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Positive Controlled Matrix Converter as a Variable Multiphase Input-Output Converter

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Abstract- A matrix converter by design is a bidirectional switch based ac-ac converter featuring high efficiency, longer lifespan and high power density. This paper proposes a positive controlled matrix converter as a variable multiphase input-output converter. Based on the characteristic of Positive PWM control technique, the generalized matrix converter can be operated as a variable multiphase topology or as any of the four categorizes of power electronic converter. The switching sequence of Positive PWM control technique ensures that open circuit and short-circuit of current and voltage sources are eliminated hence continuous current flow is provided at the source and load of the matrix converter. Also, the generated output waveforms are balanced and high quality even if the input waveforms are hugely distorted and unbalanced. Theoretical analysis of the input-output phase variation of the proposed matrix converter is provided and PSCAD software based simulation of a single-phase to single-phase and a three-phase to two-phase positive controlled matrix converters are provided.

Keywords Bidirectional switch, matrix converter, positive control, three-phase, two phase.

1. Introduction

AC-AC converters such as matrix converter are extensively utilized in industrial applications such as renewable energy integration, variable speed/motor drives, UPFCs (unified power flow controllers), installation of electric furnace and grid interfacing [1-2]. The matrix converter was introduced 1980 and is also known as a generalized transformer. Matrix converters are principally designed to provide frequency and amplitude (buck/boost) control for ac-ac voltage conditioning, they require less passive components [3-4]. Some advantages of matrix converter are sinusoidal input/output waveform, bidirectional power flow, variable input power factor, direct power conversion, high efficiency, higher controllability and fast response, variable input/output phase and no or minimum energy storage device [9-10]. The major disadvantage of the matrix converter is the higher number of semiconductor devices required. Matrix converter is categorized into DMC (direct matrix converter) and IDMC (indirect matrix converter) [7]. Detailed classification of the matrix converter is shown by Fig. 1. There are four main categories of the matrix converter i.e. hybrid, direct, three-phase and indirect matrix converters, the direct topology grouped into two categories i.e. conventional and full-bridge matrix converters.

Several control switching commutations have been proposed for the control of the matrix converter. The AV method with a voltage transfer ratio (input/output) of 50% was presented in 1981 by Alesina and Venturini [8]. This methodology was improved by the 3rd harmonic injection technique (optimum AV technique) with an improved voltage transfer ratio of 86.6% which is still a major constraint on the efficiency of the matrix converter [9]. Scalar control technique utilizes a contrasting procedure however; the results are similar to AV technique [10]. By using a fictitious dc-link, the control technique presented by [11] increases the voltage transfer ratio to 105.3%. With respect to PWM based control techniques for matrix converters, several of such techniques have been reported in [12-19] where input-side unity power-factor is maintained but output voltage control is provided. Two of such commonly used techniques are SVM (space vector modulation) and CBM (carrier-based modulation).

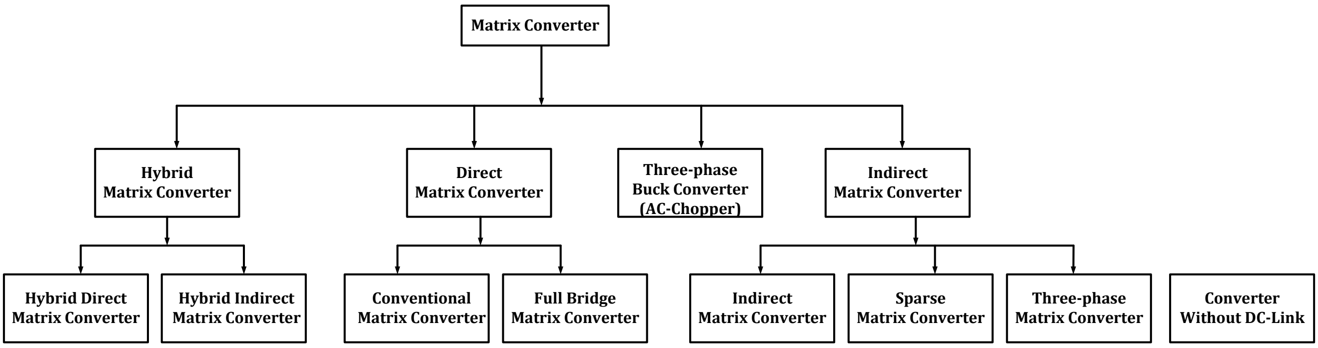

Fig. 1. Classification of matrix converter.

