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Full Length Research Paper

Simulation and analysis of the harmonic behavior of matrix converters as compared with conventional converters

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The type of the electronic converter used in a set based on power electronics has an important role in the performance of the set. For example, the quality of the converter in the drive system of a motor has a direct influence on the performance of the motor. In recent studies, the use of matrix converters in the drive system of motors has yielded very desirable results. One of the most important positive aspects of these converters, which has not been independently and thoroughly studied yet, is the quality of the signal produced with regard to the harmonic content. This is a very important subject in cases such as the drive system of electric motors, and if it is not taken into account in the design, serious problems will result. Due to the importance of the subject mentioned, this positive aspect of the matrix converters is independently studied in this article. To this end, the quality of the output signal of a two-phase matrix converter is studied and comparisons are made to clarify the relative superiority of this converter over conventional ones.

Key words: Matrix converter, total harmonic distortiontotal (THD), conventional converter, harmonic behavior.

INTRODUCTION

Matrix converters were first introduced in 1980 by Ventorini (1980). In recent years, great interest has been shown in these converters for direct conversions of ac/dc (Holmes and Lipo, 1992), dc/as (Holmes, 1990) and especially ac/ac (Ventorini, 1980; Neft and Schauder, 1983) because, as an example, ac/ac converters can produce a sine signal from a sine signal without needing a dc link (Sangshin and Hamid, 2005). Matrix converters come both as two-phase converters in two-leg and three-leg constructs and as three-phase converters. The two-phase type has applications in feeding loads such as symmetrical two- phase induction motors, and the three-phase type in drive systems of induction motors (Kyo-Beum and Blaabjerg, 2006; Altun and Sunter, 2003) and synchronous motors (Tewolde and Das, 2006). To obtain an independent unit with a low volume consisting of a motor and a drive system, the use of a compact frequency converter is desirable (Lixiang and Thomas, 2001; Stefan et al., 2005). To achieve this goal, the use of matrix converters, as compared to the conventional ones with dc links, has the following advantages:

i) Very large and sensitive- to - heat capacitors such as electrolytic capacitors are not needed (Lixiang and Thomas, 2001; Stefan et al., 2005; Zuckerberger et al., 1996).
ii) Matrix converters are basically bidirectional and four-quarter performance is easily possible with suitable control of switching. Furthermore, energy is easily returned to the network because the power switches used are

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bidirectional and no braking units (for returning energy) such as braking choppers or resistor braking are required (Lixiang and Thomas, 2001; Stefan et al., 2005).

iii) In these converters, both the output voltage and the input current are sinusoidal and contain only harmonics close to the switching frequency (Holmes and Lipo, 1992; Lixiang and Thomas, 2001). Furthermore, in these converters, a sinusoidal current with a small harmonic component is established from the network by connecting a rather small lc filter on the line side. In a conventional converter, this is achieved by replacing the uncontrolled rectifier on the line side with an inverter. In the conventional converter, a greater inductance is needed in the filter. These requirements make it impossible to use a small and cheap converter (Stefan et al., 2005).

iv) Matrix converters have a single input power coefficient (Zuckerberger et al., 1996).

Of course, in some respects, matrix converters can be considered inflexible as compared to the conventional converters. They require more electronic equipment than conventional converters do (Wheeler et al., 2005). Due to the existence of a direct connection between the output and the input , any disturbance in the input will directly affect the output (Milton et al., 2006). Moreover, switching logic in matrix converters is more complex than that of the conventional ones (Lixiang and Thomas, 2001). Nevertheless, matrix converters continue to be of interest because they have solved the important and basic negative aspects of conventional converters such as the harmonic problems; and so far, extensive and effective research has been carried out to eliminate the shortcomings of matrix converters, especially the complexity of their switching logic. Since the harmonic issue in electronic converters, and hence in the quality of the motor drive- systems, is very important, and because this topic has not been previously studied independently as a strong point in matrix converters, in this article this statement is independently dealt with and we can evaluate that if the mentioned structure can be a better choice than conventional one; on the other hand why using the proposed structure with its special complexity is logical from technical point of view. For this purpose, a two-phase matrix converter is studied. After introducing the structure of this converter and its simulation in a matrix form, the converter is simulated with the help of the Matlab software, and the quality of the output signal is studied. The outputs of the two converters are compared with respect to harmonics in order to clarify the relative their relative superiority to each other.

