AC-DC-AC CONVERTER WITH REDUCED SWITCHES AS MATRIX CONVERTER

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Abstract –This paper presents an AC-DC-AC converter as a matrix converter topology with simple commutation procedure. AC-DC-AC converter is analysed with reduced number of switches and with simple clamp circuit provides the same performance of conventional matrix converter in terms of voltage transfer ratio, unity power factor, no DC link capacitor and pure sine wave with only higher order harmonics in both line and load side around the switching frequency. Moreover the converter can utilize the conventional PWM technique on inverter side, which greatly simplifies the complexity of control. Theoretical analysis and simulation results are provided to verify its performance.

Keywords – Matrix converters, AC-DC-AC converter, Space Vector Pulse Width Modulation (SVPWM), clamp circuits.

I. INTRODUCTION

The matrix converter found revived attention recently when compared to conventional dual converter [1]-[2] with a compact structure of nine bidirectional switches to form (3x3) matrix shapes as shown in Fig.1. It has several advantages such as absence of energy storage component like capacitor or inductor, straightforward four quadrant operation and sinusoidal input current and output voltage with only harmonics around or above the switching frequency [3]-[4]. However, this topology does not found much application in industry due to potential commutation problem requiring a complex control circuit, in general, a bipolar snubber, inherent restriction to the voltage transfer ratio of 0.866 and nine bi-directional power switches. The control algorithm developed by Venturini [1] typically requires PLA (Programmable Logic Array) for avoiding commutation problem and for the implementation of PLA in the converter increases the complexity of the circuit. Several methods have been proposed to overcome the commutation problem [5]-[7] but they generally introduce a multiswitcing procedure or an additional protection circuit, which still increases the complexity. Besides this commutation problem, to attain input sinusoidal current and output sinusoidal voltage, both forward and negative sequence components must be calculated and added together. It requires very complex computational burden and additional PWM circuits.

In this paper, a matrix converter topology is analyzed in the form of conventional AC-DC-AC converter without DC link capacitor and reduced switches in the rectifier side. The performance of this AC-DC-AC converter is similar and superior to conventional matrix converter shown in Fig.1. Hence this converter can be treated as a matrix converter with the following advantages such as:

- It performs similar to conventional matrix converter such as good voltage transfer ratio capacity, four quadrant operation, unity power factor and pure sine waveforms with only higher order harmonics in both input current and output voltage.
- Conventional PWM methods can be utilized on the inverter side, which greatly simplifies its control circuit.
- No large energy storage elements like inductor or capacitor except a relatively small size ac filter at the input side are required making this filter more easily to be integrated into a system package.

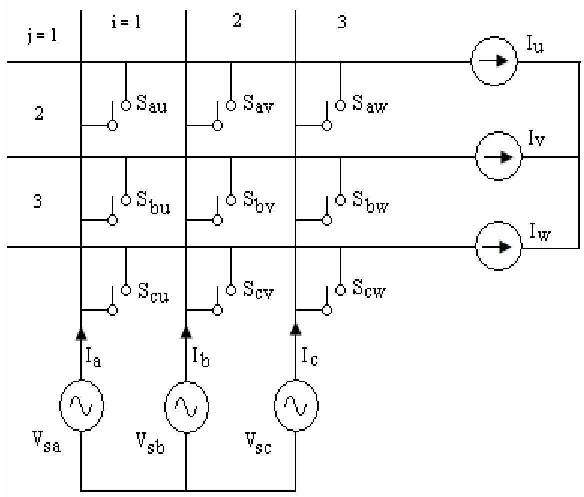

Fig. 1: Conventional Matrix Converter Topology

II. PROPOSED TOPOLOGY

Fig.2. Illustrates the structural view of the analysed matrix converter which is similar to a conventional AC-DC-AC converter but without DC link capacitor. The load side inverter is a conventional DC-AC inverter and the line side converter is a rectifier essentially consists of only three switches. Here the rectifier is operated as a current source rectifier, which is also different from conventional AC-DC-AC converter where line side converter is a voltage source rectifier [8]-[9]. The objective of the proposed converter on the line side rectifier is to maintain

