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# Investigation of Three-Phase to Single-Phase Matrix Converter

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**Abstract:** A three-phase to single-phase matrix converter is investigated in the present paper. Based on the state matrix vector, a mathematical analysis of the converter is performed giving the relation between the sinusoidal line voltage (current) and the output voltage (current). The results of the investigation are confirmed using computer simulation of the converter by the program product Cadence PSpice

**Keywords:** Power Electronics, matrix converter, PSpice simulation.

## 1 Introduction

THE development of new methods and circuits for electrical energy conversion with improved characteristics is a basic way for increasing of the energy efficiency of power electronic converters with respect to mains network. The matrix converters realize a direct conversion of alternating current to alternating current [1,2]. Investigations exist for the electrical motor control, where the frequency of the output voltage is lower than the frequency of the mains network voltage [3,4]. The single-phase matrix converter is investigated in [5]. The aim of the present paper is the investigation of the three-phase to single-phase matrix converter. The frequency of the single-phase output voltage is higher than the frequency of the three-phase line input voltage. Based on the state matrix vector, a mathematical analysis of the converter is performed giving the relation between the sinusoidal line voltage (current) and the output voltage (current). The results of the investigation are confirmed using computer simulation of the converter by the program product *Cadence PSpice*.

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## 2 Mathematical Description

The circuit for mathematical analysis is presented in Fig. 1a. Bidirectional switches are used, realized as shown in Fig. 1b and controlled by a corresponding algorithm.

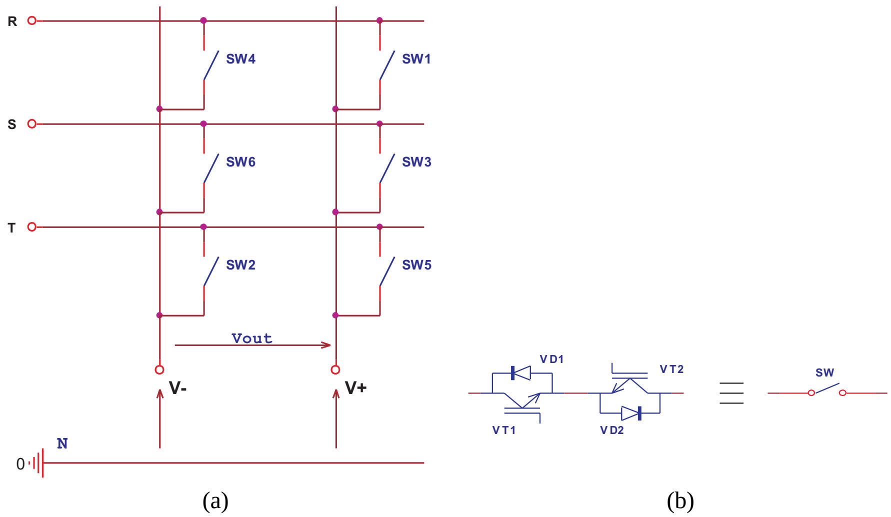


Fig. 1. Circuit for investigation. (a) Equivalent circuit. (b) Bidirectional power switch.

The converter is supplied directly by the mains network. The three-phase line input voltages are described by the following equations:

$$v_R(t) = V_m \sin \omega t \tag{1}$$

$$v_S(t) = V_m \sin(\omega t - \frac{2\pi}{3}) \tag{2}$$

$$v_T(t) = V_m \sin(\omega t + \frac{2\pi}{3}) \tag{3}$$

The state of the bidirectional switches - open or closed, can be described in matrix form in the following way:

$$[SW] = \begin{bmatrix} SW1 & SW3 & SW5 \\ SW4 & SW6 & SW2 \end{bmatrix} \tag{4}$$

The following dependencies are valid for the elements in (4):

$$\begin{aligned} SW1 &= \overline{SW4} \\ SW3 &= \overline{SW6} \\ SW5 &= \overline{SW2} \end{aligned} \tag{5}$$