OPERATION OF TWO-PHASE MATRIX CONVERTERS

Two-phase matrix converters are not as widely used as three- phase ones. Nevertheless, the two-phase converters have important applications such as feeding two-phase loads like two-phase inductive motors and single-phase conventional machines with main and auxiliary winding (Sangshin and Toliyat, 2006). Two-phase matrix converters are generally classified into the two types of two-leg and three-leg converters. These two structures can be seen in Figure 1. Since matrix converters lack dc link capacitors, the neutral point of the load in the structure of the two-leg type is directly fed back to the neutral point of the feeding (Sangshin and Toliyat, 2006). However, as can be seen, in the structure of the three-leg type, the neutral point is connected to another series of switches which form the third leg of the converter. The advantage of the three-leg type over the two-leg type is in its better harmonic behavior (Sangshin and Hamid, 2005).

MATHEMATICAL ANALYSIS OF THE TWO-LEG TWO-PHASE MATRIX CONVERTER

The two-leg two-phase matrix converter includes six bidirectional switches. There are three switches in each leg and 'U' as can be seen in the figure. The output of each leg is connected to a phase of load. The modulation technique of this converter is in fact the control of the guidance time of the switches, so that the shape of the output wave identifies the reference signal. On the basis of this performance, the input and the output voltages of the converter can be related to each other by a matrix strategy, that is:

$$\left[v_0(t)\right] = \left[M(t)\right] \cdot \left[v_i(t)\right] = \begin{bmatrix} m_{11}(t) & m_{12}(t) & m_{13}(t) \\ m_{21}(t) & m_{22}(t) & m_{23}(t) \end{bmatrix} \cdot \left[v_{i(t)}\right] \tag{1}$$

The M (t) matrix is the modulation matrix, and its elements are functions that determine the guidance time of the switches. If the input voltage is as follows:

$$\left[v_i(t)\right] = \begin{bmatrix} v_{i1}(t) \\ v_{i2}(t) \\ v_{i3}(t) \end{bmatrix} = \begin{bmatrix} V_{im}\cos(\omega_i t) \\ V_{im}\cos(\omega_i t - 2\pi/3) \\ V_{im}\cos(\omega_i t + 2\pi/3) \end{bmatrix} \tag{2}$$

The output voltage will be:

$$\left[v_0(t)\right] = \begin{bmatrix} v_{o1}(t) \\ v_{o2}(t) \end{bmatrix} = \begin{bmatrix} V_{om1}\cos(\omega_o t + \varphi_o) \\ V_{om2}\cos(\omega_o t - \pi/2 + \varphi_o) \end{bmatrix} \tag{3}$$

It must be mentioned that one switch in each leg should always be in the 'on' position so that short circuits are prevented. This will require the following conditions:

$$0 \le m_{ij}(t) \le 1 \tag{4}$$

$$\sum_{j=1}^{3} m_{ij}(t) = 1 \tag{5}$$

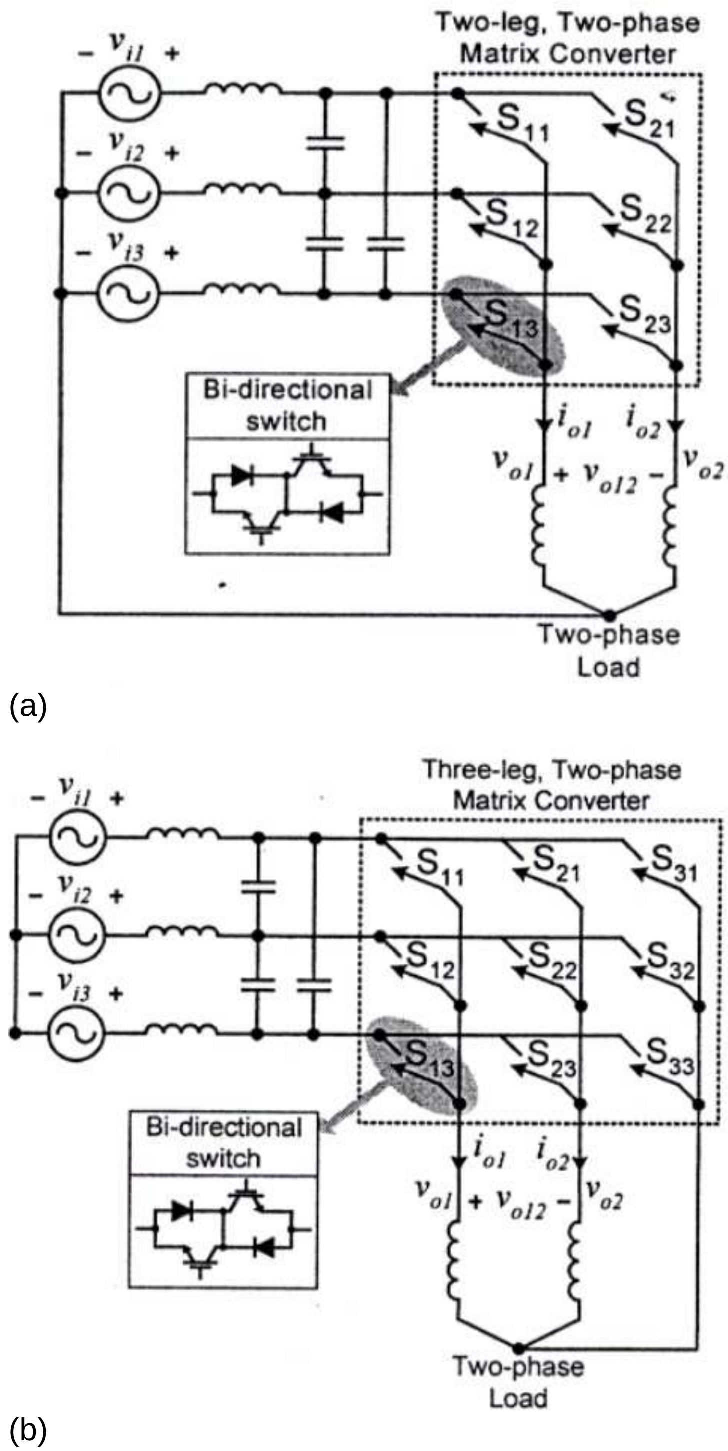

Figure 1. Schematic of two-phase matrix converter: (a) two-leg and (b) three-leg.

In a simple explanation it can be said that at a moment one phase move to output with defined time as "m" and certain switching time (T). This action takes place for every two phase. For more clarity the short part of mechanism has been mentioned here:

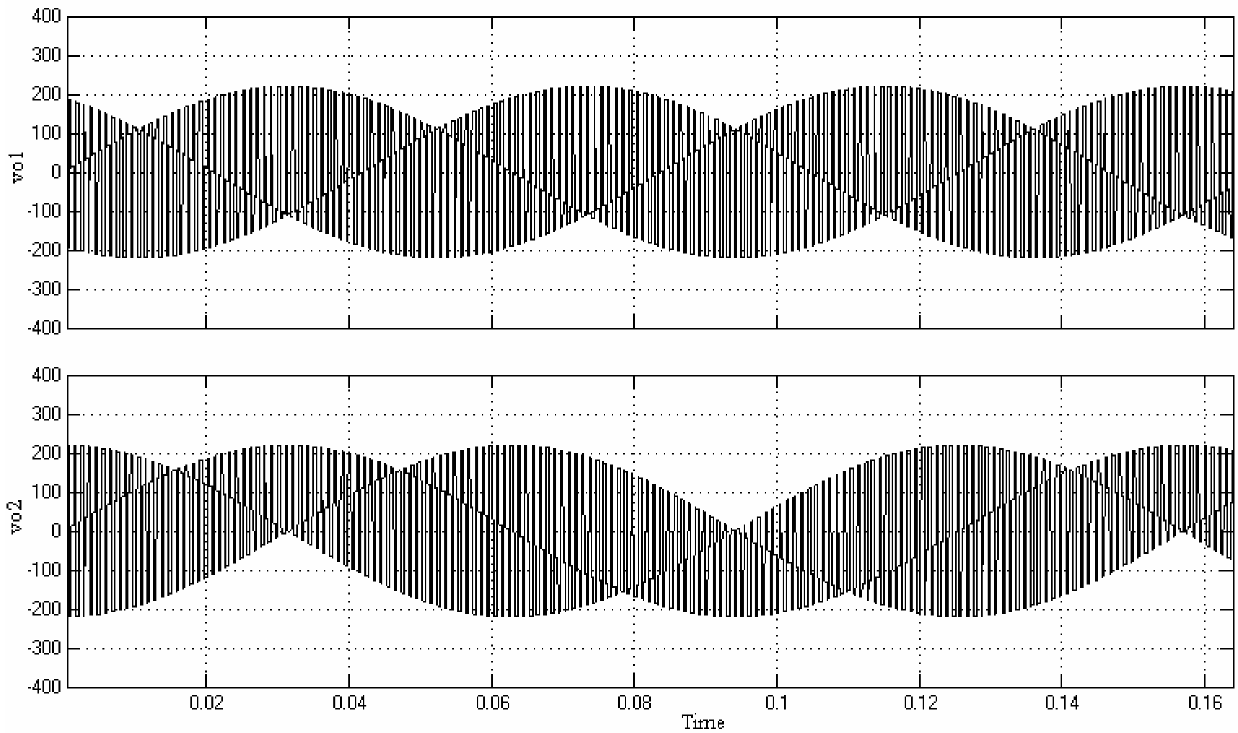

Figure 2. The output voltage of two-leg two-stage matrix converter.

```
While tt<1000*T;
If t<(m11*T) + tt and t>tt;
va = 220*sin(50*t)
end
if t<((m11+m12)*T) + tt and t>(m11*T) + tt;
va = 220*sin(50*t-2*pi/3);
end
```

and …

To carry out the harmonic assessment of the signal, which will be discussed in the subsequent study, the THD signal, which is determined from the following relationship, is used:

$$THD = \sqrt{{v_{ref}}/{v_{1ref}} - 1}$$

Where V_{ref} is the effective value of the main signal and V_{Iref} is the effective value of the main component of the signal. According to the aforementioned relationship, the higher the value of the THD, the less its harmonic contamination will be.

SIMULATION RESULTS

In order to better study matrix converters and to understand their positive aspects as compared with other converters, here, a two-leg two-phase matrix converter is compared with an inverter of the voltage source with respect to the harmonic contamination of the output signal. In this experiment, a two-leg two-phase matrix converter and an inverter type conventional converter are simulated using the Matlab/Simulink software. The frequency and the amplitude of the input signal are 50 Hz and 220 V, respectively, and the switching frequency is 1 kHz. In Figure 2, the shape of the output voltage wave is seen. The effective value and the THD of the vol signal are shown in Figures 3 and 4, respectively. The same experiment using the same switching frequency (1 kHz) was conducted on an inverter type conventional converter with the PWM logic of switching. The shape of the output wave, the RMS and the THD, are shown in Figures 5, 6, and 7, respectively. It can be seen that in the matrix converter state, the value of THD is about 0.05, while in the inverter state value is about 0.7. It is clear that less THD means less harmonic pollution. On the other hand the waveform is closer to main the component. Moreover, the effective value of the main component of the output signal is 155.56 in both states, while the effective value of the output is 155.42 for the matrix state and 186.73 for the inverter state. Therefore, it can be inferred that the matrix converter has a more suitable harmonic behavior than the inverter converter. In other words, the matrix converter produces a higher

