Commutation issues in Single Phase Matrix Converter

Santosh Sonar

***Abstract:** This paper presents a single-phase AC-AC matrix converter as a frequency converter. Due to continuous increase in the use of electronics converters like AC- AC, AC- DC, DC – AC and DC-DC, there is always a thrust to develop a converter, which generates lesser harmonics, minimum switching losses and high quality desired waveforms across output and input. It stimulates the researchers to innovate new ideas to minimize these effects. In this paper, the focus is to design and Implementation of Matrix Converter (MC) for frequency changing applications .A simple PWM mechanism is proposed to design a mathematical model of single phase Matrix Converter. There is no DC link between rectifier and inverter stage which add up some efficient properties like compact design, bi-directional current flow capabilities. A suitable commutation technique is analyzed. Simulation work is done in MATLAB Simulink environment and comparison with mathematical results is presented.*

***Keywords:** Pulse width modulation, MC- Matrix Converter, commutation.*

I. INTRODUCTION

The Matrix Converter (MC) is the type of a forced commutated cyclo-converter alternative of the Rectifier Fed Inverter systems technology (RFIS)[17].This converter has the ability to replace RFIS system. MC fed system is more reliable than the conventiona lRFIS system. It has the capability to provide bi-directional power flow. It can deliver all silicon solution by converting the input frequency to a desired output frequency.But the commutation problem is seviere.The switching algorithm and timing of the switches are quite complicated . Single phase matrix converter has four whereas in three-phase nine bi-directional switches are present [16,17,18].Cyclo converters are appropriate for high power applications. Mostly frequencies in the range 50 to 60 Hz [9]is required in the industrial applications. In three phase to three phase cyclo-converters 36 thyristors are needed, which make the circuit complicated. The two scientists namely "Alesina" and Venturini firstly mentioned MC in the early of 1980's. They proposed a general model of the MC and its relative Mathematical theory. They got the result that maximum AC to AC voltage transfer ratio is ($\sqrt{3}/2$) which nearly equals to 0.866. In comparison to three phase to three-phase cyclo-converter, they usually have a lesser number of switches but in comparison with the traditional RFIS model, they require more semiconductor power electronics devices. In SPMC consists of four and The TPMC consists of nine bidirectional switches that are arranged in such a way that any of the input phases are connected to any of the output phases at an instant. Generally, the capacitor is so large that it can occupy a total volume of the converter by 30 to 50 % that would withstand for the few kilowatt power level and another complexity is temperature control. The bridge VSI draws generally input current that contains high magnitude of 5^{th} and 7^{th} order harmonics, which becomes a burden for the converter and injected back to the mains supply and can causes severe power losses in the system. To get rid of this problem, the use of PWM based switches to the rectifier, that helps to modulate nearly input sinusoidal current is presented in [17]. [2],Concluded that it is possible to convert frequency from one form to another frequency without having an intermediate DC link in between them or not by traditional method Rectifier Inverter Frequency Changers (RFIS).[10],[11] and [17]presents four quadrant operation of semiconductor switches in power converter devices. Here the possible solutions of safe commutation of the switches are discussed. These switches have been constructed from the two-quadrant switches that are separately controllable.[9], describes the method of 'overlap' current commutation. Here the incoming switch is turned on before the outgoing switch gets turn off. There is some short circuit has been taken place for the short interval of time between the two phase. In this process, during short circuit there is an extra inductance required to restrict the current rise to the destruction level.[17],[6] the outgoing switch is turned off before the incoming switch is turned on, and proposed method is commonly known as dead time method of current commutation. It requires a snubber circuit that will provide the path to the current. This method has some limitations as snubber design complicates the bidirectional switches, which require more area and method have a poor response.[5] and [8] discussed methods of "semi-soft commutation method", the method is the most reliable method to commutate the current for bi-directional switches and depends upon the direction of the current. They do not require any snubber or inductance to decrease the losses. [6],discussed the design and realization the direct AC to AC single phase matrix converter. The input is fed from the mains supply at a constant frequency and output frequency is synthesized. Only the output frequencies, which are the multiple of the input frequency, are obtained. The papers[14,12,5]investigate the single phase matrix converter fed R-L load and asynchronous motor. In [4] and [7] the analysis and implementation of the novel new space vector modulation technique for the Forced Commutatedcyclo-converter is presented.

