# A NEW CIRCUIT FOR THREE-PHASE TO THREE-PHASE AC/AC MATRIX CONVERTERS

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## ABSTRACT

**The conventional AC/AC matrix converter uses 9 bi-directional switches. The 3×3 switches give 512 combinations of switching states, which are decreased to only 27 feasible states, if the two basic rules (preventing the short-circuit and open-circuit) to operate the converters safely are applied. The output voltage of a basic matrix converter is limited to $\frac{\sqrt{3}}{2} \approx 0.866$ of the input voltage. In this paper a new circuit for three-phase to three-phase AC/AC matrix converters is presented. This new circuit uses 10 bi-directional switches. Therefore the permitted states are increased to 45 combinations. The algorithm for controlling the matrix converter is based on Least Mean Square Errors (LMSE). The output voltage of the new circuit is increased to $\frac{2\sqrt{3}}{3} \approx 1.15$ of the input voltage. The other advantages of this circuit are: low THD, self operating under distorted and unbalanced conditions, minimum losses, simplified control algorithm and no limitations on frequency conversion.**

## I. INTRODOCTION

The matrix converter seems to be an universal converter because of its inherent bi-directional power flow and because of any desired number of inputs and output phases. In addition there is theoretically no need of energy storage elements, which are costly, space consuming and e.g. the energy stored in the dc-link of a voltage source inverter is difficult to control in case of fault. Other advantages of matrix converters are:

- Sinusoidal input current waveforms with small distortion;
- Provide independent control of the magnitude and frequency of the generated output voltages;
- Adjustable input power factor regardless of the load, generally with unity power factor;
- Has high-efficiency and fast-response;
- And many other advantages [1], [2], [3], [4].

The matrix converter consists of nine bi-directional switches arranged so that any input line can be connected to any output line as shown in Fig. 1. The converter has inputs phase voltages $v_{i1}, v_{i2}, v_{i3}$, and outputs phase voltages $v_{o1}, v_{o2}, v_{o3}$. The input voltages of the matrix converter are given by:

$$\begin{aligned} v_{i1}(t) &= V_i \sin(\omega_i t) \\ v_{i2}(t) &= V_i \sin(\omega_i t - \frac{2\pi}{3}) \\ v_{i3}(t) &= V_i \sin(\omega_i t + \frac{2\pi}{3}) \end{aligned} \quad (1)$$

Where $V_i$ denotes a peak value of input voltages, and $\omega_i$ denotes an angular frequency of input voltages.

The matrix converter will be designed and controlled in such a manner that the fundamental of the output voltages are:

$$\begin{aligned} v_{o1}(t) &= V_o \sin(\omega_o t) \\ v_{o2}(t) &= V_o \sin(\omega_o t - \frac{2\pi}{3}) \\ v_{o3}(t) &= V_o \sin(\omega_o t + \frac{2\pi}{3}) \end{aligned} \quad (2)$$

Where $V_o$ denotes a peak value of desired output voltages, and $\omega_o$ denotes an angular frequency of output voltages.

The matrix converter is very simple in structure and has powerful controllability. However, commutation problem and complicated **PWM** method keep it form being utilized in industry. This paper presents a new structure for three-phase to three-phase AC/AAC matrix converter.

## II. THREE-PHASE TO THREE-PHASE AC/AC MATRIX CONVERTER

### *A. The Conventional Matrix Converter*

The conventional three-phase to three-phase AC/AC matrix converter in a schematic form is presented in Fig. 1. The matrix components $S_{11}$, $S_{12}$, …, $S_{33}$ represent nine bi-directional switches capable to block voltage in both directions and switch without delays. The presented matrix converter will connect the three given inputs, with constant amplitude and frequency, through the nine switches to the output terminals in accordance to precalculated switching patterns. The obtained outputs three-phase voltage system, have controllable amplitudes and frequency.