The state of the power devices can be described in matrix form in the following way:

$$\begin{bmatrix} v_{+}(t) \\ v_{-}(t) \end{bmatrix} = \begin{bmatrix} SW1 & SW3 & SW5 \\ SW4 & SW6 & SW2 \end{bmatrix} \begin{bmatrix} v_R(t) \\ v_S(t) \\ v_T(t) \end{bmatrix} \tag{6}$$

The single-phase output voltage $v_{out}(t) = v_{+}(t) - v_{-}(t)$ has the form:

$$v_{out}(t) = (SW1 - SW4)v_R(t) + (SW3 - SW6)v_S(t) + (SW5 - SW2)v_T(t) \tag{7}$$

where:

$$SW1 - SW4 = A_1 \sin(\omega_S t) + \sum_{n=3,5...}^{\infty} A_n \sin(n\omega_S t) \tag{8}$$

$$SW3 - SW6 = A_1 \sin(\omega_S t - \frac{2\pi}{3}) + \sum_{n=3,5...}^{\infty} A_n \sin(n\omega_S t - \frac{2\pi}{3}) \tag{9}$$

$$SW5 - SW2 = A_1 \sin(\omega_S t + \frac{2\pi}{3}) + \sum_{n=3,5...}^{\infty} A_n \sin(n\omega_S t + \frac{2\pi}{3}) \tag{10}$$

The parameter $\omega_S$ in (8), (9) and (10) is the commutation frequency of the bidirectional switches. The coefficient $A_1$ is the magnitude of the commutation function. The first harmonic of the Fourier expansion of $A_1$ is of the value $\frac{4}{\pi}$ . The higher harmonics $A_n$ have significantly lower magnitudes and can be neglected. Replacing (8), (9) and (10) in (7), the following dependence is obtained for $v_{out}(t)$:

$$\begin{aligned} v_{out}(t) = &\frac{4}{\pi} V_m \sin\omega\, t \sin\omega_S t + \frac{4}{\pi} V_m \sin(\omega\, t - \frac{2\pi}{3}) \sin(\omega_S t - \frac{2\pi}{3}) \\ &+ \frac{4}{\pi} V_m \sin(\omega t + \frac{2\pi}{3}) \sin(\omega_S t + \frac{2\pi}{3}) \end{aligned} \tag{11}$$

The program product *CadencePSpice* is used for the investigation of the matrix converter. The voltages on the bidirectional switches are shown in Fig. 2. The single-phase output voltage $v_{out}(t)$ is presented in Fig. 3.

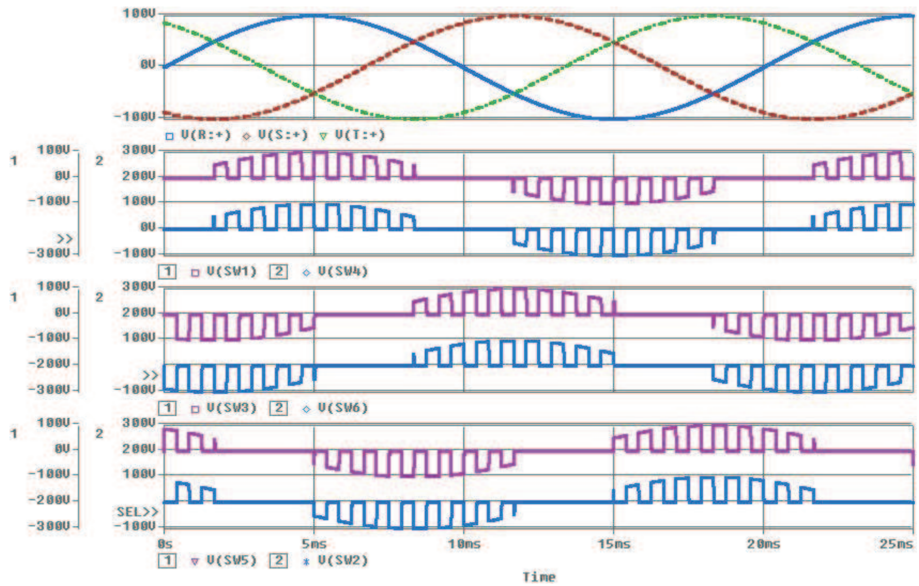


Fig. 2. The voltages on the bidirectional switches.

