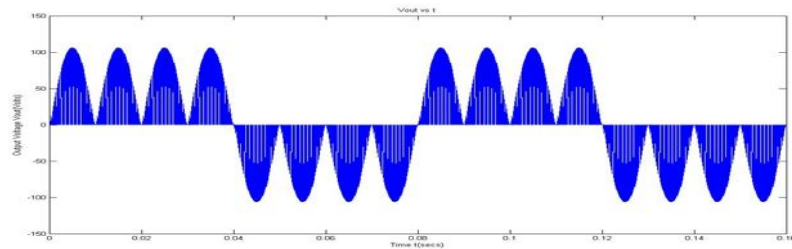


Fig 17: for 12.50 Hz frequency

8.3.2 For step down frequencies

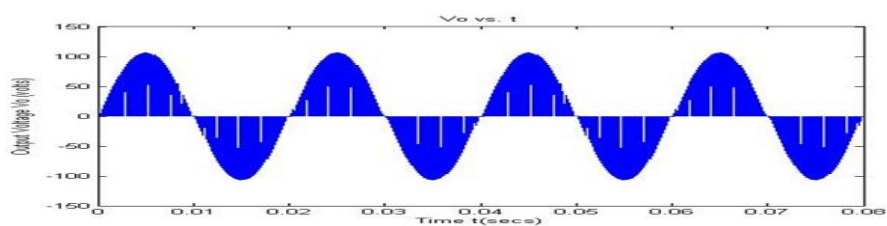


Fig 18: for 50 Hz frequency

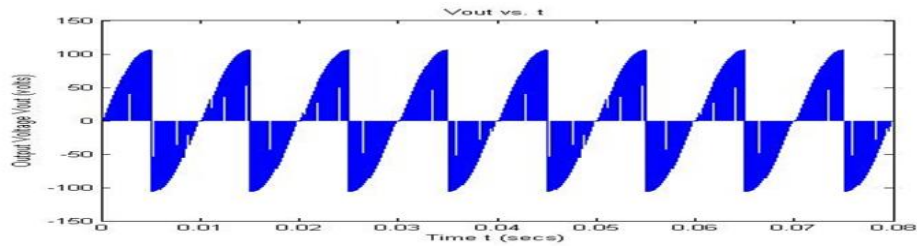


Fig 19: For 100 Hz frequency

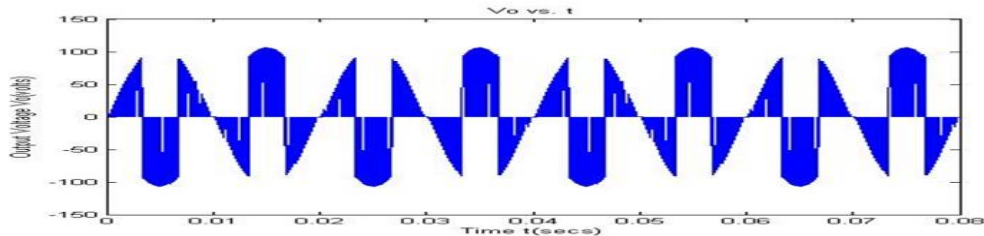


Fig 20: for 150 Hz frequency

All the results are done with the resistive load. Modulation index is put to 0.7 and the supply voltage is at 110 Volt RMS.

8 CONCLUSIONS

Matrix converter is the all silicon solution for the basic electric drive system. Here the matrix converter is working as ac-ac converter. Frequency of input supply is changed with the special switching arrangement and the pulses provided to the gate terminals of the silicon switches is with the help of sinusoidal pulse width modulation technique. Bidirectional switches used in this work are the combination of the IGBT and Diode. IGBTs are connected in the antiparallel and common emitter configuration. That configuration allows the flow of current in both the direction. Diode is used for the blocking of reverse voltage in the circuit. The topology is capable of regeneration. In this circuit the reactive storage element is eliminated and therefore the system is comparatively light weighted, took lesser volume, cost effective and has lesser complexity in circuit design. So with all these qualities the SPMC is the best solution for single phase cycloconversion process and efficiency of system can be improved with more improved controlling techniques.

REFERENCES

- [1] Z.Idris, Mustafar Kamal Hamzah, Nagah Ramzi Hamzah, "Modeling and simulation of a new single phase to single phase cycloconverter based on spmc topology with sinusoidal pulse width modulation using Matlab/Simulink", pp.1557-1562 IEEE PEDS 2005.
- [2] Lee Empringham, P.W.Wheeler, Johan W.Kolar, Jose Rodriguez, John C.Clare,"Technological Issues and Industrial application of Matrix Converter", IEEE Transactions on Industrial Electronics, Vol. 60, no. 10, October 2013.
- [3] Muhammad H.Rashid, "Power Electronics Handbook", Academic Press, 2001, web address: <http://www.academicpress.com>
- [4] Andrzej M.Trzydlowski, "Introduction to Modern Power Electronics", 3rd edition, copyright by John Wiley and sons, 2016.
- [5] Maamoun, A., "Development of cycloconverters," Canadian Conference on Electrical and Computer Engineering, 2003. IEEE CCECE Vol.1,4-7, pp.521 –524 May 2003.
- [6] Z.Wang and Y. Liu, "Modeling and Simulation of a Cycloconverter Drive System for Harmonic studies", IEEE Transactions on Modern Electronics, vol. 47, no. 3, , pp. 533-541, June 2000.
- [7] Zahirrudin Idris, Mustafar Kamal hamzah, "Implementation of a new Single phase Cycloconverter based on Single phase Matrix Converter Topology using Sinusoidal Pulse Width Modulation with passive Load Condition", in 2006 first IEEE Conference on Industrial Electronics and Applications.
- [8] Mahendran Nagalingam, Dr. G.Guruswamy. "Computer Applications in Power Electronic Systems", in International Journal of Computer Applications, Volume 10, No.7, November 2010.
- [9] Vytla Satish, Sravan Kumar Konathala, A. Uday Ravi Kiran, "Design and Implementation of Single Phase Matrix Converter for Cycloconverter Operation", in International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 1, January – 2014 ISSN: 2278-0181.
- [10] K.Vijay Kumar, R.Sundar Raj, S. Kannan, "Realization of Matrix Converter as revolutionized Power Electronic Converter employing Sinusoidal Pulse Width Modulation", IEEE International Conference on Computational Intelligence and Computing Research, 2013.
- [11] Ziogas P D, Khan S I, Rashid M.H., "Analysis and design of forced commutated cycloconverter structures with improved transfer characteristics", IEEE Transaction on Industrial Electronics.1986,IE-33:271-280.