The paper first received 8 Dec 2007 and in revised form 31 Mar 2008
Digital ref: AI70201188

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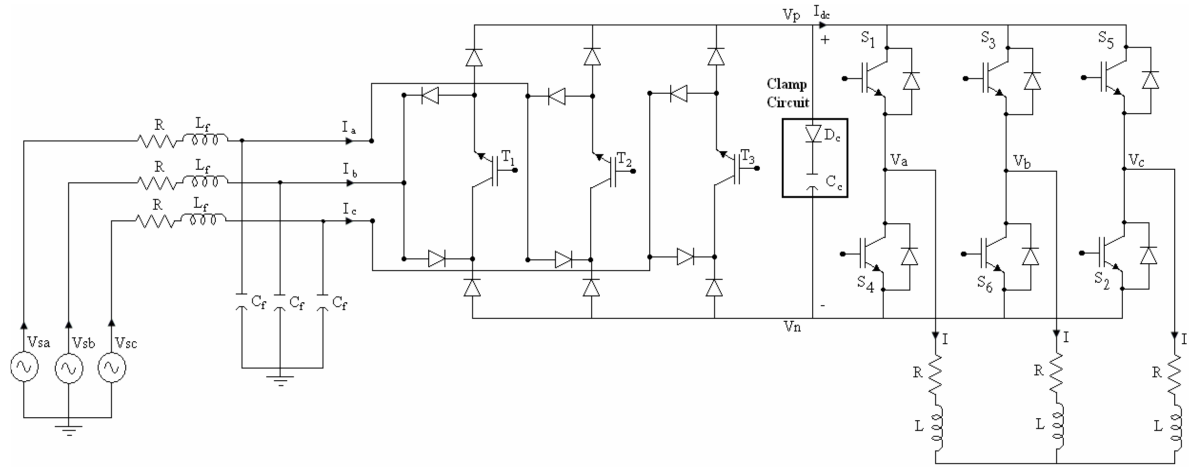

Fig. 2: Basic topology of the proposed matrix converter

a fixed DC voltage on the DC link without capacitor and improve the power factor on the input supply side. Now the capacitor in the DC link is replaced by an AC filter on the line side with a much small value to reduce higher order harmonics. Since converter has no large energy storage elements like a capacitor or an inductor it can be designed for higher capacity utilization. Conventional voltage source inverters are normally equipped with an electrolyte capacitor in their DC link which has a short life compared with an AC capacitor (metalised polyester film, etc.) [10]- [12] and also they occupy a considerably greater space in the inverter. This supports the proposed topology of AC-DC-AC converter without DC link capacitor.

A. STEPS TO REDUCE SWITCHES IN AC-DC-AC CONVERTER

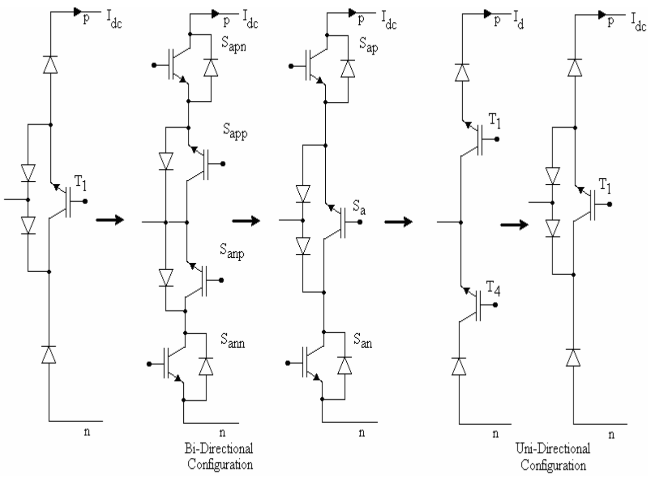

Fig. 3 – 7: Steps to reduce the Switch Number

In general, AC-DC-AC converter requires, 18 switches for current conducting, voltage blocking can be reduced by appropriate assumptions. For example, if V_p is always higher than V_n, the bi-directional switches on the load side can be replaced by uni-directional voltage blocking 6 switches on the inverter side as shown in Fig. 2 and Fig. 3 rectifier with equivalent circuit of input side phase leg "a" and the switches S_{app} and S_{anp} can share the same gate drive signal. These two switches can be replaced by one single switch and two clamp diodes. As a result, a 15-switch topology is developed as shown in Fig. 5.