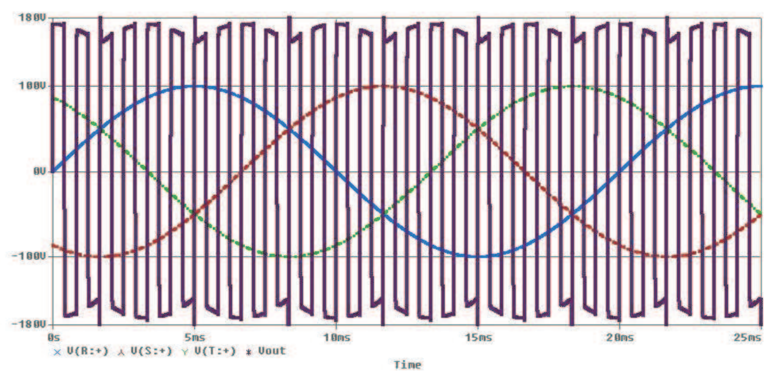


Fig. 3. The single-phase output voltage $v_{out}(t)$.

## 3 PSPICE Simulation of the Electrical Circuit of the Three-Phase to Single-Phase Matrix Converter

### 3.1 Basic electrical circuit

The electrical circuit of the matrix converter is shown in Fig. 4. The principle of operation is illustrated using equivalent circuits, corresponding to the respective intervals, in which the bidirectional switches act.

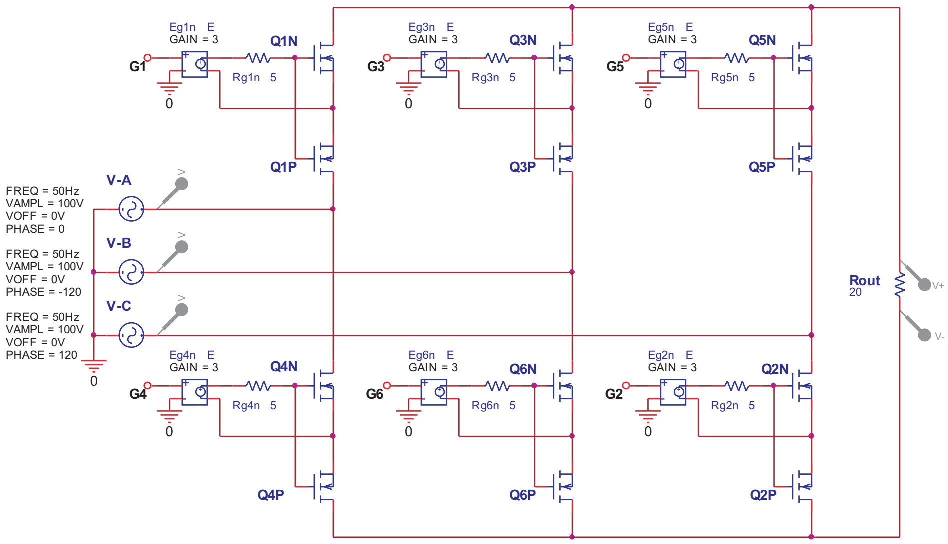


Fig. 4. Electrical circuit of the matrix converter.

In the interval, in which the most positive is the phase $A$, the switches SW1 and $SW4$ $(SW4 = \overline{SW1})$ are active. The duration of this interval corresponds to 1200. From 0° to 60° the switches SW6 and SW3 $(SW3 = \overline{SW6})$ , connected to the most negative phase $B$, are active. The switches SW5 and SW2 are non-active. This allows to simplify the electrical circuit as shown in Fig. 5.