Revised Manuscript Received on January 15, 2020

***** Correspondence Author

Santosh Sonar*, This work has been supported by Thapar Institute of Engineering and Technology, Patiala, Punjab, India.The Author is with the department of Electrical and Instrumentation Engineering, Thapar Institute of Engineering and Technology, Patiala, Punjab, India (email: santosh.sonar@thapar.edu,).

The modulation strategy adopted helps to attain nearly sinusoidal output voltage waveform. [10],[17]proposes a space vector Modulation control topology to control variable speed drives in AC/DC/AC applications. Here the calculations of time duration on zero states and reference vector for each switching states are analyzed.[13], examine various approaches of SVM technique. The schemes have 512 maximum States but possibly it has 27 switching states that are useful and among them 21 having 18 active vector states and 3 zero vector states and has 6 synchronous configuration states..[6]proposed a novel technique of commutation for the bi-directional switches and improvement in the output voltage errors. The merits of proposed commutation are that they suppressed the input current vibrations in the motor and do not require any damping circuit and there is low THD realization in the waveform.

II. METHODOLOGY PROPOSED FOR SINGLE PHASE MATRIX CONVERTER (SPMC)

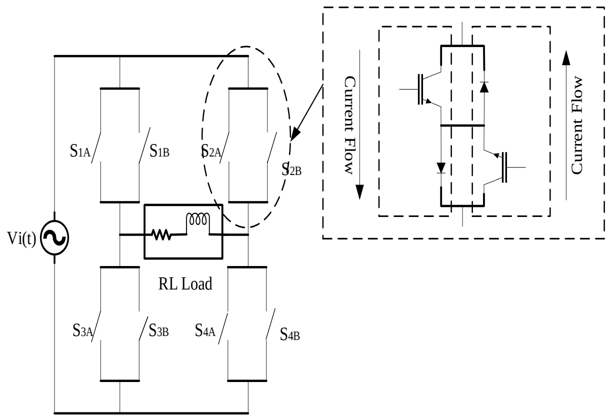
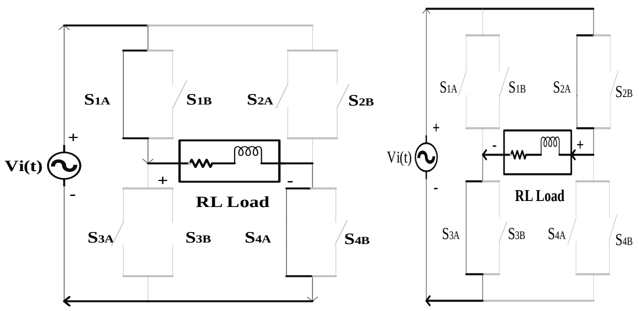
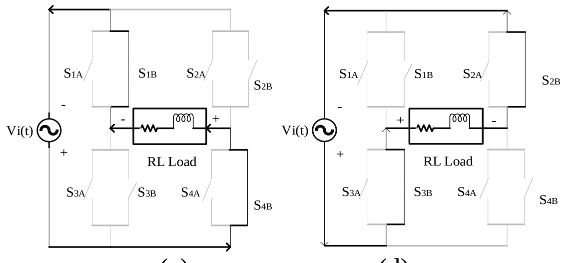


Fig.1.Circuit Configuration of SPMC

Single-phase matrix converter is a single phase Single-step direct and single step AC to AC power frequency converter having bi-directional switches in the form of 2x2 array combinations without any DC link. The circuit configuration of SPMC is shown in Fig..1.Various output voltage frequency can be obtained from the input voltage. The converter basically operates in four different modes. Mode 1, When the Input and output both are in the positive half cycle. In this mode of operation of SPMC, the Switches S_{4A} and S_{1A} are switched on and all other are off. The direction of current flowing from S_{1A} to RL load to S_{4A} is shown in Fig. 2(a). A similar process is followed in all other three modes of operations and corresponding polarities of output voltage is marked.



(a) (b)



(c) (d)

Fig.2 (a) Mode 1 operation of SPMC (b) Mode 2 operation (c) Mode 3 operation (d) Mode 4 operation

It is complex to define a time cycle, which allows carrying out a safe commutation of the load current between two diode bridge switches. To highlight the issue of commutation in the converter a sample circuit with R-L load is shown in Fig.3. In the case of a make-before-break, switching method, if the switch is turned on but the off-going switch is still on, dead short circuit will occur. Both the bi-directional switches S_1 and S_2 create a short-circuited path in between the V_1 and V_2 voltage sources resulting current spikes. Anyhow if these spikes were not limited, would be the cause of the destruction of switches. Similarly in the case of a break-before-make switching method, in this situation, if the off-going switch is turned off before turn on of the on-coming switch, results in the open path for induction load. It causes voltage spikes on the open switch.