If the condition that DC link current $i_{dc} \geq 0$ is guaranteed, the number of switches can be reduced to obtain 12 and 9 as shown in Fig. 6 and 7. Hence reduced switched configuration is obtained for AC-DC-AC matrix converter topology with 9 switches is shown in Fig. 2.

III. PWM METHOD ON RECTIFIER SIDE

For the purpose of analysis the values of filter components C, L and R are assumed to be zero. The switching frequency on the rectifier side is assumed to be far greater than the fundamental frequency of the input voltage. DC side voltage is essentially decided by the switching function of the rectifier and the input voltage. Analyzing the six interval of a 3Φ sinusoidal voltage of a cycle, during each interval one of the line or phase voltages will have the maximum absolute value as shown in Fig.8. Each of the switching cycle is split into two portions. For example during interval 1, V_{sa} has the largest absolute voltage, with the corresponding line voltages V_{sa}-V_{sb} and V_{sa}-V_{sc}.

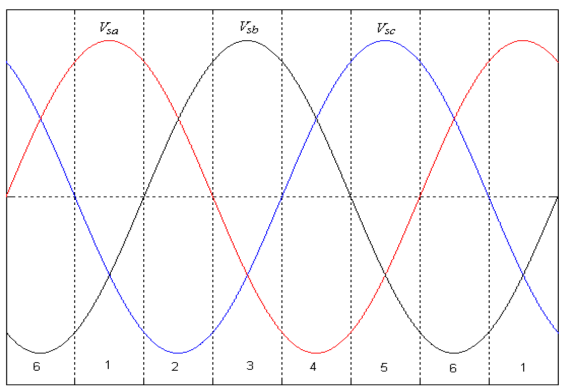

Fig. 8: Six intervals of a switching cycle

The line side switching state in each portion can be determined by the following sequence: In portion 1, for the first 30° conduction period T_1 & T_2 remain turned on;

all other line side switches are turned off. The DC side voltage V_{dc} is equal to V_{sa}-V_{sb}. In portion 2, for the next 30^{o} conduction period T_1 and T_3 remain turned on; all other line side switches are turned off. The DC side voltage V_{dc} is equal to V_{sa}-V_{sc}. This sequence is applicable for all other intervals. By providing this switching sequence, DC voltage at the DC link can be maintained with a fixed value. Since the DC voltage is fixed, the inverter can be operated even with conventional PWM techniques.

IV. Space Vector Pulse Width Modulaton On Inverter Side

SVM is an advanced computation-intensive PWM method which provides good voltage transfer capacity and reduced harmonics on the load side. SVM is possibly the best PWM techniques for inverters. The inverter is analyzed as a VSI, the three-phase output voltages V_{su}, V_{sv} and V_{sw} are supplied by the DC voltage source which is fed from the line side fully controlled current source rectifier where $V_{dc}= 3V_m/2$. Here the symmetrical conduction mode of operation of SVM is used to ensure the reduction of harmonics at the inverter output.