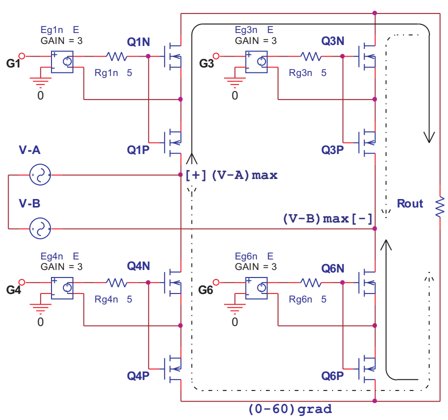


Fig. 5. Equivalent cicuit from 0° to 60°.

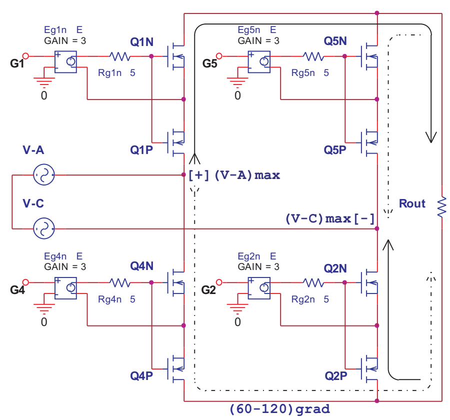


Fig. 6. Equivalent cicuit from 60° to 120°.

The matrix converter is reduced to a single-phase full bridge inverter. The positive half-wave of the voltage on the load resistor $R_{out}$ is obtained when $SW1$

and $SW6$ are switched on, and the negative half-wave - when $SW4$ and $SW3$ are switched on. From 60° to 120° the most negative is phase $C$. In this subinterval the active switches are $SW1$, $SW4$, $SW5$ and $SW2$ $(SW5 = \overline{SW2})$. The switches SW3 and SW6 are non-active. The equivalent circuit is shown in Fig. 6. The positive half-wave of the voltage on the load resistor $R_{out}$ is obtained when SW1 and SW2 are switched on, and the negative half-wave - when $SW4$ and SW5 are switched on. Similar considerations are valid for the next intervals when the most positive are phase $B$ or phase $C$.

The basic waveforms, illustrating the principle of operation of the matrix converters are shown in Fig. 7. They are obtained using the *CadencePSpice* simulator. The sequence of intervals can be seen, in which two couples of switches act simultaneously (connected to the most positive and to the most negative phase for each interval).

