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TWO-PHASE TWO-STAGE HF MATRIX CONVERTER FOR SUPPLYING TWO-PHASE MOTOR LOAD

This paper deals with the two-stage two-phase electronic systems with orthogonal output voltages and currents – DC/HF_AC/2AC. It also introduces the design and prototype of two-stage DC/HF_AC/2AC high frequency converter with two-phase orthogonal output using two single-phase matrix converters in full-bridge connection operated with the unipolar PWM. Simulation and experimental results of matrix converter for both steady and transient states for IM motors are given in the paper together with experimental verification under R-L load. The results confirm a very good time-waveform of the phase current and the system seems to be suitable for low-cost application in automotive/aerospace industries and application with high frequency voltage sources.

Keywords: Matrix Converter, Two-Phase Induction Machine TPIM, Orthogonal System.

1. Introduction – Single-phase HF Matrix converter

The matrix converters are among to direct converters – there is a direct conversion of the input voltage to the output voltage with another frequency. The use of high switching frequency reduces the effect of harmonic current back to the power grid. The bidirectional switches are necessary because they allow flow current in both directions. The basic connection of direct converter – matrix converter (3×3) is shown in Fig. 1a. From this scheme is derived the connection of single-phase matrix converter, Fig. 1b, [1] and [2].

The relations between output and input voltages, and between output currents and v_o are:

$$[v_o(t)] = [M(t)] \cdot [v_i(t)] \text{ and}$$

$$[v_o(t)]' = [A] \cdot [i_o(t)] + [B] \cdot [v_o(t)] \quad (1, 2)$$

where $[M(t)]$ is modulation matrix, $m_{aA}(t) = \frac{t_{aA}}{T_{seq}}$ is modulation index, t_{aA} is time of switched state, with restrictions:

$$\sum_{K=a,b,c} m_{KA}(T) = \sum_{K=a,b,c} m_{KB}(T) = \sum_{K=a,b,c} m_{KC}(T) = 1 \quad (3)$$

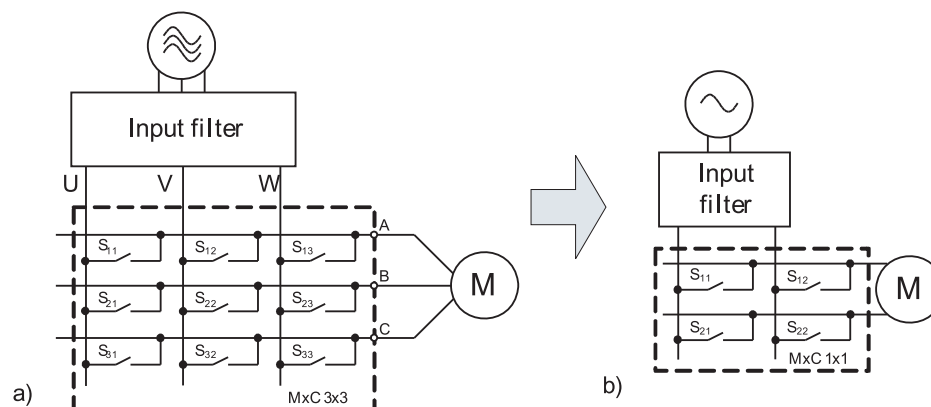


Fig. 1 Scheme of matrix converter (a) and single-phase derivation (b)

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2. Two-stage two-phase systems with HF AC interlink and matrix converters (DC/HF_AC/2AC)

Two-stage two-phase systems with HF AC interlink and matrix converters (DC/HF_AC/2AC) usually consist of a single-phase voltage inverter, AC interlink, HF transformer, 2-phase AC/AC converter and 2-phase AC motor. This is the best choice due to an AC interlink direct converter (cyclo or matrix converter). The system with matrix converter and high frequency AC interlink can generate two-phase orthogonal output with both the variable voltage and the frequency [3], [4] and [5]. The proposed scheme of two-stage two-phase converter system is shown in Fig. 2. The switching frequency of the converter is rather high (~ tens of kHz) and the second stage operates with twice switching frequency. Since the voltages of the matrix converter system should be orthogonal ones, the second phase converter is the same as the first one and its voltage is shifted by 90 degree. The switches of the inverter operate with hard commutation, the switches of matrix converters are partially soft-commutated in the zero-voltage instants of the AC voltage interlink using unipolar PWM [6]. Therefore, the expected efficiency of the system can be higher than usually by using the classical three-phase inverter .

3. Control of matrix converter with high-frequency input

The theoretical analysis of single-phase matrix converter has been done, e.g. [4] and [6]. The full-bridge converter provides unipolar and bipolar PWM control. Switching-pulse-width can be determined on the basis of the equivalence of average values of reference waveform and the result is the average value of positive or negative switching pulse area during switching period [7].