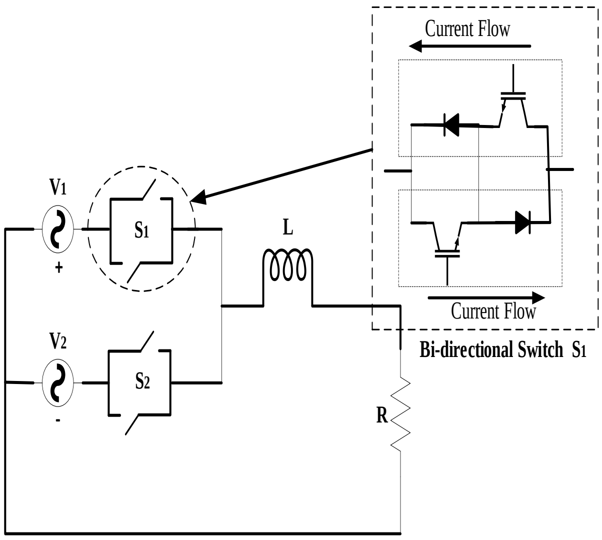


Fig..3Sample circuit with commutation issue

In SPMC, there are no freewheeling diodes available for the proper commutation of bi-directional switches. In order to avoid this problem the switches S_3 and $S_4$are operated at high frequency. These switches have DT and (1-D) T on and off time respectively as shown in Fig..3.Where D is the duty cycle and T is the complete time period.

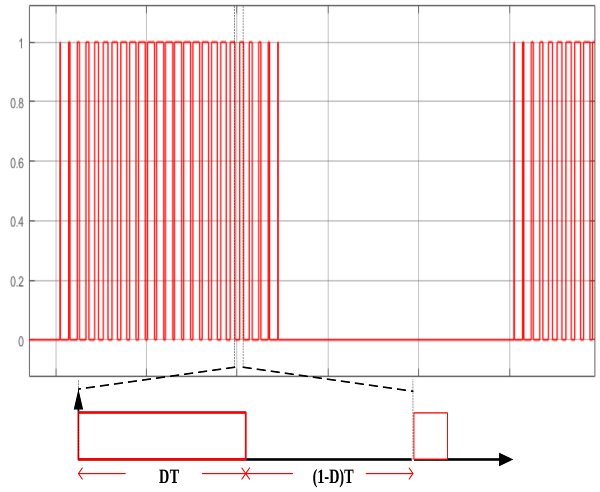
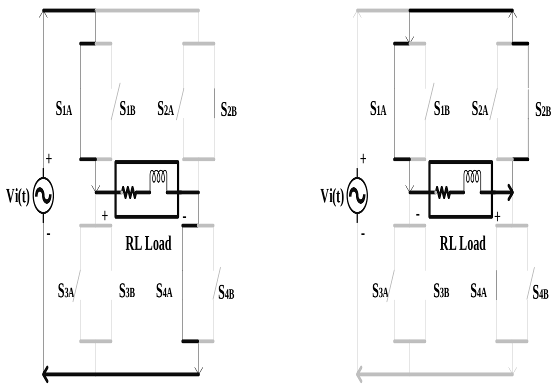


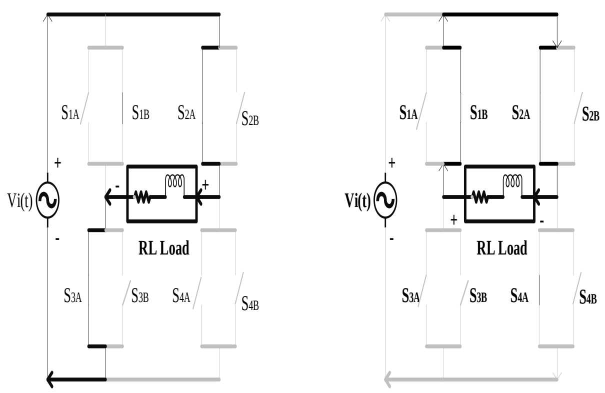
Fig..4.Duty cycle of the high-frequency switch

The mode-1 operation of SPMC is divided into two parts. Here switches S_{1A} and $S_{2B}$are switched on and S_{4A} is operated at high-frequency as shown in Fig.4. In part 1, the time interval is DT, during this time high-frequency switch S_{4A} is switched on and the current flows in the direction of S_{1A} to RL load to S_{4A} to source. During this period, the load inductor gets charged. Then after in time interval (1-D)T, high frequency switches S_{4A} is switched off and the charge stored in the inductor is freewheeled through S_{2B} as shown in Fig..5(b). The Commutation of SPMC in all four modes of operations are shown in Fig.5 to Fig.8.