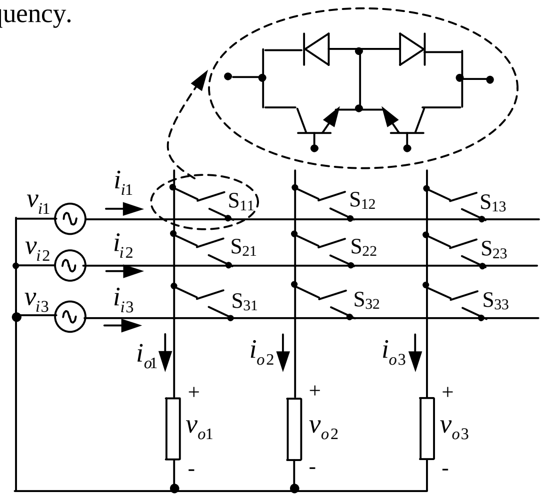


**Figure 1.** The conventional matrix converter topology

This matrix converter consists of 3×3 switches. The 3×3 switches give 512 combinations of switching states, which are decreased to only 27 feasible states, if considering the following basic safety conditions:

- For prevent of short-circuit of power supplies, do not connect two different input lines to the same output line (over currents);
- For prevent of open circuit of loads (Load is inductive), do not disconnect the output line circuits (over voltages).

The 27 different **Modes** of this circuit completely are discussed in [5]. We emphasis the peak value of the output voltages for circuit shown in Fig. 1 is equal with the peak value of the input voltages [5].

### *B. The New Circuit for Three-Phase To Three-Phase AC/AC Matrix Converters*

The new circuit for three-phase to three-phase AC/AC matrix converter uses 10 bi-directional switches and in schematic form is shown in Fig. 2. The difference of this circuit with previous circuit is in the applying of switch $S_N$. This matrix converter consists of 10 switches. The 10 switches have 1024 combinations of switching states. Considering the two basic rules mentioned previously, these states are decreased to only 45 feasible states. Table I shows the matrix converter **Modes**. As it is shown the patterns of switches are in such a way that they cause the input voltages not to be short-circuited and also the output current not to be open-circuited.
The output voltage of a conventional matrix converter with a classic method control (except **LMSE** method) is limited to 0.866 of the input voltage. This limitation occurs because the maximum peak-to-peak output voltage can not be greater than the minimum voltage difference between two phases of the input.

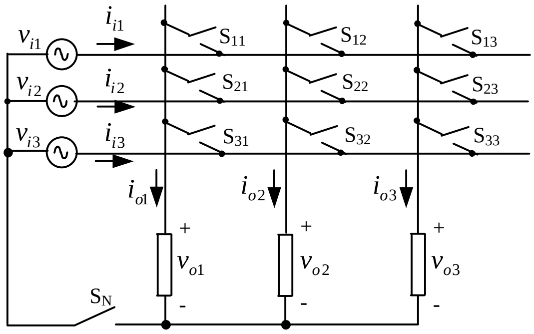


**Figure 2.** The new circuit for matrix converter

Although techniques have been proposed for boosting the output voltage of the matrix converter, the increase in output voltage is achieved at the cost of added complexity or deterioration in waveform quality. In the basic matrix converter, the maximum possible output voltage is achieved by introducing third harmonics of the input and output frequencies into the output waveform to make full use of the available input voltage. These third harmonics will give the line output voltages described by eqn. (3). The 86% voltage limit is the only significant restriction on the performance of a matrix converter [3].

$$\begin{bmatrix} v_{o1}(t) \\ v_{o2}(t) \\ v_{o3}(t) \end{bmatrix} = \begin{bmatrix} \sin(\omega_o t) + 0.25\sin(3\omega_i t) + 0.12\sin(3\omega_o t) \\ \sin(\omega_o t - \frac{2\pi}{3}) + 0.25\sin(3\omega_i t) + 0.12\sin(3\omega_o t) \\ \sin(\omega_o t + \frac{2\pi}{3}) + 0.25\sin(3\omega_i t) + 0.12\sin(3\omega_o t) \end{bmatrix} \quad (3)$$

As Table I shows the output voltage of the new circuit is limited to 1.15 of the input voltage. As we will see in the simulation results this circuit not only has not effect on waveform quality, but also has less THD. Since this circuit is capable to produce the output voltages greater than input voltages, therefore this circuit can be used as an amplifier.
The relations between the output voltages and the output currents for the three-phase load ( $R-L$ ) are given by:

$$\begin{aligned} v_{o1}(t) &= R\, i_{o1}(t) + L\frac{d\, i_{o1}(t)}{dt} \\ v_{o2}(t) &= R\, i_{o2}(t) + L\frac{d\, i_{o2}(t)}{dt} \\ v_{o3}(t) &= R\, i_{o3}(t) + L\frac{d\, i_{o3}(t)}{dt} \end{aligned} \quad (4)$$