In the CBM method, the input/source power-factor is regulated by controlling the carrier slope and applying offset voltage [15]. SVM technique synthesizes the zero state vectors and adjacent two vectors to produce the required reference [16-17]. Other control techniques are DTC (direct torque control) [18-19], predictive control [20], PTC (predictive torque control) [21-22], closed-loop control and HB (hysteresis band) control [23-24].

This paper proposes a positive controlled matrix converter as a variable multiphase input-output converter which is suitable for application in grid integration of wind energy, UPFCs (unified power-flow controllers), direct DVR compensations, induction cookers, microgrids etc. The emergence of PET (power electronic transformers) provides another avenue where the proposed converter can be used for voltage amplitude and frequency regulation and also for voltage phase regulation [25-29].

2. System Configuration

The conventional *m*n* matrix converter topology is illustrated by Fig. 2; from this structure, various matrix converter topologies with equal or varying input-output phases can be designed. Fig. 3 to Fig. 7 shows various topologies derived from the conventional structure of Fig. 2. A three-phase to two-phase structure is depicted by Fig. 3. A three-phase to single-phase structure is illustrated by Fig. 4. A single-phase to three-phase structure is illustrated by Fig. 6. A single-phase to single-phase structure is illustrated by Fig. 5. A three-phase to three-phase structure is illustrated by Fig. 7. The commonly used three-phase to three-phase 9-switch matrix converter is illustrated by Fig. 7.

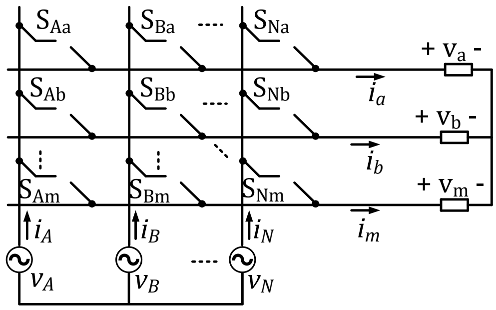

Fig. 2. Conventional *m*n* matrix converter.

The nine switches which are bidirectional with respect to current flow are derived from any of the four topology configurations i.e. common emitter, common collector, reverse/antiparallel and diode configurations [30-32] illustrated by Fig. 8. The nine bidirectional switches of Fig. 7. constitutes a 3*3 matrix which provides a logical switching states of twenty-seven.

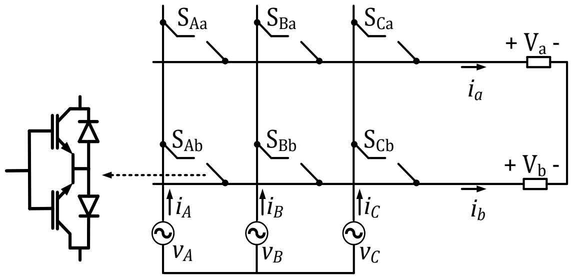

Fig. 3. Three-phase to two-phase matrix converter.

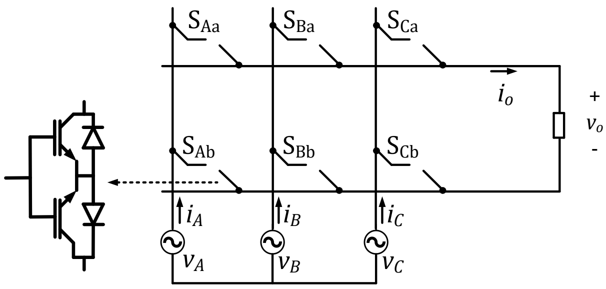

Fig. 4. Three-phase to single-phase matrix converter.