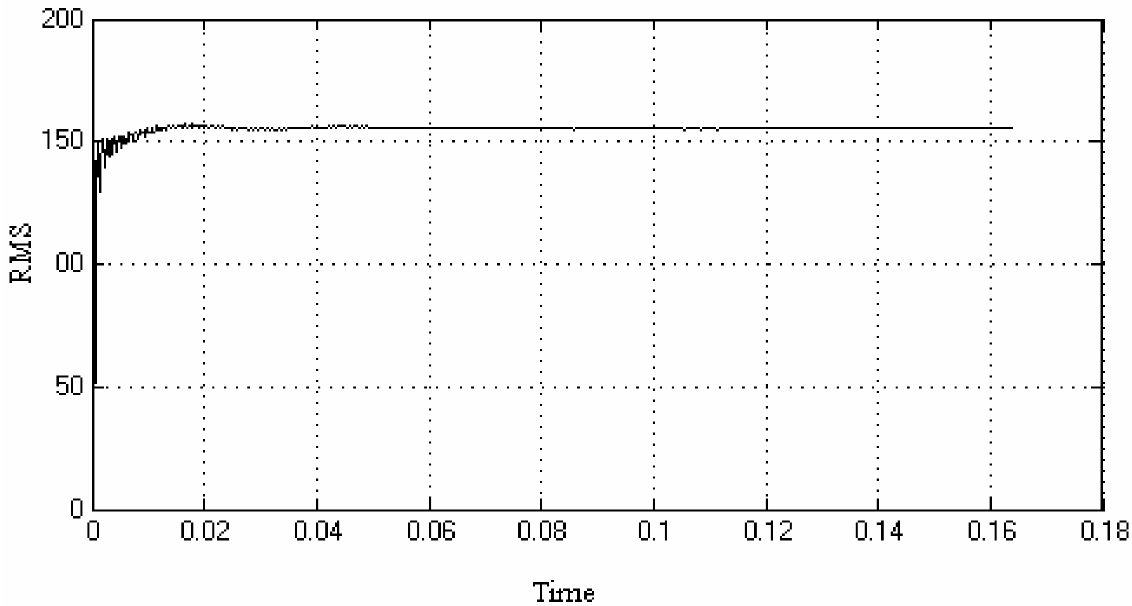

Figure 3. The RMS of the vol signal.

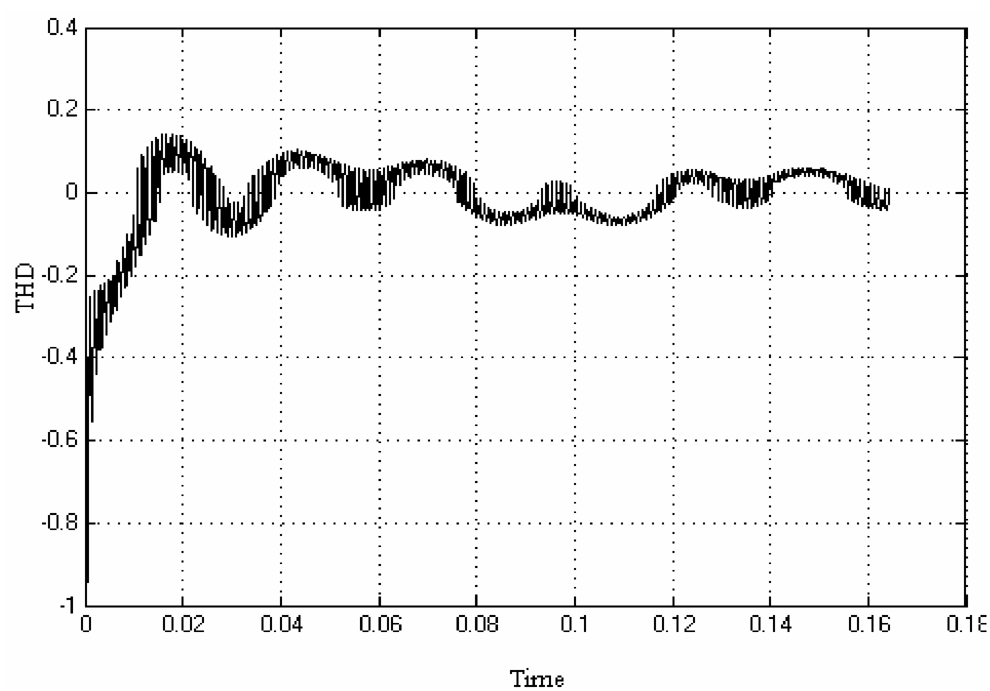

Figure 4. THD of the vo 1 signal (F = 1 kHz).

quality signal as far as harmonic to load is concerned. A similar simulation with a switching frequency of 300 Hz and the same conditions of the previous state was carried out, the THD diagrams of the output voltages of which are shown in Figures 8 and 9 for the matrix and inverter converter states, respectively. As can be seen in