The fundamentals of the output voltages are given by eqn. (2). Using eqns. (2) and (4), the fundamental output currents are given by:

$$\begin{aligned} i_{o1}(t) &= \frac{V_o}{\sqrt{(L\omega_o)^2 + R^2}}\sin(\omega_o t - \tan^{-1}(\frac{R}{L})) \\ i_{o2}(t) &= \frac{V_o}{\sqrt{(L\omega_o)^2 + R^2}}\sin(\omega_o t - \frac{2\pi}{3} - \tan^{-1}(\frac{R}{L})) \\ i_{o3}(t) &= \frac{V_o}{\sqrt{(L\omega_o)^2 + R^2}}\sin(\omega_o t + \frac{2\pi}{3} - \tan^{-1}(\frac{R}{L})) \end{aligned} \quad (5)$$

**TABLE I.** Different feasible modes for circuit shown in Fig. 2

| MODES | ON SWITCHES | $v_{o1}$ | $v_{o2}$ | $v_{o3}$ | $i_{i1}$ | $i_{i2}$ | $i_{i3}$ |
|---|---|---|---|---|---|---|---|
| **1** | $S_{11}$ $S_{22}$ $S_{33}$ $S_N$ | $v_{i1}$ | $v_{i2}$ | $v_{i3}$ | $i_{o1}$ | $i_{o2}$ | $i_{o3}$ |
| **2** | $S_{12}$ $S_{23}$ $S_{31}$ $S_N$ | $v_{i3}$ | $v_{i1}$ | $v_{i2}$ | $i_{o2}$ | $i_{o3}$ | $i_{o1}$ |
| **3** | $S_{13}$ $S_{21}$ $S_{32}$ $S_N$ | $v_{i2}$ | $v_{i3}$ | $v_{i1}$ | $i_{o3}$ | $i_{o1}$ | $i_{o2}$ |
| **4** | $S_{13}$ $S_{22}$ $S_{31}$ $S_N$ | $v_{i3}$ | $v_{i2}$ | $v_{i1}$ | $i_{o3}$ | $i_{o2}$ | $i_{o1}$ |
| **5** | $S_{11}$ $S_{23}$ $S_{32}$ $S_N$ | $v_{i1}$ | $v_{i3}$ | $v_{i2}$ | $i_{o1}$ | $i_{o3}$ | $i_{o2}$ |
| **6** | $S_{12}$ $S_{21}$ $S_{33}$ $S_N$ | $v_{i2}$ | $v_{i1}$ | $v_{i3}$ | $i_{o1}$ | $i_{o2}$ | $i_{o3}$ |
| **7** | $S_{11}$ $S_{22}$ $S_{23}$ $S_N$ | $v_{i1}$ | $v_{i2}$ | $v_{i2}$ | $i_{o1}$ | $i_{o2}+i_{o3}$ | 0 |
| **8** | $S_{21}$ $S_{32}$ $S_{33}$ $S_N$ | $v_{i2}$ | $v_{i3}$ | $v_{i3}$ | 0 | $i_{o1}$ | $i_{o2}+i_{o3}$ |
| **9** | $S_{12}$ $S_{13}$ $S_{31}$ $S_N$ | $v_{i3}$ | $v_{i1}$ | $v_{i1}$ | $i_{o2}+i_{o3}$ | 0 | $i_{o1}$ |
| **10** | $S_{12}$ $S_{13}$ $S_{21}$ $S_N$ | $v_{i2}$ | $v_{i1}$ | $v_{i1}$ | $i_{o2}+i_{o3}$ | $i_{o1}$ | 0 |
| **11** | $S_{22}$ $S_{23}$ $S_{31}$ $S_N$ | $v_{i3}$ | $v_{i2}$ | $v_{i2}$ | 0 | $i_{o2}+i_{o3}$ | $i_{o1}$ |
| **12** | $S_{11}$ $S_{32}$ $S_{33}$ $S_N$ | $v_{i1}$ | $v_{i3}$ | $v_{i3}$ | $i_{o1}$ | 0 | $i_{o2}+i_{o3}$ |
| **13** | $S_{12}$ $S_{21}$ $S_{23}$ $S_N$ | $v_{i2}$ | $v_{i1}$ | $v_{i2}$ | $i_{o2}$ | $i_{o1}+i_{o3}$ | 0 |
| **14** | $S_{22}$ $S_{31}$ $S_{33}$ $S_N$ | $v_{i3}$ | $v_{i2}$ | $v_{i3}$ | 0 | $i_{o2}$ | $i_{o1}+i_{o3}$ |