The switching instant is equal to:

$$t_s(k) = \frac{1}{U_{DC}} \cdot S_{\Delta}(k) \tag{4}$$

and the area under sine wave during k-switched interval $S_{\Delta}(k)$ is:

$$S_{\Delta}(k) = U_m \cdot \frac{m_f}{2\pi} \cdot \left[\cos\left(\frac{2\pi}{m_f} \cdot k\right) - \cos\left(\frac{2\pi}{m_f} \cdot (k+1)\right) \right] \tag{5}$$

The total harmonic distortion of the current is:

$$\frac{\sqrt{\sum I_v^2}}{I_1} = \sqrt{\frac{I^2 - I_1^2}{I_1^2}} = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1} = \sqrt{[(8.34822/8.34386)^2 - 1]} \approx 2\% \tag{6}$$

Fourier analysis is useful and needed for the determination of total harmonic distortion of the phase current of the matrix converter. Unipolar switching strategy of one full-bridge matrix converter can be explained using Fig. 3 in greater details [4] and [8], [9], [10], [11].

4. Simulation Experiment

The simulation model of a two-stage converter was modeled in OrCAD programming environment, Fig. 4 and the simulation model of motor load was modeled in MatLab programming environment and they together were connected using Matlab SPLS. The simulation results of two-stage single-phase full-bridge matrix converter with R-L load are shown in Fig. 5. Both stages of converter are realized in full-bridge connection - (unipolar or bipolar PWM can be used). To protect the inverters against overvoltage surges in both stages the floating protection is used, which returns stored energy back to the DC-link and, thereby, improves the efficiency of the converter.

The simulation results show the response of the two-phase AS motor (230 V/150 W, 50 Hz, 2730 rpm) to step change of motor load (in open loop). At time $t = 0.2$ s the motor was loaded with torque ($M = 1$ Nm). The simulated waveforms during start-up of the two-phase induction machine (TPIM) supplied by two-phase switched voltage ($PWM, U_{DC} = 350V, f_{sw1} = 10kHz, f_{sw2} = 20kHz, U_{outAC} = 230V, f_{out} = 50Hz$) voltage shifted by 90 degree are depicted in Fig. 6.

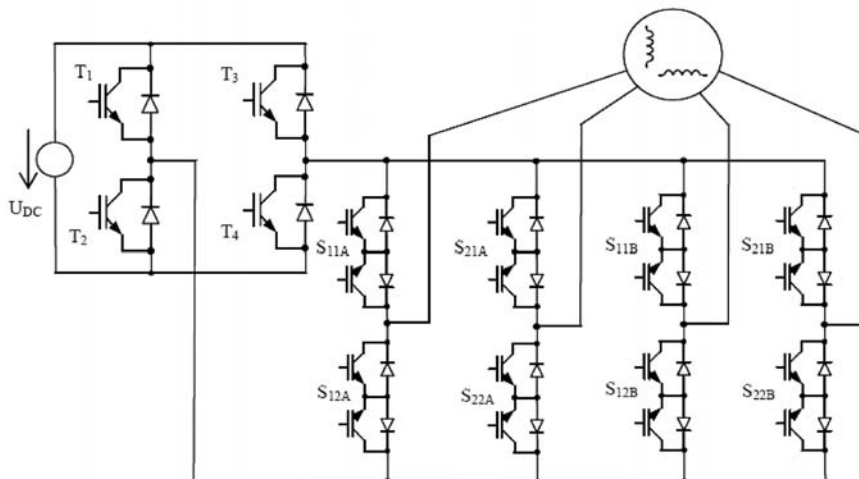


Fig. 2 Two-stage two-phase systems with HF AC interlink, matrix converters and motor load

