# PREDICTION OF CONDUCTED INTERFERENCE (EMI) AND TOTAL EMC IN MATRIX CONVERTERS

*T. Kapusta*

Department of electronics and mechatronics, Faculty of Electrical Engineering, University of Žilina, Univerzitna 8215/1, 010 26 Žilina, Slovakia, kapusta.tomas86@gmail.com

**Abstract**

**This paper deals about matrix converters compatibility especially electromagnetic interference and about electromagnetic compatibility as a criterium forusing electronic devices on international market. EMC is relatively new area of electrical engineering which has an important role in power electronic systems or industry bud also in medicine e.g. It is belong to everyday life. Matlab simulation analysis of electrical processes going into matrix converter together with possible research of electromagnetic interference, electromagnetic wawes in Comsol multiphysics is effective tool for engineers is stage of design.**

## 1 Matrix converter

Matrix converters looking for use in regulated drives which seeks to integrate the inverter into the motor terminal box. An arbitrary number of input lines can be connected to an arbitrary number of output lines directly using bidirectional semiconductor switches, as shown in Fig. 1.

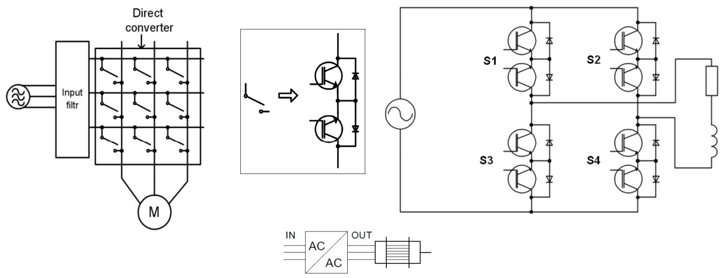


Fig. 1 Block diagram of the matrix converter

Matrix converters come within the same category as cycloconverters. It is a category of direct frequency converters. For these converters there is a direct conversion of input voltage (current) with a given frequency the output voltage (current) of another frequency as input, usually smaller. In cycloconverters the ratio of frequencies (input/output) is less than 0,5. with matrix converter is this ratio same or more than 0,5. Due to the higher modulation frequency is reduced impact of harmonic current on power line. It is are self-commutated inverter. Time course of the output voltage on each output is determined from the best way functions of the switch in the matrix.

Used switches are bidirectional. There are several options as possible to construct a two-way (birection) switch:

- involvement of one switch located in the diode bridge. Main advantages of such involvement is that there should be only one switch and therefore only one driver. Switching losses are tax outflows on the diode and one switch (Fig. 2,a)

- anti serial connection of two separate switching elements (collectively emittors or collectors)(Fig. 2, b). Circuit requires two switching elements and two semiconductor diodes. Provides the possibility of independent current flow through the elements and hence the possibility for different types of switching. Research and optimization of the switching process is also available solution to eliminate interference in a matrix converters.

- Bidirection switch on the Fig. 3,c is created by integrating the structure of blocking diodes in the semiconductor switch. Also by connecting antiparallel-series connection of two switches and two diodes.

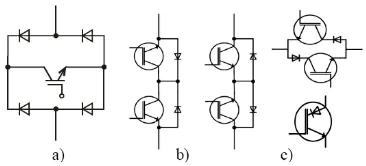


Fig. 2 Bidirectional switches used in matrix converter

To control of matrix converter it is possible to use two control techniques. The first starts from the equations (1) and the second is based on the PWM control, it is a sine-pulse PWM. For time of switching is equation (2), where $T_V$ is the switching time of the individual switches and the switching period $T_s$ [1].

$$v_i(t) = \sqrt{2}V_i \sin(\omega_i t) \qquad v_o(t) = \sqrt{2}V_o \sin(\omega_o t) \tag{1}$$

$$v_o = \frac{T_V}{T_s} v_i \qquad T_V = \frac{1}{2}\left(\frac{v_o T_s}{v_i} - T_s\right) \tag{2}$$

Probably the biggest drawback of matrix converters is the complexity of control. Complex matrix converter topology provides more options for the management of control and therefore more options for its how switching semiconductor devices are commutated. On the other hand, has many great advantages. In its work does not require large and expensive filters (capacitor and inductor). In terms of EMI is a significant fact that the inverter has a minimum sampling current harmonics and power factor approaching 1.

# 2 EMC of matrix converters

Electrical and electronic equipment is not applicable in real life unless they satisfy the requirements of the EMC. Two fundamental criteria state that:

- device must not affect himself. Prevent self-degradation is priority number one,

- but shall not be affected especially around the devices (radiating, inductive coupling e.g through air) and galvanic coupling (galvanic coupling, capacitance coupling).

- Further dividing of EMC is for compatibility and susceptibility depending on it if the device is source (transmitter) of interference, or receiver of interference.

## 2.1 Galvanic coupling and EMI of matrix converter

Galvanic coupling is essentially composed of arbitrary impedances in converter. It is usually a serial connection resistance R and inductance L. The most commonly occurs in the galvanic coupling and grounding power lines, which also causes interference. Galvanic coupling is always present everywhere. Is necessary to minimize its impact. Conducted interference can be divided into interference:

- Differential Mode interferences (DM),

- Common Mode interferences (CM).