| **15** | $S_{11}$ $S_{13}$ $S_{32}$ $S_N$ | $v_{i1}$ | $v_{i3}$ | $v_{i1}$ | $i_{o1}+i_{o3}$ | 0 | $i_{o1}$ |
| **16** | $S_{11}$ $S_{13}$ $S_{22}$ $S_N$ | $v_{i1}$ | $v_{i2}$ | $v_{i1}$ | $i_{o1}+i_{o3}$ | $i_{o2}$ | 0 |
| **17** | $S_{21}$ $S_{23}$ $S_{32}$ $S_N$ | $v_{i2}$ | $v_{i3}$ | $v_{i2}$ | 0 | $i_{o1}+i_{o3}$ | $i_{o2}$ |
| **18** | $S_{12}$ $S_{31}$ $S_{33}$ $S_N$ | $v_{i3}$ | $v_{i1}$ | $v_{i3}$ | $i_{o2}$ | 0 | $i_{o1}+i_{o3}$ |
| **19** | $S_{13}$ $S_{21}$ $S_{22}$ $S_N$ | $v_{i2}$ | $v_{i2}$ | $v_{i1}$ | $i_{o3}$ | $i_{o1}+i_{o2}$ | 0 |
| **20** | $S_{23}$ $S_{31}$ $S_{32}$ $S_N$ | $v_{i3}$ | $v_{i3}$ | $v_{i2}$ | 0 | $i_{o3}$ | $i_{o1}+i_{o2}$ |
| **21** | $S_{11}$ $S_{12}$ $S_{33}$ $S_N$ | $v_{i1}$ | $v_{i1}$ | $v_{i3}$ | $i_{o1}+i_{o2}$ | 0 | $i_{o3}$ |
| **22** | $S_{11}$ $S_{12}$ $S_{23}$ $S_N$ | $v_{i1}$ | $v_{i1}$ | $v_{i2}$ | $i_{o1}+i_{o2}$ | $i_{o3}$ | 0 |
| **23** | $S_{21}$ $S_{22}$ $S_{33}$ $S_N$ | $v_{i2}$ | $v_{i2}$ | $v_{i3}$ | 0 | $i_{o1}+i_{o2}$ | $i_{o3}$ |
| **24** | $S_{13}$ $S_{31}$ $S_{32}$ $S_N$ | $v_{i3}$ | $v_{i3}$ | $v_{i1}$ | $i_{o3}$ | 0 | $i_{o1}+i_{o2}$ |
| **25** | $S_{11}$ $S_{12}$ $S_{13}$ $S_N$ | $v_{i1}$ | $v_{i1}$ | $v_{i1}$ | $i_{o1}$ | $i_{o2}+i_{o3}$ | 0 |
| **26** | $S_{21}$ $S_{22}$ $S_{23}$ $S_N$ | $v_{i2}$ | $v_{i2}$ | $v_{i2}$ | 0 | $i_{o1}$ | $i_{o2}+i_{o3}$ |
| **27** | $S_{31}$ $S_{32}$ $S_{33}$ $S_N$ | $v_{i3}$ | $v_{i3}$ | $v_{i3}$ | $i_{o2}+i_{o3}$ | 0 | $i_{o1}$ |
| **28** | $S_{11}$ $S_{22}$ $S_{23}$ | $\frac{2}{3}(v_{i1}-v_{i2})$ | $\frac{1}{3}(v_{i2}-v_{i1})$ | $\frac{1}{3}(v_{i2}-v_{i1})$ | $i_{o1}$ | $i_{o2}+i_{o3}$ | 0 |
| **29** | $S_{21}$ $S_{32}$ $S_{33}$ | $\frac{2}{3}(v_{i2}-v_{i3})$ | $\frac{1}{3}(v_{i3}-v_{i2})$ | $\frac{1}{3}(v_{i3}-v_{i2})$ | 0 | $i_{o1}$ | $i_{o2}+i_{o3}$ |
| **30** | $S_{12}$ $S_{13}$ $S_{31}$ | $\frac{2}{3}(v_{i3}-v_{i1})$ | $\frac{1}{3}(v_{i1}-v_{i3})$ | $\frac{1}{3}(v_{i1}-v_{i3})$ | $i_{o2}+i_{o3}$ | 0 | $i_{o1}$ |
| **31** | $S_{12}$ $S_{13}$ $S_{21}$ | $\frac{2}{3}(v_{i2}-v_{i1})$ | $\frac{1}{3}(v_{i1}-v_{i2})$ | $\frac{1}{3}(v_{i1}-v_{i2})$ | $i_{o2}+i_{o3}$ | $i_{o1}$ | 0 |
| **32** | $S_{22}$ $S_{23}$ $S_{31}$ | $\frac{2}{3}(v_{i3}-v_{i2})$ | $\frac{1}{3}(v_{i2}-v_{i3})$ | $\frac{1}{3}(v_{i2}-v_{i3})$ | 0 | $i_{o2}+i_{o3}$ | $i_{o1}$ |