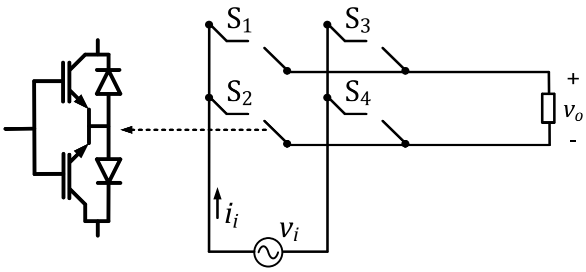

Fig. 5. Single-phase to single-phase matrix converter.

Equation (1) expresses the three-phase voltage input and Equation (2) and (3) provide the relationship between the three-phase input and the three-phase output of the converter with respect to the voltage and current accordingly. *S* in equation (2) represent the switch matrix and S^T in equation (3) represent the transpose of S. Simplifying equation (2) yields equation (3).

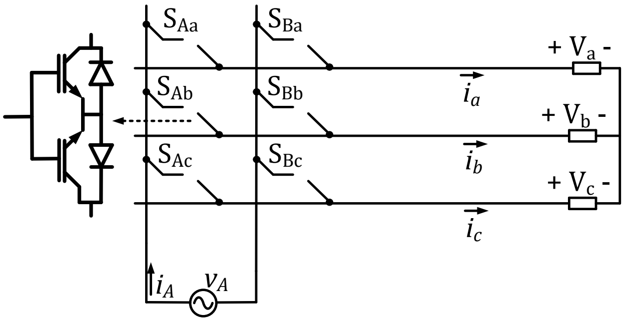

Fig. 6. Single-phase to three-phase matrix converter.

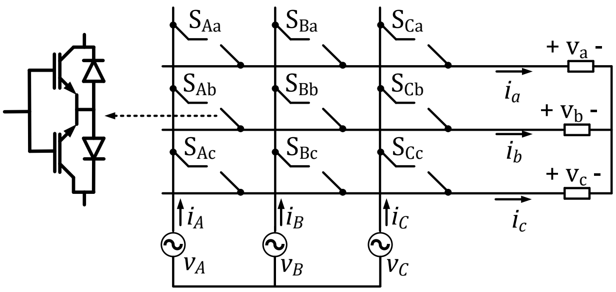

Fig. 7. Three-phase to three-phase matrix converter.

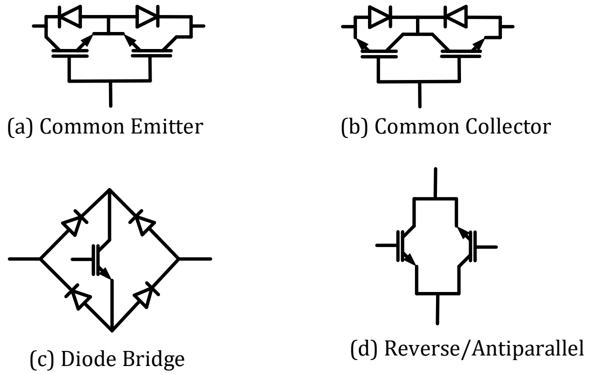

Fig. 8. Bidirectional switch configuration.

$$\begin{aligned} v_a &= S_{Aa}v_A + S_{Ba}v_B + S_{Ca}v_C \\ v_b &= S_{Ab}v_A + S_{Bb}v_B + S_{Cb}v_C \\ v_c &= S_{Ac}v_A + S_{Bc}v_B + S_{Cc}v_C \end{aligned} \tag{1}$$

$$\begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix} = \begin{bmatrix} \mathrm{S_{Aa}} & \mathrm{S_{Ba}} & \mathrm{S_{Ca}} \\ \mathrm{S_{Ab}} & \mathrm{S_{Bb}} & \mathrm{S_{Cb}} \\ \mathrm{S_{Ac}} & \mathrm{S_{Bc}} & \mathrm{S_{Cc}} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = S \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} = \begin{bmatrix} \mathrm{S_{Aa}} & \mathrm{S_{Ba}} & \mathrm{S_{Ca}} \\ \mathrm{S_{Ab}} & \mathrm{S_{Bb}} & \mathrm{S_{Cb}} \\ \mathrm{S_{Ac}} & \mathrm{S_{Bc}} & \mathrm{S_{Cc}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = S^T \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{3}$$