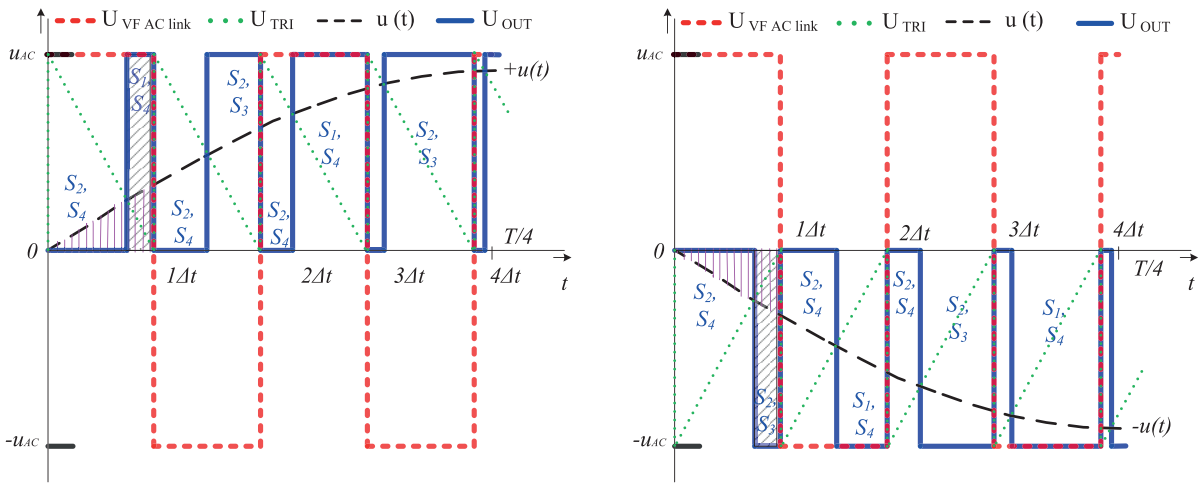


Fig. 3 Switching strategy for positive (a) and negative (b) half period of operation

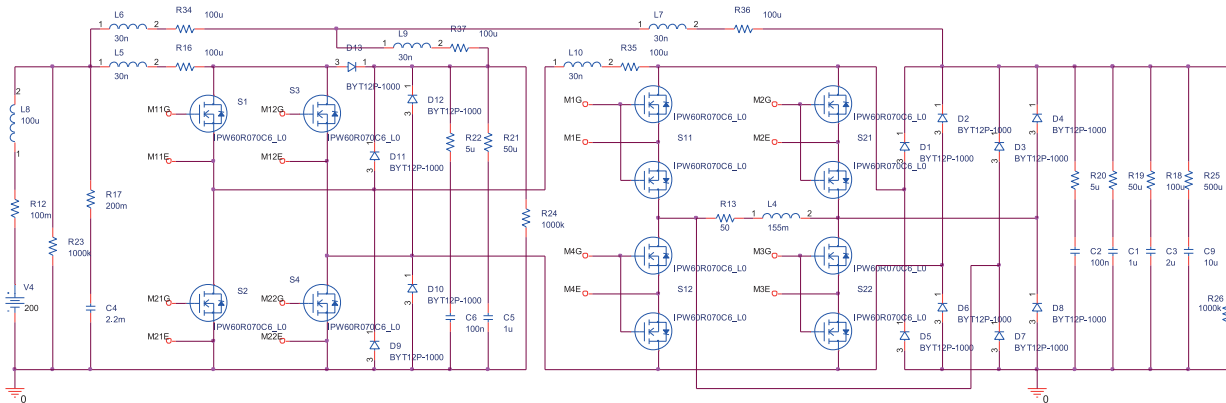


Fig. 4 Simulation model of two-stage single-phase converter

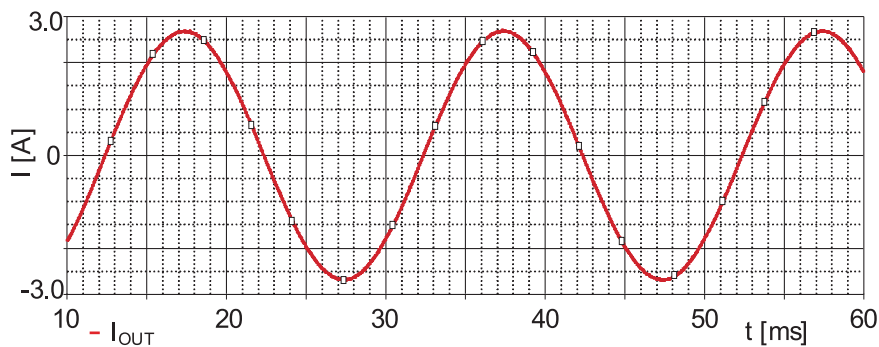


Fig. 5 Simulated waveform of output current of the single-phase converter under R-L load ($U_{DC} = 350V$, $R = 10 \Omega$, $L = 30 mH$, $f_{SW1} = 10 kHz$, $f_{SW2} = 20 kHz$, $f_{OUT} = 50 Hz$)