| **33** | $S_{11}$ $S_{32}$ $S_{33}$ | $\frac{2}{3}(v_{i1}-v_{i3})$ | $\frac{1}{3}(v_{i3}-v_{i1})$ | $\frac{1}{3}(v_{i3}-v_{i1})$ | $i_{o1}$ | 0 | $i_{o2}+i_{o3}$ |
| **34** | $S_{12}$ $S_{21}$ $S_{23}$ | $\frac{1}{3}(v_{i2}-v_{i1})$ | $\frac{2}{3}(v_{i1}-v_{i2})$ | $\frac{1}{3}(v_{i2}-v_{i1})$ | $i_{o2}$ | $i_{o1}+i_{o3}$ | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **35** | $S_{22}$ $S_{31}$ $S_{33}$ | $\frac{1}{3}(v_{i3}-v_{i2})$ | $\frac{2}{3}(v_{i2}-v_{i3})$ | $\frac{1}{3}(v_{i3}-v_{i2})$ | 0 | $i_{o2}$ | $i_{o1}+i_{o3}$ |
| **36** | $S_{11}$ $S_{13}$ $S_{32}$ | $\frac{1}{3}(v_{i1}-v_{i3})$ | $\frac{2}{3}(v_{i3}-v_{i1})$ | $\frac{1}{3}(v_{i1}-v_{i3})$ | $i_{o1}+i_{o3}$ | 0 | $i_{o1}$ |
| **37** | $S_{11}$ $S_{13}$ $S_{22}$ | $\frac{1}{3}(v_{i1}-v_{i2})$ | $\frac{2}{3}(v_{i2}-v_{i3})$ | $\frac{1}{3}(v_{i1}-v_{i2})$ | $i_{o1}+i_{o3}$ | $i_{o2}$ | 0 |
| **38** | $S_{21}$ $S_{23}$ $S_{32}$ | $\frac{1}{3}(v_{i2}-v_{i3})$ | $\frac{2}{3}(v_{i3}-v_{i2})$ | $\frac{1}{3}(v_{i2}-v_{i3})$ | 0 | $i_{o1}+i_{o3}$ | $i_{o2}$ |
| **39** | $S_{12}$ $S_{31}$ $S_{33}$ | $\frac{1}{3}(v_{i3}-v_{i1})$ | $\frac{2}{3}(v_{i1}-v_{i3})$ | $\frac{1}{3}(v_{i3}-v_{i1})$ | $i_{o2}$ | 0 | $i_{o1}+i_{o3}$ |
| **40** | $S_{13}$ $S_{21}$ $S_{22}$ | $\frac{1}{3}(v_{i2}-v_{i1})$ | $\frac{1}{3}(v_{i2}-v_{i1})$ | $\frac{2}{3}(v_{i1}-v_{i2})$ | $i_{o3}$ | $i_{o1}+i_{o2}$ | 0 |
| **41** | $S_{23}$ $S_{31}$ $S_{32}$ | $\frac{1}{3}(v_{i3}-v_{i2})$ | $\frac{1}{3}(v_{i3}-v_{i2})$ | $\frac{2}{3}(v_{i2}-v_{i3})$ | 0 | $i_{o3}$ | $i_{o1}+i_{o2}$ |
| **42** | $S_{11}$ $S_{12}$ $S_{33}$ | $\frac{1}{3}(v_{i1}-v_{i3})$ | $\frac{1}{3}(v_{i1}-v_{i3})$ | $\frac{2}{3}(v_{i3}-v_{i1})$ | $i_{o1}+i_{o2}$ | 0 | $i_{o3}$ |
| **43** | $S_{11}$ $S_{12}$ $S_{23}$ | $\frac{1}{3}(v_{i1}-v_{i2})$ | $\frac{1}{3}(v_{i1}-v_{i2})$ | $\frac{2}{3}(v_{i2}-v_{i1})$ | $i_{o1}+i_{o2}$ | $i_{o3}$ | 0 |
| **44** | $S_{21}$ $S_{22}$ $S_{33}$ | $\frac{1}{3}(v_{i2}-v_{i3})$ | $\frac{1}{3}(v_{i2}-v_{i3})$ | $\frac{2}{3}(v_{i3}-v_{i2})$ | 0 | $i_{o1}+i_{o2}$ | $i_{o3}$ |
| **45** | $S_{13}$ $S_{31}$ $S_{32}$ | $\frac{1}{3}(v_{i3}-v_{i1})$ | $\frac{1}{3}(v_{i3}-v_{i1})$ | $\frac{2}{3}(v_{i1}-v_{i3})$ | $i_{o3}$ | 0 | $i_{o1}+i_{o2}$ |