3. Positive Control Technique

Positive control technique is employed in controlling the proposed matrix converter. In this work, a single-phase to single-phase and a three-phase to two-phase PWM positive controlled matrix converters are proposed. In the positive controlled technique, the switching sequence is developed into a matrix based on the number of switches in the specific matrix converter under investigation. Using Fig. 6, the developed matrix is shown by equation (4) and the total switching period T_{TS} is expressed by equation (5) where t_x and t_y represent the active switches during positive and negative switching cycles accordingly. Diagonally switching determines the active switches during t_x and t_y intervals. In t_x time interval, switches S_4 and S_1 are gated on and during t_y time interval, switches S_3 and S_2 are gated on. In other to derive equal diagonal switching, the first column of equation (4) has to be repeated and its expressed by equation (6). The resulting diagonal switching is expressed equation (7) [33 – 35].

$$m = \begin{bmatrix} S_1 & S_3 \\ S_2 & S_4 \end{bmatrix} \tag{4}$$

$$T_{TS} = t_x + t_y \tag{5}$$

$$m = \begin{bmatrix} S_1 & S_3 & S_1 \\ S_2 & S_4 & S_2 \end{bmatrix} \tag{6}$$

$$m = \begin{bmatrix} S_1 & S_3 & S_1 \\ S_2 & S_4 & S_2 \end{bmatrix} \quad (t_x,\ t_y) \tag{7}$$

Based on equations (5) and (6), the average output voltage v_o and the parameters of switching *P* (duty cycle) are expressed by:

$$v_o = v_i (t_x + t_y) \frac{1}{T_{TS}} \tag{8}$$

$$\begin{cases} P_1 = \dfrac{t_x}{T_{TS}} \\ P_2 = \dfrac{t_y}{T_{TS}} \end{cases} \tag{9}$$

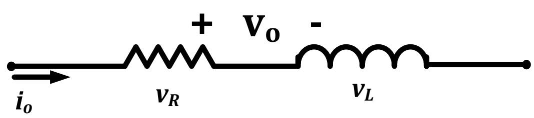

Fig. 9. Resistance-inductance (*RL*) load.

From the *RL* load equivalent circuit of Fig. 9, the average output voltage v_o and average output current i_o are computed by equations (10) and (11) accordingly. The input and output currents are related by equation (12).

$$\begin{cases} v_o = v_R + v_L \\ v_o = Ri_o + L\dfrac{di_o}{dt} \end{cases} \tag{10}$$

$$i_o = I_{om}\sin(\omega_o t + \phi_o) \tag{11}$$

$$i_i = i_o(P_1 - P_2) \tag{12}$$

4. Simulation Results

Simulation result of the proposed single-phase to single-phase and three-phase to two-phase PWM positive controlled matrix converters are presented in this section. Based on the above control technique, the matrix converter functions as a buck converter with respect to voltage and a boost converter with respect to frequency. Firstly, simulation results are produced for the single-phase to single matrix converter of Fig. 6 using the simulation parameters of Table 1.

Table 1. Simulation parameters

Parameter	**Value**
Input voltage V_i	200V
frequency f_o	50Hz
Switching frequency f_s	5kHz
Resistance R	20Ω
Inductance L	0.04H

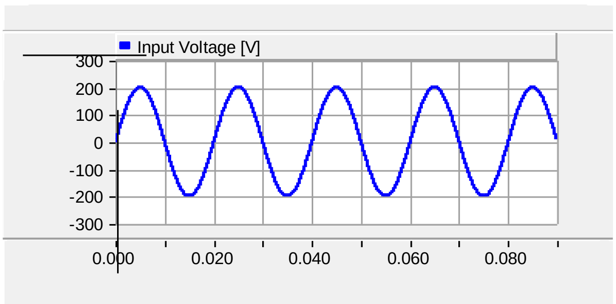

Fig. 10. Source voltage waveform.