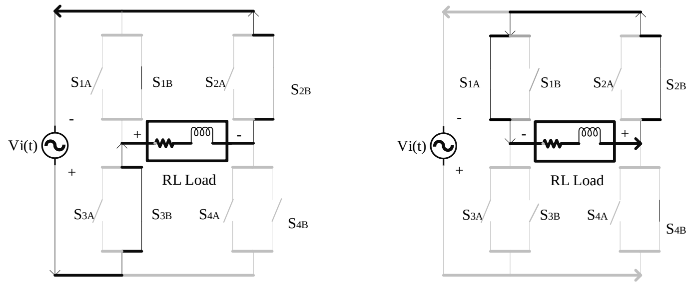
(a) (b)

Fig.5 Current Flow in mode-1 operation (a) DT time interval (b) (1-D) time interval



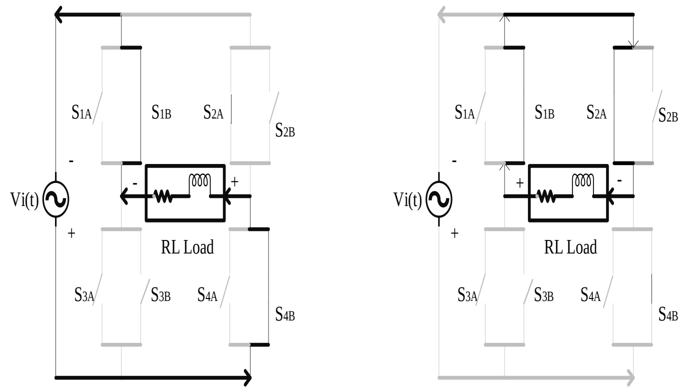
(a) (b)

Fig.6 Current Flow in mode-2 operation (a) DT time interval (b) (1-D) time interval



(a) (b)

Fig.7. Current Flow in mode-3 operation (a) DT time interval (b) (1-D) time interval



(a) (b)

Fig.8 Current Flow in mode-4 operation (a) DT time interval (b) (1-D) time interval

Table.1 represents all the switching states of operation .The switch on condition is represented as 1 and off condition as 0 .The on period is represented as DT and off duration as (1-D)T. All four modes of operations are shown.

Table 1.Switching states of SPMC during Commutation processes

Mode	DT period								(1-D)T period							
	S_{1A}	S_{1B}	S_{2A}	S_{2B}	S_{3A}	S_{3B}	S_{4A}	S_{4B}	S_{1A}	S_{1B}	S_{2A}	S_{2B}	S_{3A}	S_{3B}	S_{4A}	S_{4B}
1	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0
2	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0
3	0	0	0	1	0	1	0	0	1	0	0	1	0	0	0	0
4	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0

III. SIMULATION RESULTS AND DISCUSSION

Simulation of the proposed converter is done in Matlab Simulink environment. The simulation parameters used are presented in Table.2. Fig. 9 shows the simulation result of the output during all four modes of operation based on the switching pattern of the SPMC as explained in Table.1.

Table.2 Simulation parameters for SPMC

Input Voltage	220 Volts
Input Frequency	50 Hz
R load	50 ohm
L load	10 mH
Output Frequencies	50 Hz, 100 Hz and 25 Hz
Switching Frequency	5000 Hz
LC Filters	L=136 Uh ,C=64.5 uF
Modulating Index	0.8

Fig.9 represents the output voltage waveform of two complete cycles .The frequency is 100 Hz. All four modes are marked. It clearly shows that the waveform is symmetrical in positive and negative half cycle.

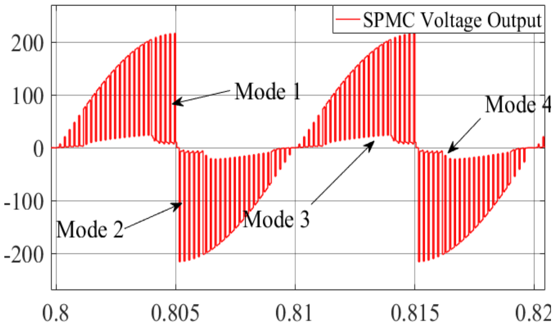


Fig.9 Simulation result of the output during all four modes of operation

The generation of the switching pulses as shown in Table.1 is shown in Fig.10 .It is generated by comparing a high frequency triangular signal with sinusoidal reference signals.