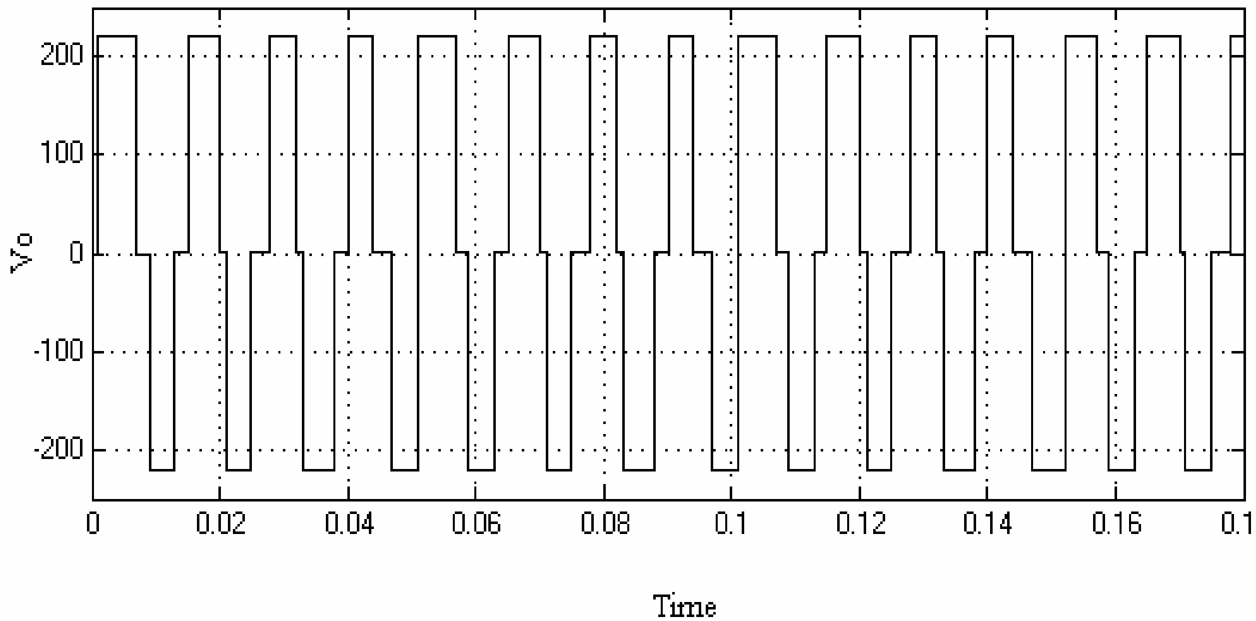

Figure 5. The shape of the output voltage of the inverter.

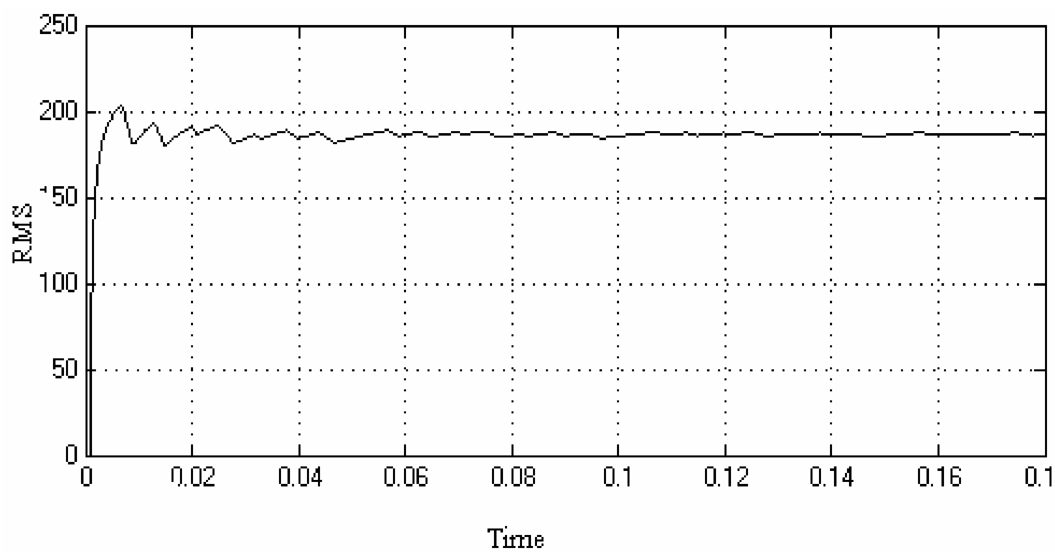

Figure 6. The RMS of the output voltage of the inverter.

the diagrams, in the matrix converter state the THD has oscillated around zero, while in the inverter state its value is about 0.42, which again confirms the result of the previous experiment.

If we look at how the values change with a reduction in the switching frequency, it is clear that the THD value has decreased in both states. Therefore, it can be concluded that with a reduction in the switching frequency, the harmonic contamination decreases. In Table 1, the results of the simulation experiments are shown.