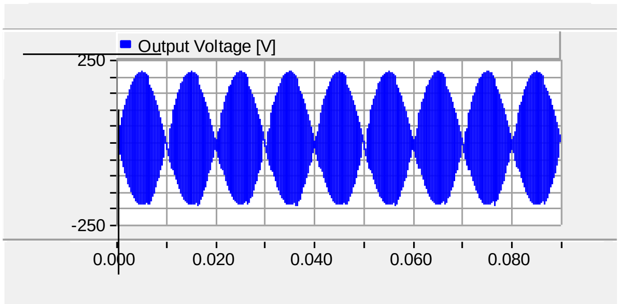

Fig. 11. Load voltage waveform.

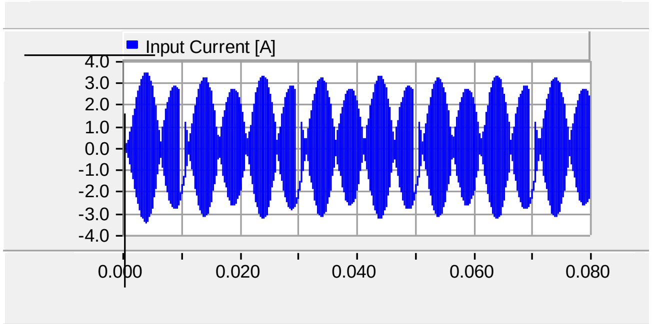

Fig. 12. Source current waveform.

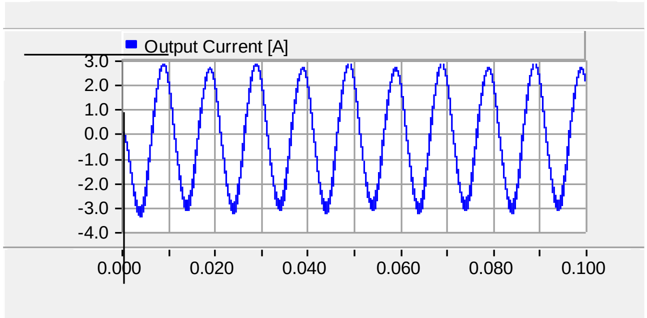

Fig. 13. Load current waveform.

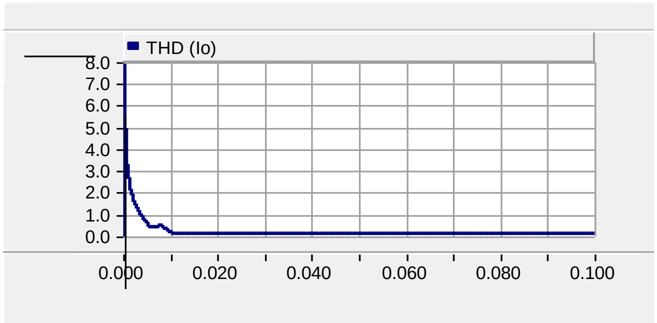

Fig. 14. Total harmonic distortion of load current.

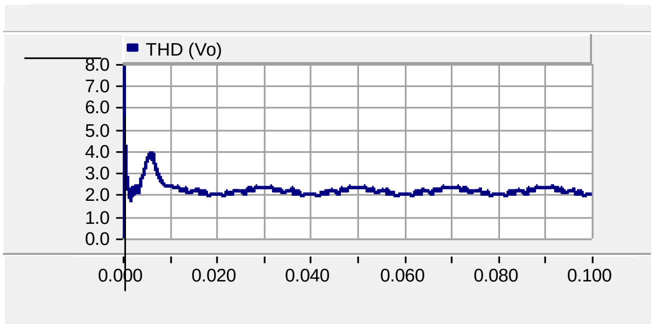

Fig. 15. Total harmonic distortion of load voltage.

