Control Systems with Pulse Width Modulation in Matrix Converters

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Abstract. In this article, the matrix frequency converter for the system of the frequency control of the electric drive is considered. Algorithms of formation of an output signal on the basis of pulse width modulation were developed for the quantitative analysis of quality of an output signal on the basis of mathematical models. On the basis of simulation models of an output signal, assessment of quality of this signal was carried out. The analysis of harmonic composition of the voltage output received on the basis of pulse width modulation was made for the purpose of determination of opportunities of the control system for improving harmonic composition. The result of such analysis led to the fact that the device formation of switching functions of the control system on the basis of PWM does not lead to a distortion reduction of a harmonic of the control signal, and leads to offset of harmonic in the field of frequencies, the multiple relatively carrier frequency.

1. Introduction

Now the problem of creation of energy efficient asynchronous electric drives is connected to a problem of synthesis of voltage sine wave voltage of the system of the frequency control of the electric drive according to the required value of such quality factor as a coefficient of harmonics.

Nonharmonics of system voltage output of the frequency control of the electric drive lead to origin of the higher harmonics. At the same time, higher harmonics of the reverse sequence create the brake moment of the asynchronous engine. The higher harmonics of a direct sequence are the useful moment of the engine, but harmonics of the zero sequence create the pulsating field.

As a result, higher harmonics of system voltage output of the frequency control lead to losses of the electric power in the asynchronous engine. There is overheating of the asynchronous engine, the useful moment decreases and there are essential noises in an electrical network.

Therefore improving the quality of system voltage output of the frequency control of the electric drive by reduction of the coefficient of harmonics is the relevant task.

2. Control System

A conventional matrix converter (see Fig. 1) consists of nine bilateral switches, which enables each of its inputs and outputs to connect with each other at any time. The input terminals of the device are linked to a three-phase power line; the output terminals are connected to a three-phase current load, for instance, an asynchronous motor [1].
This scheme is used in such matrix converters as FSDrive-MX1S (Yaskawa, Japan), which is implemented when low-rpm operation or fast response to braking are required [2]. Russian matrix converters with switches based on semiconductor IGBTs, providing pulse width modulation (PWM), are manufactured by Drive Technique R&D Center (Chelyabinsk, Russia).

To eliminate harmonic content—similarly to autonomous voltage source inverters (VSI) — three-phase voltage and frequency at the output of a matrix converter can be controlled by the scalar method at high carrier frequency by PWM [2].

The switching is performed when a reference signal and a three-phase modulating signal are equal.

Application of PWM to matrix converters on the basis of control signal comparison with reference signal can be exemplified by the method of scalar control of a three-phase matrix converter [3].

A general scheme of power and control sections of a matrix converter is depicted in Fig. 2.

The power section of the device consists of a 3x3 matrix (1) including transistor switches V1–V9 with bilateral conductivity, which horizontal buses are connected to phases $e_a$, $e_b$, $e_c$ of the supply line, while the vertical buses are connected to the circuits of the three-phase load (2). The control section (3) contains a unit (4), which inputs feed three-phase reference signal $x_a(t)$, $x_b(t)$, $x_c(t)$ having a harmonic form. The system
also includes distributing modulator unit (5) that at its inputs compares a modulating signal and a reference \( x_{rv} \) signal coming from unit (6), which is typical of scalar control systems. This generates nine sequences of control pulses at the output of unit (5) for switches comprising matrix (1).

Figure 3 represents the diagrams of three-phase sinusoidal PWM.

The principle of sine PWM control is in the implementation of sine voltage \((x_a, x_b, x_c)\) for controlling each output. The sine voltage period corresponds to required reference frequency of output voltage. The reference voltage \((x_{rv})\) is overlaid on three sine voltages.

In the case, reference voltage \(x_{rv}\) crosses sine voltage \(x_a\) and the sine voltage in magnitude exceeds sawtooth voltage \(|x_a| - x_{rv} > 0\), switches V1, V4 and V7 that commutate corresponding phases of input voltage with the load (depending on the zone active at a given period of time) open. If reference voltage \(x_{rv}\) crosses sine voltage \(x_a\) and the sine voltage goes below sawtooth voltage \(|x_a| - x_{rv} < 0\), then the switch that was closed until then opens, and the voltage applied to the load becomes zero. As a result, the output voltage of the matrix converter has the form depicted in Figure 4 [4].

\[ U_{out} \]

\[ U_{out} \]
for reference signal frequency $x_r$ of 2 kHz: $a$ – half-period output voltage; $b$ – full-period output voltage

Output voltage (Figure 4) has the frequency of 50 Hz and was obtained for reference signal frequency $x_r$ of 2 kHz.

The harmonic content of the matrix converter output voltage obtained by PWM was analysed in Mathcad 14.0 [5, 6].

Figure 5 demonstrates the plots of modulating function $M(t) = \sin(\omega t)$, where $\omega$ is the frequency of output voltage (on the plot it is equal to 314.15 deg/s, which corresponds to 50 Hz) and synchronizing sawtooth function $f(t) = \arcsin(\sin(\omega_c t))$, where $\omega_c$ is the synchronization frequency of 2 kHz.

Figure 5. Plots of modulating function $M(t) = \sin(\omega t)$ and synchronizing sawtooth function $f(t) = \arcsin(\sin(\omega_c t))$

Figure 6 shows the spectrum of output voltage harmonics, where $A$ is the amplitude of the harmonics and $f$ is the frequency of the harmonics (Hz).
The dependence of Total Harmonic Distortion (THDr) on output voltage frequency $f$ is shown in Figure 7.

3. Results and Discussion
   1. The device for generation of switching functions of the PWM-based matrix converter control system leads to the shift of harmonics to regions that are a factor of carrier frequency rather than to a decrease in sine voltage distortions. THDr takes on values $64.9\% \geq THDr \geq 63.5\%$ for the following frequency range: $50 \text{ Hz} \geq v > 5 \text{ Hz}$.
   2. PWM introduces additional distortions of output voltage and, hence, causes the increase in THDr. For instance, THDr takes on values $51.1\% \geq THDr \geq 39.1\%$ for the following frequency range: $50 \text{ Hz} \geq v > 5 \text{ Hz}$ without PWM.

4. Conclusions
   Thus, the study results allow the following conclusions to be made.
   PWM does not provide the quality of output voltage as per GOST 32144-2013, which disables it for output voltage generation.
Thus, PWM can only be applied as an additional method for shifting certain harmonics to a high-frequency region.

The following weak points of devices that form switching functions of matrix converter control systems with PWM were revealed:

- presence of noise at switching frequency and their recurrence;
- high-frequency harmonics generate radio interference and induce distortions in electric devices, cause rapid wear of insulation and interruption of power supply to consumers;
- increased frequency of carrier signal shifts higher harmonics to a region of higher frequencies rather than eliminating them from the output voltage spectrum.

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