### *C. Control Strategy for Three-Phase to Three-Phase AC/AC matrix Converters*

In this paper the ***LMSE*** is utilized because it offers some advantages over traditional modulation technique such as easy comprehension of the required commutation process, simplified control algorithm and minimum loss of the converter. Using this approach it is also possible to define some criteria in order to minimize the number of switching required in a commutation process and to implement control strategy suitable for operation under very low loss conditions. In this algorithm we sample the output voltages, and compare with the forecasted outputs at the decision unit and then the commands of ON or OFF states send to gating circuits.

The difference (Error) between forecasted and measured outputs is $E_1$, when $S_{11}$, $S_{22}$, $S_{33}$, $S_N$ are closed (Mode 1), $E_2$ when $S_{12}$, $S_{23}$, $S_{31}$, $S_N$ are closed (Mode 2), … and finally $E_{45}$ when $S_{13}$, $S_{31}$, $S_{32}$ are closed (Mode 45). The equations of $E_1$, $E_2$, …, $E_{45}$, are as follow:

$$E_1(t) = [v_{o1,Forc.}(t) - v_{i1}(t)]^2 + [v_{o2,Forc.}(t) - v_{i2}(t)]^2 + [v_{o3,Forc.} - v_{i3}(t)]^2$$

$$E_2(t) = [v_{o1,Forc.}(t) - v_{i3}(t)]^2 + [v_{o2,Forc.}(t) - v_{i1}(t)]^2 + [v_{o3,Forc.} - v_{i2}(t)]^2$$

$$\vdots$$

$$E_{27}(t) = [v_{o1,Forc.(t)} - \frac{1}{3}(v_{i3}(t) - v_{i1(t)})]^2 + [v_{o2,Forc(t).} - \frac{1}{3}(v_{i3}(t) - v_{i1}(t))]^2 + [v_{o3,Forc.}(t) - \frac{2}{3}(v_{i1}(t) - v_{i3}(t))]^2$$

This method is based on minimizing the difference between forecasted and measured outputs. In other words we have:

$$IF(\min(E_1, E_2, ..., E_{45}) = E_1) \quad THEN \quad S_{11} \; S_{22} \; S_{33} \; S_N = ON$$

$$IF(\min(E_1, E_2, ..., E_{45}) = E_2) \quad THEN \quad S_{12} \; S_{23} \; S_{31} \; S_N = ON$$

$$\vdots$$

$$IF(\min(E_1, E_2, ..., E_{45}) = E_{45}) \quad THEN \quad S_{13} \; S_{31} \; S_{32} = ON$$

One of important and valuable characteristic of this algorithm is that even under unbalanced and highly distorted input voltage waveforms, the output waveforms turn out to be reasonably clean and balanced and this is shown in simulation results.

## III. SIMULATION RESULTS

We use the Simulink Matlab and PSpic soft wares. They prove that we can obtain the expecting results. According to the operation principle, the input and output current and voltage waveforms may be determined by the digital simulation method. Ideal switches constitute the matrix converter. The output terminals loaded by a three-phase $R-L$ load $(R = 20^{\Omega}, L = 40^{mH})$, and the input voltage sources parameters are $V_i = 220^V$ and $f_i = 50^{HZ}$. For indicating the ability of this circuit, the waveforms of output voltage for circuit shown in Fig. 1 at different output voltages are shown in Fig. 3.