Simulation waveforms of the proposed PWM positive controlled single-phase to single-phase matrix converter is are shown by Fig.10 to Fig.17. The source voltage and current are represented by Fig.10 and Fig.12 having peak values of 200V and 3A accordingly. The corresponding output voltage and current are illustrated by Fig.11 and Fig.13 with peak magnitudes of 190V and 2.75A accordingly. The output voltage and current THD are expressed by Fig.15 and Fig.14 respectively. The FFT of the output current and voltage are given by Fig.16 and Fig.17.

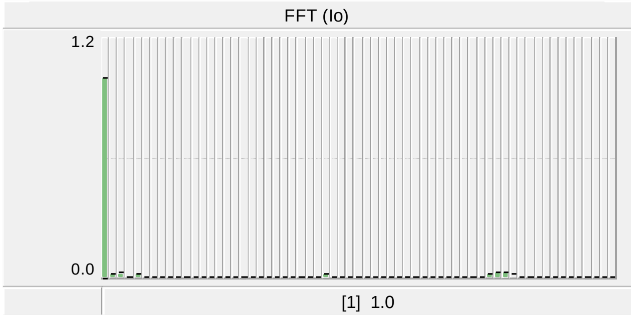

Fig. 16. FFT of load current.

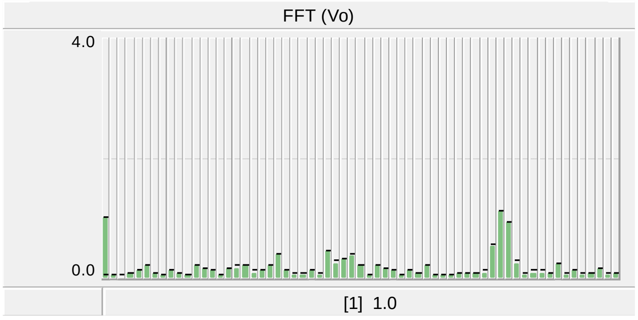

Fig. 17. FFT of load voltage.

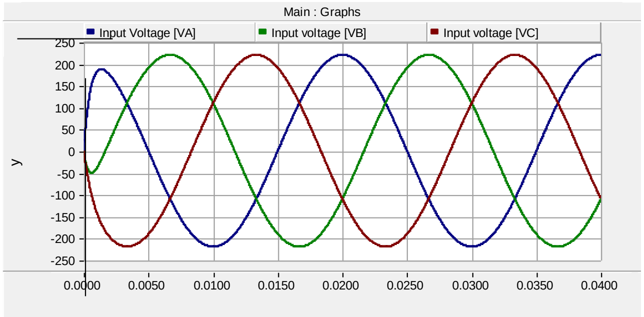

Fig. 18. Source voltage waveform.

Table 2. Simulation parameters

Parameter	Value
Input voltage V_i	220V
frequency f_o	50Hz
Switching frequency f_s	5kHz
Resistance R	18Ω
Inductance L	0.055H

Lastly, simulation results of the proposed three-phase to two-phase PWM positive controlled matrix converter represented by Fig.4 is provided in this section. Parameters of the simulation are expressed by Table 2. A low-pass filter is connected at the input section of the matrix converter just after the source voltage. Fig.18 shows the three-phase input voltage waveforms with maximum amplitude of 220V. Fig.19 and Fig.20 shows the load voltage waveforms of phase A and B accordingly with an average maximum amplitude of 210V. The three-phase current waveform before the low-pass filter is depicted by Fig.21 and the filtered current waveforms are shown by Fig.22. The load current waveform of phase A and B are shown by Fig.23.