The DM currents are equal in magnitude but opposite in direction in the two wires, while the CM currents are equal in magnitude and have the same direction in both wires. Common mode noise interference spreads the power lines approvingly and concluded a ground loop through the parasitic elements (e.g. between the capacity of the converter (PCB) and metal packaging of converter) (Fig. 3). DM interference is caused by the switching process and a way of commutation in switching converters. Suppose that with increasing frequency DM disturbance decline. Significant is the crossover frequency (several tens of MHz), where decrease impact of DM interference (Fig. 3). CM interference effect increases with increasing frequency vice versa. This is caused by parasitic elements occurring in real converters, cable management and linkages between the chassis and the various components of the converter.

## 3 Simulation analysis

In the simulation analysis I decided to audit the disturbance arising from the activities of the inverter and the commutation processes in different parts of the converter. In principle it is the DM interference. The research of CM interference is in simulation conditions very limited. Although it is possible to simulate a supposedly finished of a converter, but it is assumed that the estimate resulting interference would be highly inaccurate. And therefore be in the design phase will not dedicate. I am interested in simulation the impact of the commutation emissions and emission from activity of matrix converter.

Simulation analysis diagram consist of DC source (battery) forming part of the matrix converter from the input filter. Followed by an inverter block. The inverter operates with frekvecniou 10kHz and its output is rectangular (switched) voltage which is further fed to the input matrix converter. The matrix converter is controled using sine-pulse PWM. PWM generator uses a source of saw signal and references to establish the value of control signal. Control signal is further supplied to the switches. As the load is using a simple RL circuit (Fig 4). Simulation was made via the environment Matlab Simulink.

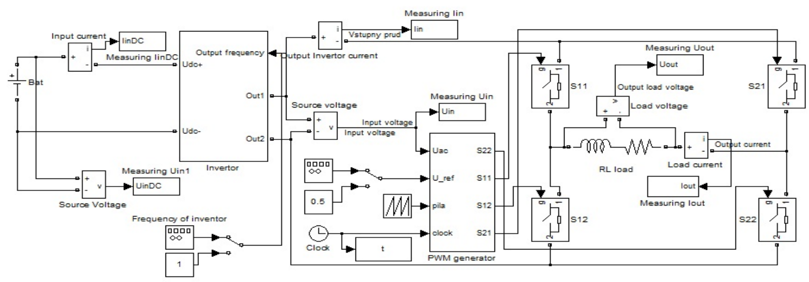


Fig.4 Simulation analysis diagram of matrix converter

Figure 5. shows the flow of disturbing currents in the converter. green line shows the flow of common mode interference and red line flow differential mode interference.

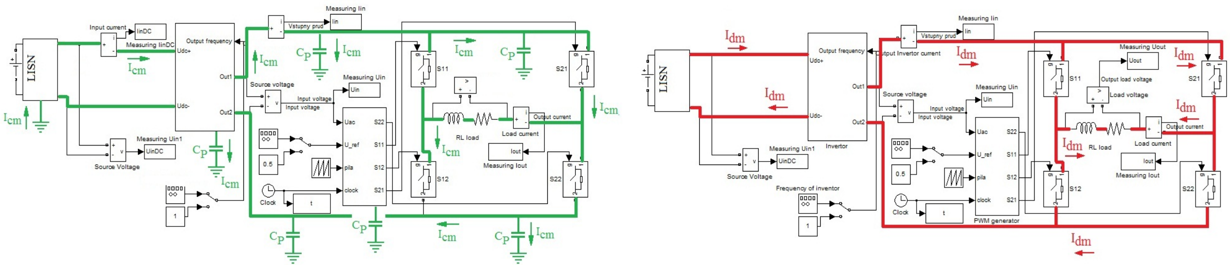


Fig. 5 Differential mode and common mode currents flow trought matrix converter

Matrix changer as much of this equipment is intended the power from mains. In Fig. 6 is converter from the mains through a rectifier, input filter to the matrix converter with artificial network (LISN).

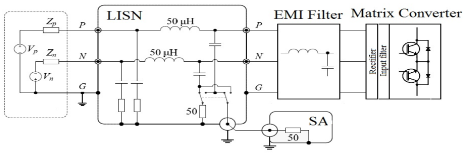


Fig. 6 Conection of LISN and matrix converter with EMI line filter

Equation (3) described the course of disturbing currents in the inverter. These currents may be decomposed into two auxiliary currents, which are referred to as the CM current $i_{cm}$ and the DM current $i_{dm}$. Then can be determined $i_{cm}$ and $i_{dm}$. Current $i_p$ flows through power cable and current $i_n$ flows through neutral cable. Ground current $i_g$ is sum of $i_p$ and $i_n$.

$$i_p = i_{cm} + i_{dm} \qquad i_{cm} = \frac{i_p + i_n}{2} \qquad i_g = i_p + i_n = 2i_{cm} \tag{3}$$
$$i_n = i_{cm} - i_{dm} \qquad i_{dm} = \frac{i_p - i_n}{2}$$

Curves of voltage at the load and current flowing through the load is in Fig. 8 with its details.