Conclusions

In this article, the features of matrix converters and a summary of the matrix analysis of the two-leg two-phase type were studied. Using suitable simulations, it was concluded that matrix converters have more suitable

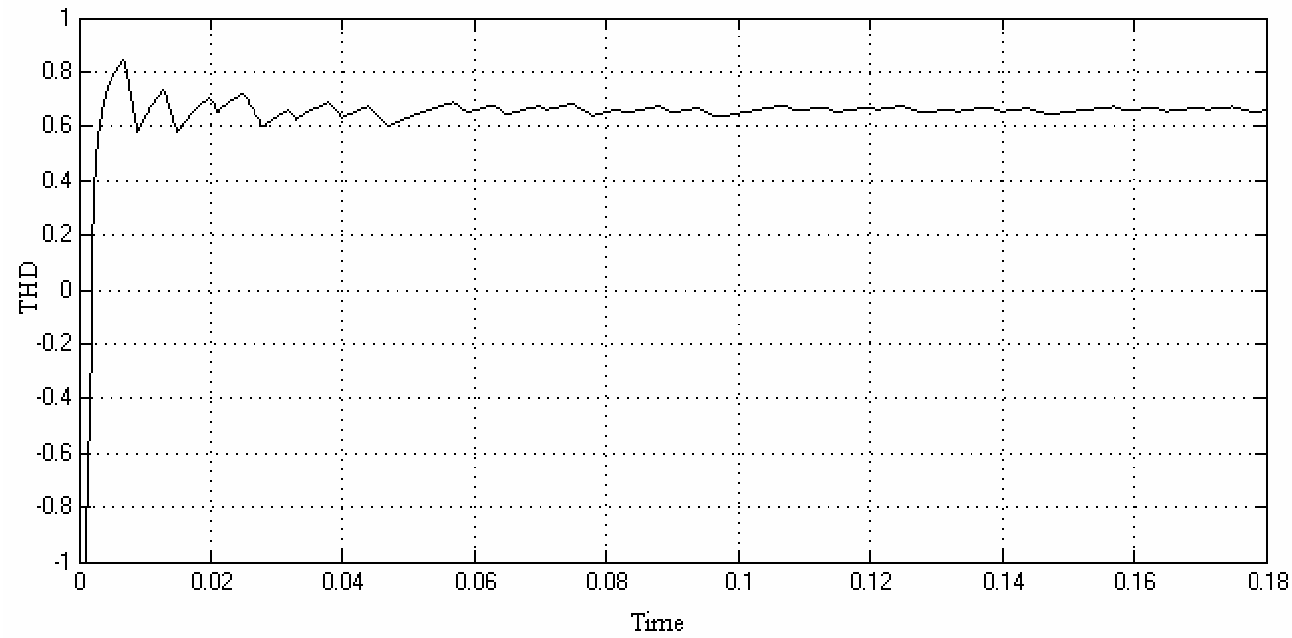

Figure 7. The THD of the output voltage of the inverter (F = 1 kHz).