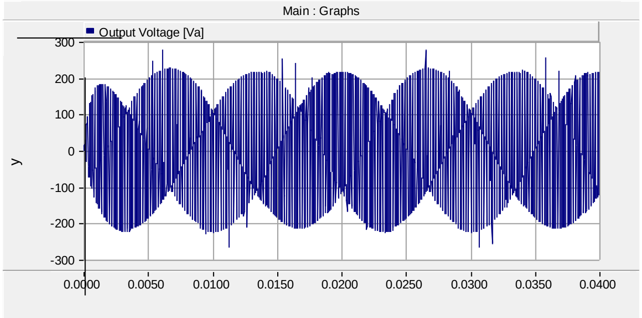

Fig. 19. Phase A load voltage waveform.

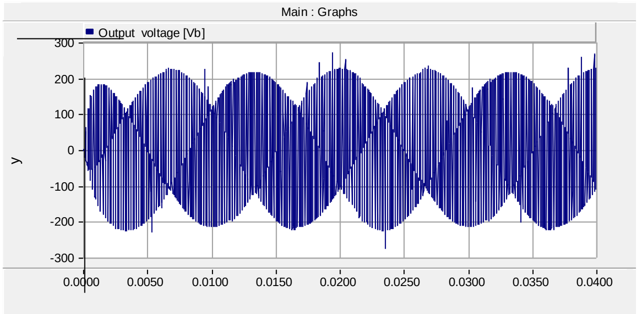

Fig. 20. Phase B load voltage waveform.

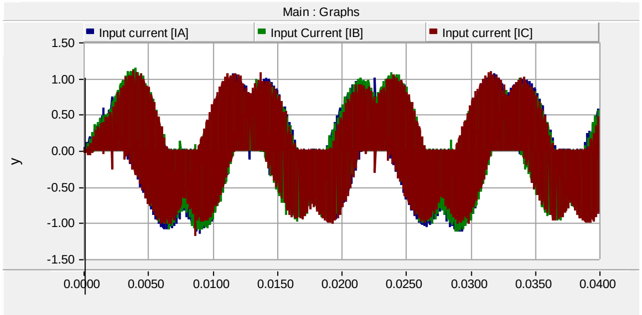

Fig. 21. Source current waveform (before low-pass filter).

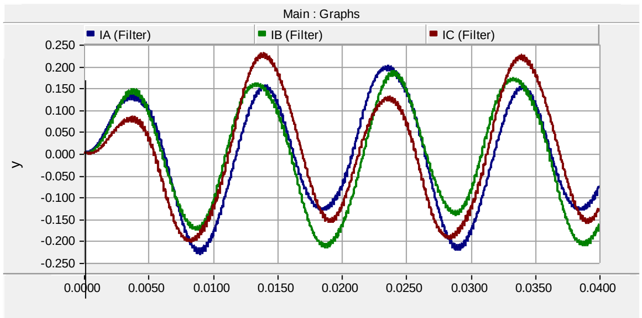

Fig. 22. Source current waveform (after low-pass filter).

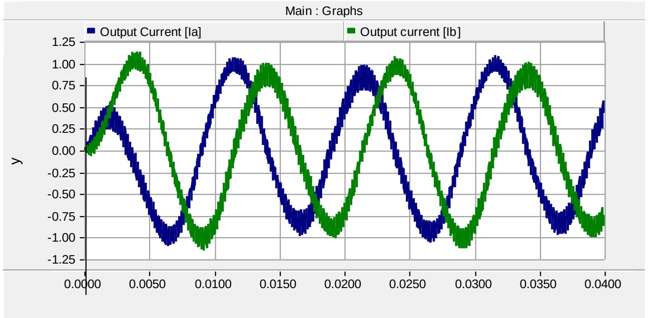

Fig. 23. Load current waveform.

5. Conclusion

This work proposed the application of a PWM positive controlled matrix converter as a variable multiphase input-output converter. The generalised structure of the matrix converter is analysed in this work and various input-output multiphase variations are provided. Simulation results of a single-phase to single-phase and a three-phase to a two-phase matrix converters are provided. Some inherent advantages of the positive control method are continuous input-output current flow due to the elimination of short-circuit and open-circuit of the converter, quality output waveforms and buck voltage and boost frequency characteristics.

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