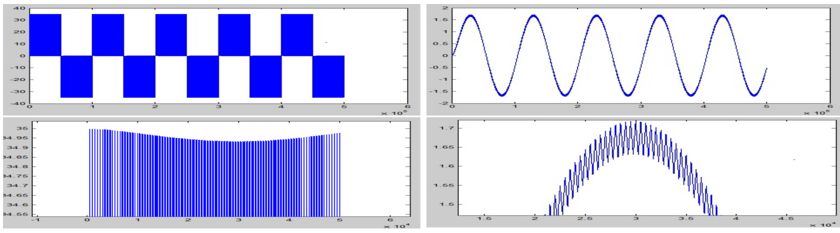

Fig. 7 Output voltage (+detail) and output current (+detail)

Any (sufficiently smooth) function f(t) that is periodic can be built out of sin's and cos's. We have also seen that complex exponentials may be used in place of sin's and cos's. We shall now use complex exponentials because they lead to less writing and simpler computations, but yet can easily be converted into sin's and cos's. If f(t) has period 2ℓ, its (complex) Fourier series expansion is (4).

$$f(t) = \sum_{k=-\infty}^{N} c(k) e^{ik\frac{\pi}{l}t} \quad \text{and} \quad c_k = \frac{1}{2l}\int_{-l}^{l} f(t) e^{-ik\frac{\pi}{l}t}\,dt \tag{4}$$

Using of fast Fourier transform in Matlab as defined by (5) can be obtained spectrum of source current and other adjustments to the actual interference. Y=fft(x) returns the discrete Fourier transform (DFT) of vector x, computed with a fast Fourier transform (FFT) algorithm. N is root of equation.

$$X(k) = \sum_{j=1}^{N} x(j)\,\omega_N^{(j-1)(k-1)} \qquad \text{where} \qquad \omega_N = e^{(-2\pi i)/N} \tag{5}$$
$$x(j) = (1/N)\sum_{k=1}^{N} X(k)\,\omega_N^{(j-1)(k-1)}$$

In terms of the EMI is interesting current from supply. His course is possible to analyze using the Fourier transform and information about harmonic spectrum is significant in terms of total EMC. At the fig. 8 is the course of input current and detail of his harmonic analysis (for clarity, at the picture is not first harmonic with magnitude 0,37A). But the composition of the harmonic spectrum contains harmonics in relatively small amounts (second harmonic with magnitude about 0,1A, third harmonic about 0,06A). Source-input current with a small amount of harmonic components is essential to minimize the DM interference that comes from the switching process.

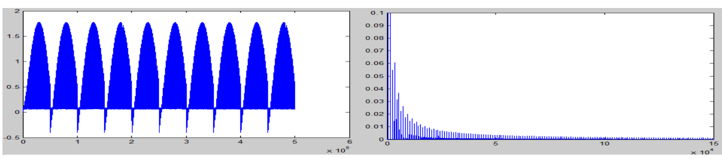

Fig. 8 Input current and its harmonic analysis

Resulting interference current spectrum (in dBm) is shown in Fig. 9 Since this interference measured in the simulation is only caused by switching processes (in the simulation have not been defined parasitic properties) can say that it is only interference DM.

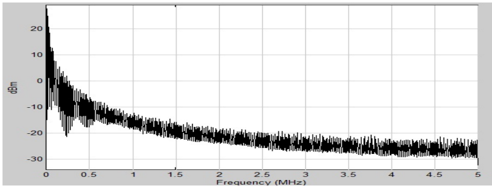


Fig. 9 DM interference in matrix converter

## 4 Conclusion

Conducted interference in the power converter can be divided into differential and common mode noise. Common mode interference is created and conducted due to parasitic capacitive elements between circuit and e.g. chassis or in the circuit itself. Different mode interference is created in converter and concluded via internal connections, the process of switching. It usually depends on the topology. DM interference can be eliminated by optimization of switching process. For example, soft commutation in the converter significantly contribute to reducing emissions. Another significant factor especially in a matrix converter which is very sensitive for precision and accurate commutation is suitable choise of dead time. Matrix converter simulation worked with output voltage 35V and output current 1.7 A. Maximum simulated level of interference was about 30 dBm. This level meets international standards. In case of similarly interference measured on a functional converters (as in the simulation), this would be applicable in engineering practice. In the event that CM interference is added to the simulated (DM) interference, it is likely that the converter will no longer meet international standards for EMI. Partial solution offer appropriately designed EMI line filter. From simulated data further confirms that the impact of DM interference with increasing frequency decreases. But the opposite behavior can be expected from CM interference (Fig. 10).

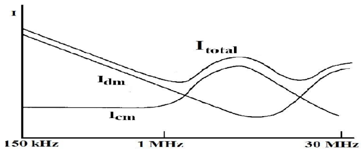


Fig. 10 Frequency dependence of CM and DM interference


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Tomáš Kapusta
Kapusta.tomas86@gmail.com