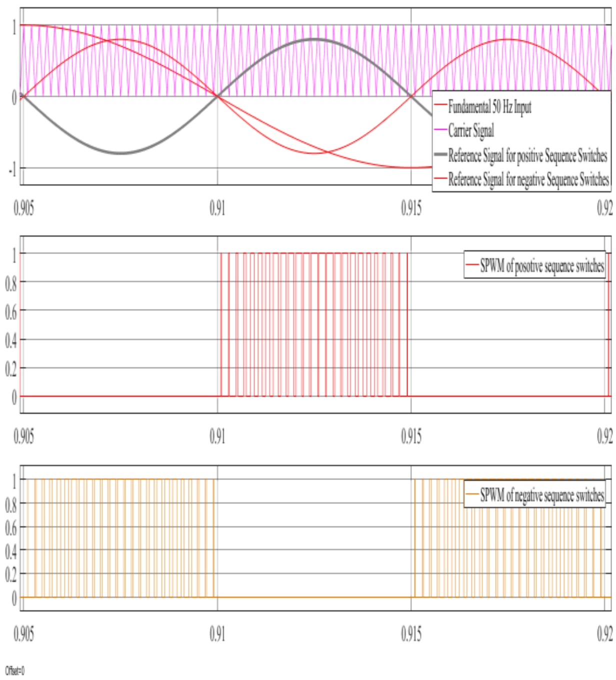


Fig.10 Sinusoidal PWM Signal Generation at 100 Hz output Frequency

The two sinusoidal signals have been compared with the triangular signal. Both the reference signal is in 180-degrees phase with each other.Table.3 represents the different operating modes required to obtain different output frequencies.Fig.11 shows the switching pulses for the generation of 100 Hz output.

Table. 3 SPMC Active Switches

Input Frequency	Output Frequency	Mode	Active Switches		PWM Switches
50 Hz	50 Hz	1	S_{1A}	S_{2B}	S_{4A}
		2	S_{2B}	S_{1B}	S_{3B}
	100 Hz	1	S_{1A}	S_{2A}	S_{4A}
		2	S_{2A}	S_{1B}	S_{3A}
		3	S_{2B}	S_{1A}	S_{3B}
		4	S_{1B}	S_{2A}	S_{4A}
	25 Hz	1	S_{1A}	S_{2B}	S_{4A}
		2	S_{1B}	S_{2A}	S_{4B}
		3	S_{2A}	S_{1B}	S_{3A}
		4	S_{2B}	S_{1A}	S_{3B}

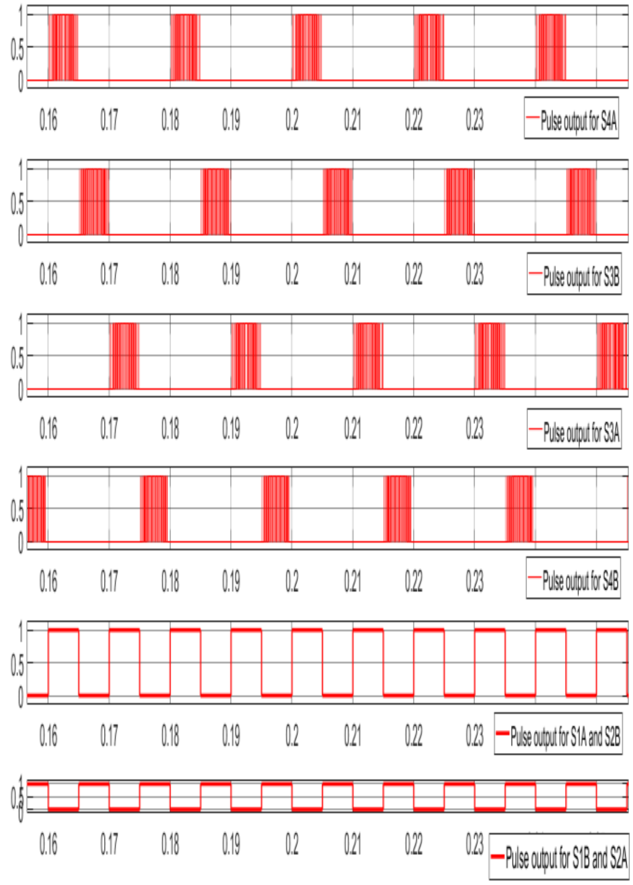


Fig.11.Switching Sequence of SPMC at 100 Hz Output frequency

IV. CONCLUSION

The paper presented a comprehensive analysis of different modes of single phase Matrix converter. Commutation issues are addressed and suitable PWM technique is proposed. Carrier comparison approach is selected to generate the switching pulses. To justify the suitability of the proposed technique simulation results are presented. For the ease of understanding, the switching pulses are presented in tabular form.