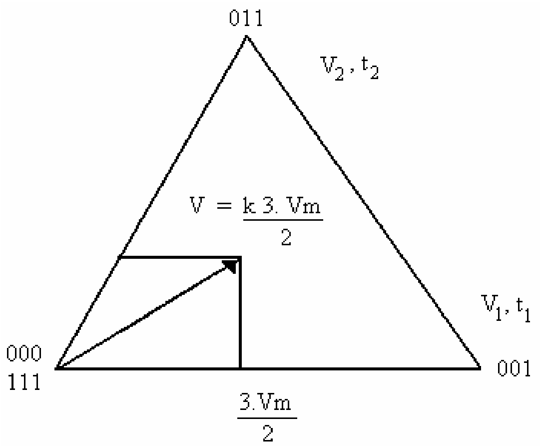

Fig. 9: Space Vector PWM for inverter during the instant $0<\theta<60^0$

In the symmetrical conduction mode, to overcome commutation problem dead time has to be introduced by allowing zero voltage vector before and after of the each conduction cycle. The duty cycle of conduction period has to be appropriately selected for the switching sequences using (1) – (3). The voltage available across the load will be kV_m where V_m is the peak voltage of the line side voltage, which ensures that the converter is similar to the conventional matrix converter. Since V_{dc} is fixed the inverter side operation is free from commutation problem. However dead time is required for its feasible operation. Fig. 9 shows the space vector PWM for inverter during the interval $0<\theta<60^0$ of the sector 1, where the output voltage $V=k.3V_m/2$.

$$T_1 = \frac{2}{\sqrt{3}}\frac{V_1}{V_2}T_c \sin(60° - \theta_s) \quad (1)$$

$$T_2 = \frac{2}{\sqrt{3}}\frac{V_1}{V_2}T_c \sin(\theta_s) \quad (2)$$

$$T_0 = T_c - T_1 - T_2 \quad (3)$$

V. Simulation Results

The proposed AC-DC-AC converter is analyzed as a matrix converter using Matlab/Simulink software for its performance. All the switches utilized are ideal switches.

Simulation parameters taken for analysis are: -

Input line Voltage	= 220V
Input and Output Frequency	= 60Hz
Modulation Index	= 0.8
Filter Inductance	= 200µH
Filter Capacitance	= 900µF
Filter Resistance	= 0.2 ohm
Load Inductance	= 5mH
Load Resistance	= 8 ohm

Switching Frequency:-

Rectifier side	= 12000 Hz
Inverter side	= 2000 Hz

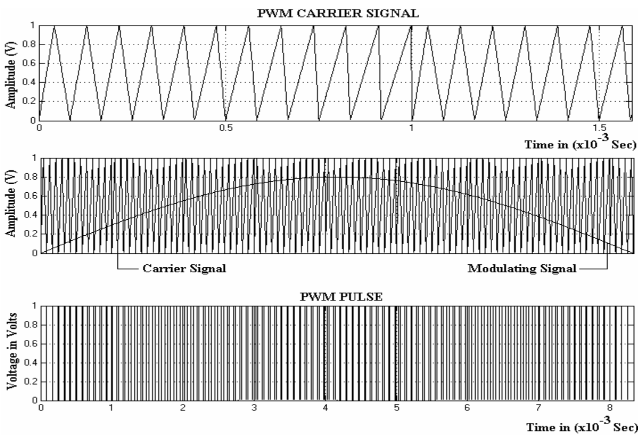

Fig. 10 – 12: PWM scheme for Rectifier

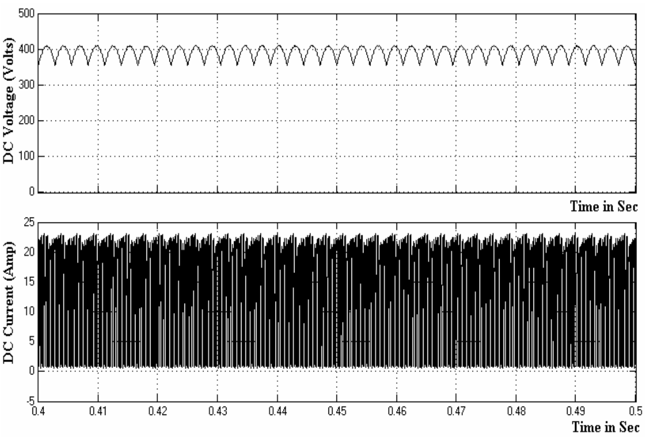

Fig. 13 – 14: DC link voltage V_{dc} and current I_{dc}

In Fig. 10 to 12 PWM signal applied to the input converter (rectifier) using sinusoidal modulation technique is given where the carrier is initially triangular in nature, which slowly changes into ramp. With this type of carrier line side THD is significantly reduced.