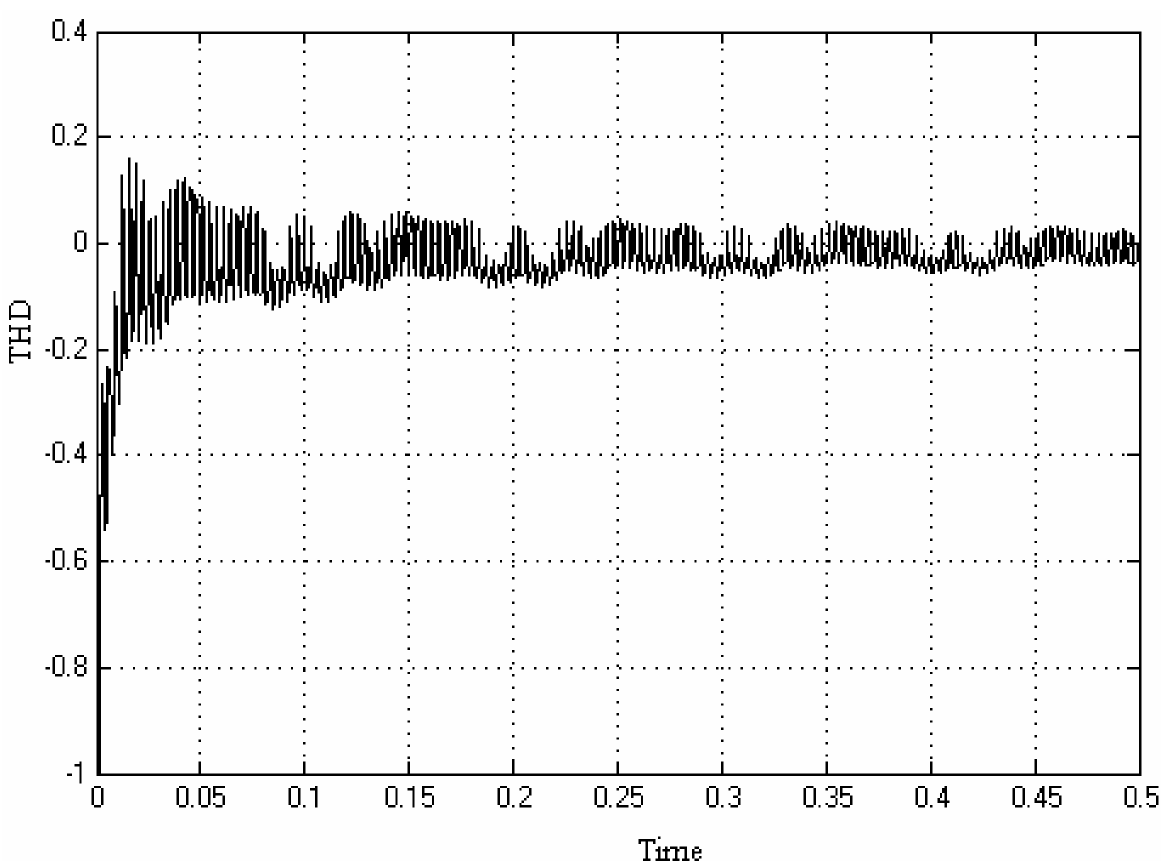

Figure 8. The THD of the vol voltage of the matrix converter (F = 300 Hz).

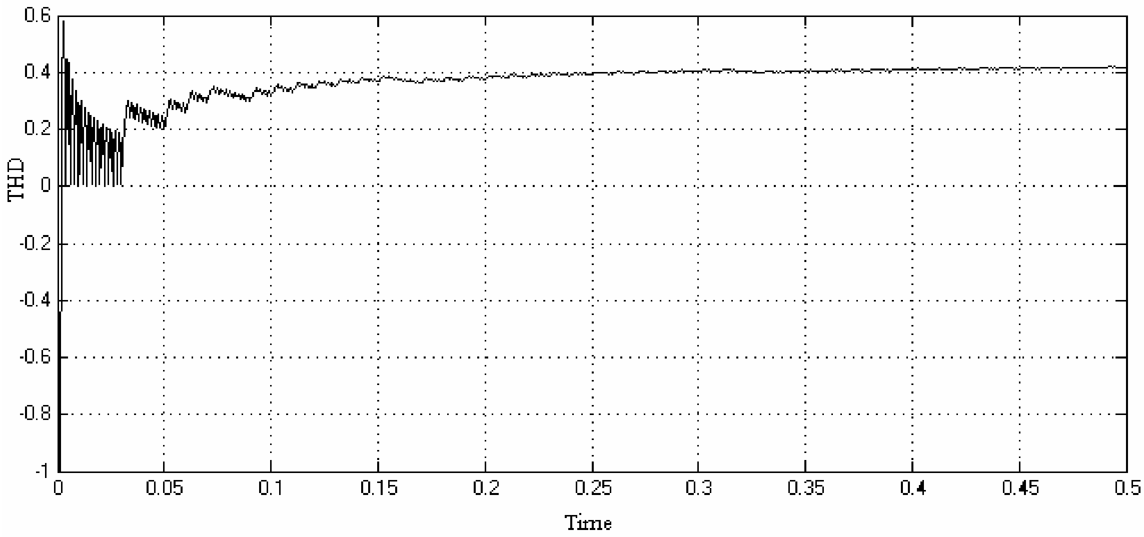

Figure 9. The THD of the output voltage of the inverter (F = 300 Hz).

Table 1. Numerical comparison of the values of the THD and the RMS of the two types of converters studied.

The kind of convertor	RMS (F = 1 kHz); Vrms 1 = 155.66	THD (F = 1 kHz)	THD (F = 300 Hz)
Matrix	155.42	0.05	0
Conventional	186.73	0.7	0.42

$V_{rms\ I}$: The effective value of the main component.

harmonic behavior than inverter converters. It means that these kind of converters can be more secure in practical usage especially motor-drive systems and it seams that serious problem of conventional electronics drives is going to be solved and it can be evaluated that complexity of proposed scheme is reasonable but this point can be a separate research in a future.

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