If we suppose that the input voltages are unbalanced and significantly distorted, e.g. expressed as eqn. (6)[5], simulation results show that this method is able to produce the undistorted and balanced output voltages, even if the input supply voltages are distorted and unbalanced (Fig. 4).

$$v_{i1}(t) = 1.3V_i \sin(\omega_i t - \frac{5\pi}{4}) + 0.25V_i \sin(2\omega_i t)$$
$$v_{i2}(t) = V_i \sin(\omega_i t + \frac{\pi}{3}) + 0.15V_i \sin(3\omega_i t) \quad (6)$$
$$v_{i3}(t) = 1.2V_i \sin(\omega_i t - \frac{\pi}{2}) + 0.2V_i \sin(5\omega_i t)$$

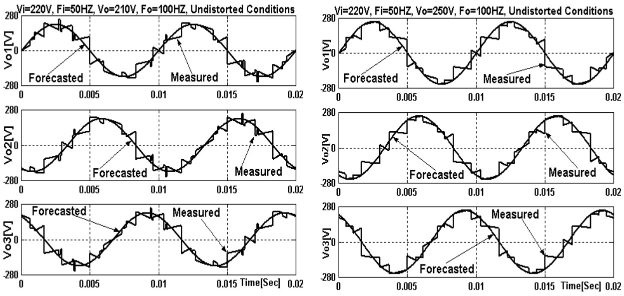


**Figure 3.** The Waveforms of output voltages under undistorted conditions (Left Column $V_o = 210^V$ , $f_o = 100^{HZ}$ and Right Column $V_o = 250^V$ , $f_o = 100^{HZ}$

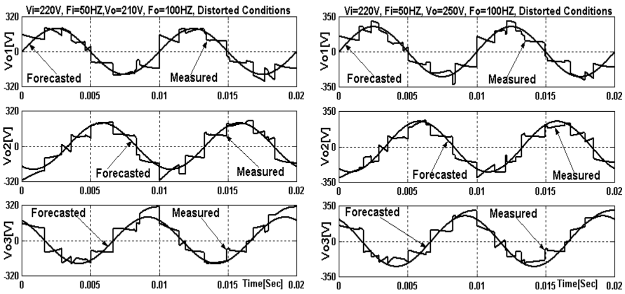


**Figure 4.** The Waveforms of output voltages under distorted conditions (Left Column $V_o = 210^V$ , $f_o = 100^{HZ}$ and Right Column $V_o = 250^V$ , $f_o = 100^{HZ}$

Table (II) shows **THD** of the output voltages, under undistorted and distorted conditions.

**TABLE II.** The **THD** of the output voltages under undistorted and distorted conditions

| | UNDISTORTED | DISTORTED |
|---|---|---|
| $V_o$ | 7.65% | 10.3% |

Let us summarize some results of this research:

- The peak value of the output voltages for circuit shown in Fig. 1 is equal with the peak value of input voltages.
- The peak value of the output voltages for circuit shown in Fig. 2 is limited to $\frac{2\sqrt{3}}{3} \approx 1.15$ of the input voltage.
- The output voltages contain fundamental and additional high order harmonics.
- The output currents contain high order harmonics. Because of the load of the converters is almost always a low pass filter (R-L), therefore the output currents contain loss high order harmonics than the output voltages.
- Simulation results show that this new circuit is able to produce the undistorted and balanced output voltages, even if the input supply voltages are distorted and unbalanced.
- Because of the less number of switching, these converters have very low power loss.

## IV. CONCLUSIONS

In this paper a new circuit for three-phase to three-phase AC/AC matrix converters is presented. This new circuit uses 10 bi-directional switches. Therefore the permitted states are increased to 45 combinations. The algorithm for controlling the matrix converter is based on **LMSE** method. The output voltage of the new circuit is increased to $\frac{2\sqrt{3}}{3} \approx 1.15$ of the input voltage, which was not available in the previous conventional matrix converters. The other advantages of this circuit are: low THD, simplified control algorithm and no limitations on frequency conversion. Because of the less number of switching, this converter has very low power loss. The most important and valuable characteristic of this new circuit is that even under unbalanced and significantly distorted input voltage waveforms, the output waveforms turn out to be reasonably clean and balanced. Therefore these converters can be used as an active filter.

## REFERENCES

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