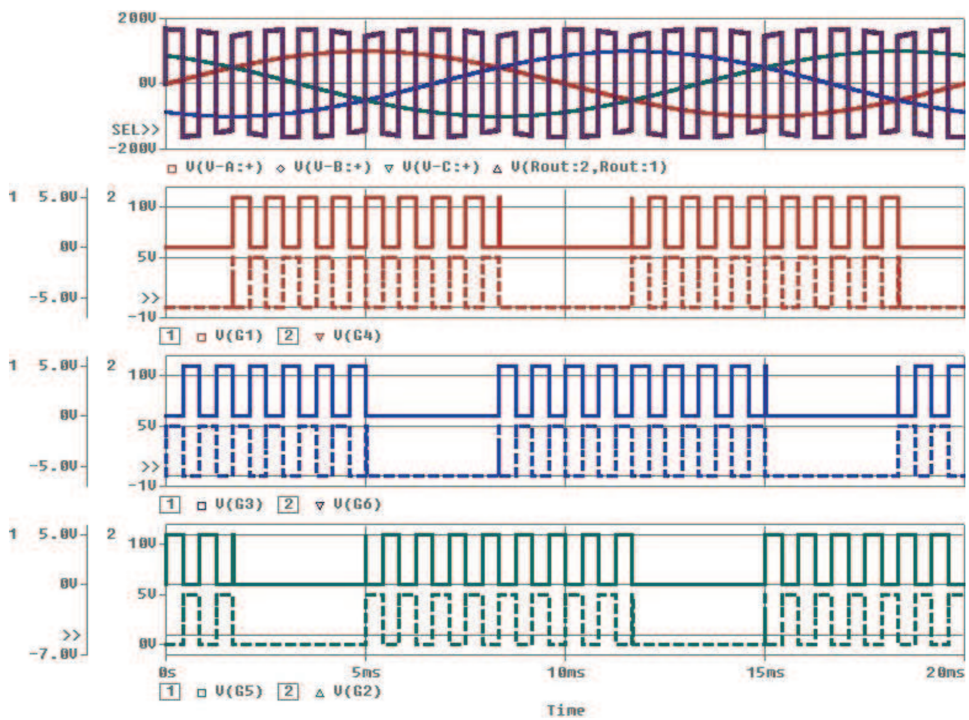


Fig. 7. The basic waveforms, illustrating the principe of operation of the matrix converter.

The obtained rectangular alternating voltage on the load resistor $R_{out}$ can be used for example to supply a resonant converter for induction heating [5, 6].

### 3.2 Basic control circuit

An example circuit of the system producing the basic control signal for the bidirectional switches, is shown in Fig. 8. The full bridge diode rectifier D1-D6 together with the optocoupler OC1-OC6, produce logical impulses Q1-Q6. They define the intervals, in which the phases $A, B$ and $C$ are the most positive or the most negative. The commutation impulses for the couples of switches $SW1 - SW4$, $SW3 - SW6$ and $SW5 - SW2$, are produced by three equal logical circuits. The logical circuit for the switches $SW1 - SW4$ is presented in Fig. 8. Q1=1 and Q4=0 when the phase $A$ is the most positive. In this case $(SW4 = \overline{SW1})$ , i.e. G1 advances in phase G4. The logical values Q1=0 and Q4=1 when the phase $A$ is the most negative. In this case $(SW1 = \overline{SW4})$, i.e. G4 advances in phase G1. It can be seen from the waveforms presented in Fig.7.

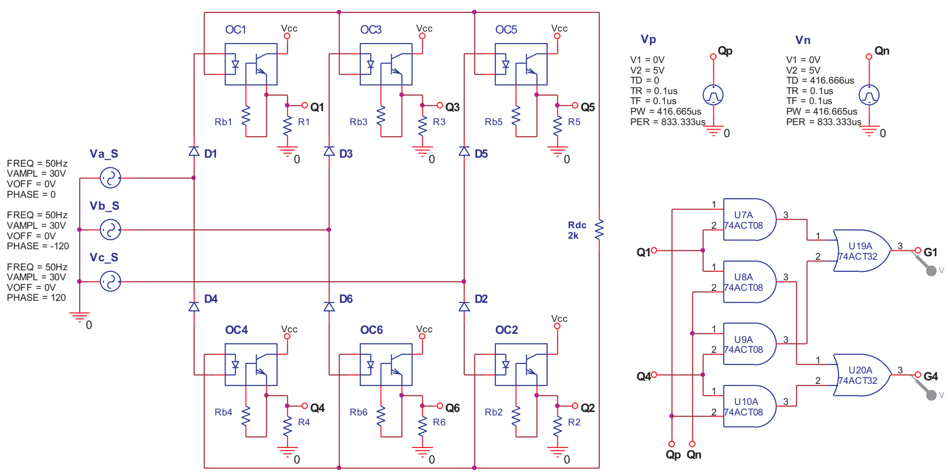


Fig. 8. Basic control circuit.

## 4 Conclusions

A three-phase to single-phase matrix converter has been investigated. Based on the state matrix vector, a mathematical analysis of the converter is performed giving the relation between the sinusoidal line voltage (current) and the output voltage (current). Based on corresponding equivalent circuits, the principle of operation is considered and the control circuit is constructed. The matrix converter is simulated using the Cadence PSpice and the waveforms illustrating the principle of operation, are obtained.

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