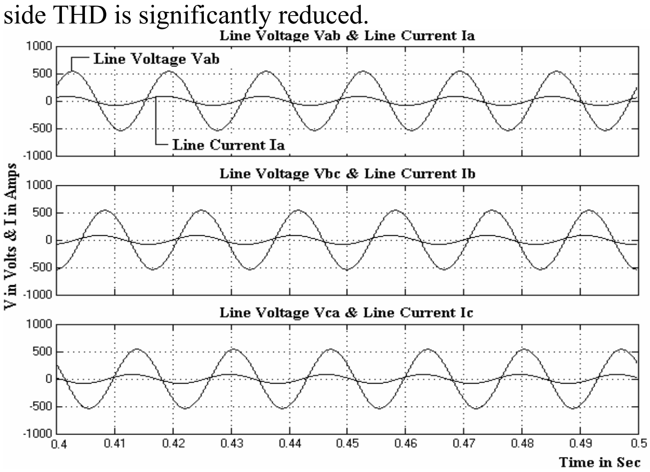

Fig. 15 – 17: Line voltage and current (Rectifier side)

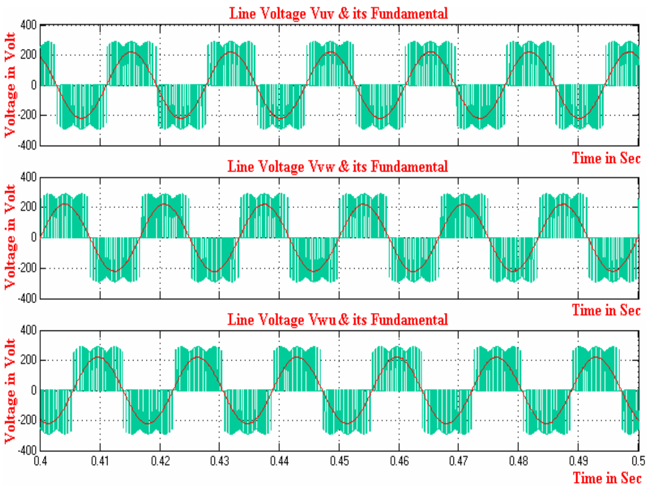

Fig. 18 – 20: Load voltage and its Fundamental

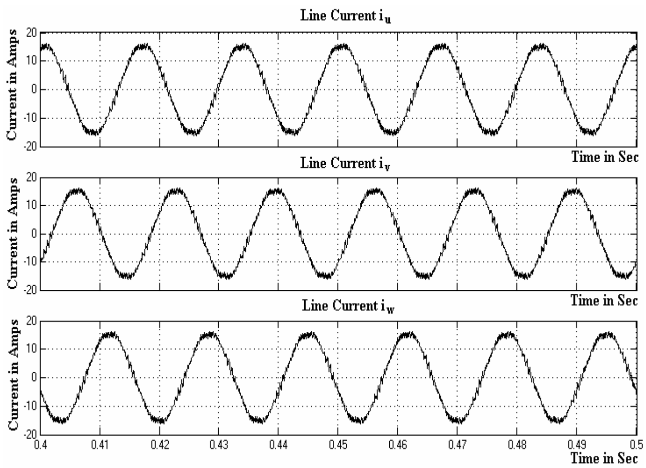

Fig.21–23: Load current showing sinusoidal characteristics

Fig. 13 to 14 depict the DC link voltage V_{dc} and current I_{dc}. Fig. 15 to 17 show the waveform of three-phase voltage and current at the input side providing leading power factor. This results that at line side there are no lower order harmonics and all other higher order harmonics are suppressed by the filter. Fig. 18 to 20 shows that three phase output voltages of the inverter (rms) are essentially sinusoidal and the fundamental component is found to be 90% of square wave operation. This in turn, demonstrates that there are no lower order harmonics in the output voltage. Fig. 21 to 23 shows that three-phase output line current (rms) are essentially sinusoidal with only harmonics above or around the switching frequency. Fig. 24 - 25 shows the THD response on Line Side Rectifier with 12000Hz Switching Frequency and on Load Side Inverter with 2 kHz Switching Frequency.