.

.

REFERENCES

1. T. G. Habetler, “A Space Vector-Based Rectifier Regulator for AC/DC/AC Converters,” IEEE Trans. Power Electron., vol. 8, no. 1, pp. 30–36, 1993.
2. P. Wheeler, H. Zhang, and D. A. Grant, “A theoretical and practical consideration of optimised input filter design for a low loss matrix converter,” Electromagn. Compat. 1994., Ninth Int. Conf., no. 396, pp. 138–142, 1994.
3. Zuckerberger, D. Weinstock, and A. Alexandrovitz, “Single-phase matrix converter,” IEE Proc. - Electr. Power Appl., vol. 144, no. 4, pp. 235–240, 1997.
4. P W Wheeler,L Empringham“Matrix Converter Bi-Directional Intelligent Gate Drives” no. 456, pp. 21–23, 1998.
5. B. K. Lee and M. Ehsani, “A simplified functional simulation model for three-phase voltage-source inverter using switching function concept,” IEEE Trans. Ind. Electron., vol. 48, no. 2, pp. 309–321, 2001.
6. P. W. Wheeler, J. Rodriguez, J. C. Clare, L. Empringham and A. Weinstein, "Matrix converters: a technology review," in IEEE Transactions on Industrial Electronics, vol. 49, no. 2, pp. 276-288, Apr 2002.
7. U. T. Mara, U. T. Mara, and U. T. Mara, “Safe Commutation Strategy in Single Phase Matrix Converter,” pp. 886–891, 2005.
8. R. Anusuya and R. Saravanakumar, "Realization of a Single Phase Matrix Converter with Reduce switch count as a buck/boost rectifier with close loop control," 2012 International Conference on Computing, Electronics and Electrical Technologies (ICCEET), Kumaracoil, 2012, pp. 218-223.
9. C. Wang, “A Novel Soft-Switching Single-Phase AC – DC – AC Converter Using New ZVS – PWM Strategy,” vol. 22, no. 5, pp. 1941–1948, 2007.
10. F. A. Author, S. B. Author, and T. C. Author, “Improved Switching Strategy For Single Phase Matrix Converter.”Industrial Electronics and Applications, 2008. ICIEA 2008.
11. H. Karaca, “Control of Venturini Method Based Matrix Converter in Input Voltage Variations,” Proc. Int. MultiConference Eng. Comput. Sci. 2009, vol. II, no. 1, pp. 1412–1416, 2009.
12. S. Lopez Arevalo, “Matrix converter for frequency changing power supply applications,” no. January, 2010.
13. J. Rodriguez, M. Rivera, J. W. Kolar, and P. W. Wheeler, “A Review of Control and Modulation Methods for Matrix Converters,” vol. 59, no. 1, pp. 58–70, 2012.
14. “Realization of a Single Phase Matrix Converter with Reduce Switch Count as a Buck/Boost Rectifier with Close Loop Control,” pp. 218–223, 2012.
15. M. Rivera, J. W. Kolar, J. Rodriguez, M. Rivera, J. W. Kolar, and P. W. Wheeler, “A Review of Control and Modulation Methods for Matrix Converters,” vol. 59, no. 1, pp. 58–70, 2012.
16. Szcześniak, Paweł, “Review of AC–AC Frequency Converters,” vol. 59, no. 1, pp. 58–70, 2013.
17. T. Nottingham and N. E. User, “Design control and implementation of a four - leg Matrix Converter for ground power supply application,” 2013.

AUTHORS PROFILE

Santosh Sonar, was born in Asansol, West Bengal, India in Nov, 1979. He received his graduation and master’s degree in Electrical Engineering from National Institute of Technology Durgapur, India in 2004 & 2009 respectively and PhD degree in Electrical Engineering from IIT(ISM), Dhanbad (Previously ISM Dhanbad) India in 2014. Currently, he has been working as Assistant Professor in the Department of Electrical and Instrumentation Engineering, Thapar Institute of Engineering and Technology, Patiala, Punjab, India. His current research includes Z-source Inverters, AC-AC Converters and SMPS design.