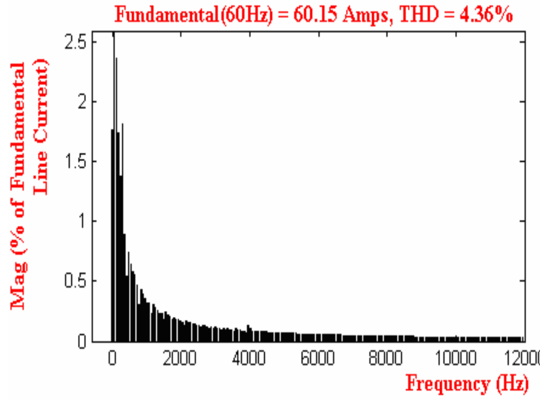

Fig. 24: THD response on Line Side Rectifier with 12000Hz Switching Frequency

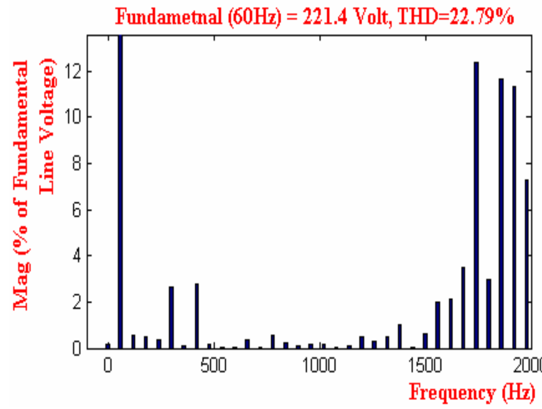

Fig. 25: THD response on Load Side Inverter with 2 kHz Switching Frequency

VI. CONCLUSION

This paper presents a successful analysis of matrix converter topology in the form of AC-DC-AC converter with reduced switch configuration and simplified commutation strategy, which reduces complexity of control when compared with the conventional matrix converter. Both the input current and output voltage are pure sine waveforms with only harmonics around or above the switching frequency. Hence filter requirement on both line and load side are reduced in size. The converter provides leading power factor at the line side and also improved power factor at the load side. Since DC link capacitor is eliminated, large capacity compact converter system can be designed. It has a good voltage transfer ratio similar to conventional matrix converter. Total Harmonic Distortion (THD) on line side is 4.36% and on the load side is 22.79%. This implies that PWM methods analyzed provide feasible results. Space vector modulation is utilized for good voltage transfer from DC link and reduced distortion. Clamp circuit requirement is reduced in size when compared to the conventional matrix converter. From the performance analysis it can be concluded that the proposed converter is free from commutation problem and has better performance than conventional matrix converter.

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BIOGRAPHIES

P.Sanjeevikumar received Bachelor of Engineering (Electrical & Electronics) from the University of Madras and Master of Technology (Electrical Drives & Control) from Pondicherry University in 2002, 2006. He worked as a Lecturer in the Department of Electrical & Electronics Engineering in IFET College of Engineering, Tamilnadu, India (2002 – 2007). He also worked as Manager Training at Edutech LLC, Dubai, Middle East, UAE. Presently he is with Simulation Solutions as a Senior Project Engineer in Research and Development. He is currently working in the area of alternate topology for Matrix converter, Luo Converters, soft switching PWM schemes and power electronics application towards power systems. He has published papers in national, international conferences and journals in the field of power electronics and power system.

Dr.Rajambal received her Bachelor of Engineering in Electrical & Electronics, Master of Engineering in power electronics and Ph.D in Wind Energy Systems in 1991, 1993 and 2005 respectively from Anna University, Chennai, India. She is working as a Assistant professor in the Department of Electrical and Electronics in Pondicherry Engineering College, Pondicherry, India. Her area of interest includes in the fields of wind energy systems and power converter with soft switching PWM schemes.