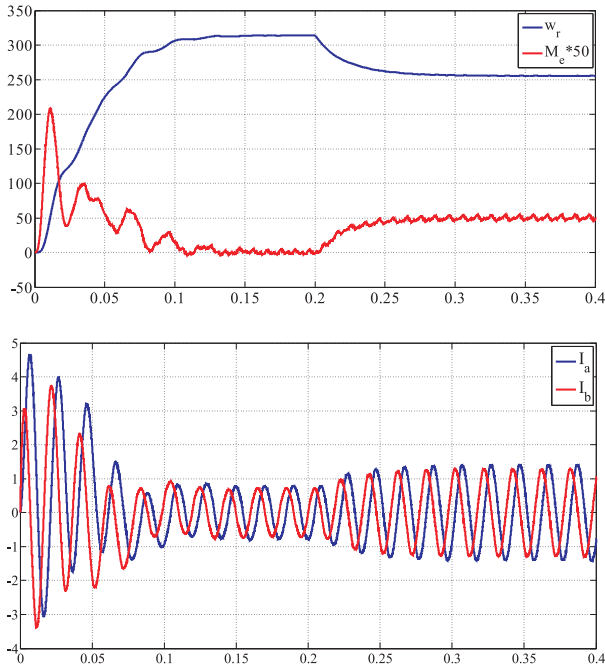


Fig. 6 Time-waveforms speed, torque and currents of TPIM during start-up

5. Experimental verification

The switching strategy described in previous chapter is used on the two-phase two-stage converter. The first stage was the voltage source inverter (VSI) and the second stage two matrix converters (MxC) were realized in a bridge connection without transformer in HF interlink. In this case the matrix converter works as a cyclo-converter. The block scheme and photo of converter are shown in Figs. 7 and 8.

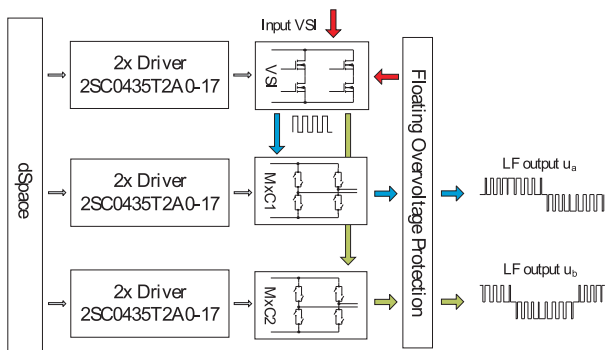


Fig. 7 Block scheme of two-stage two-phase converter with HF_AC interlink and matrix converters

Figure 9 depicts output voltages and currents from the matrix converter. Yellow and blue waveforms are output voltages. Purple

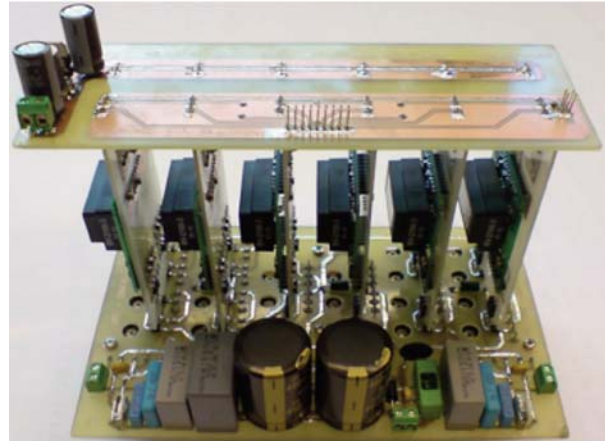


Fig. 8 Photography of complet two phase two stage converter with high-frequency AC link and ortogonal output

and green wave forms are output currents. The output phase is shifted by 90 degrees. The waveforms of current in HF interlink and output currents are shown in Fig. 10.

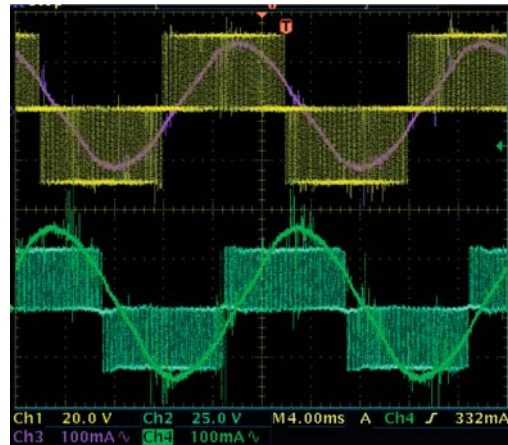


Fig. 9 Waveforms of output voltages and currents for unipolar control

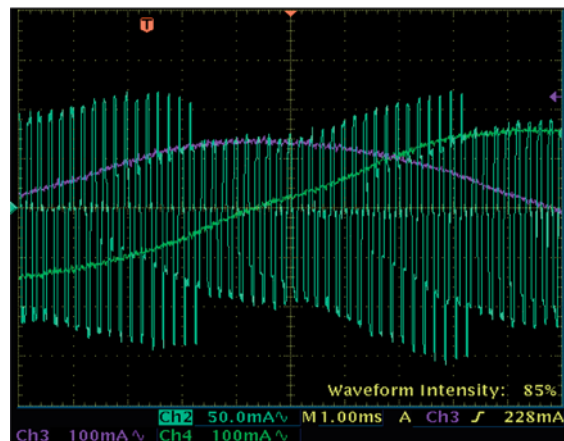


Fig. 10 Waveforms of output and HF interlink currents

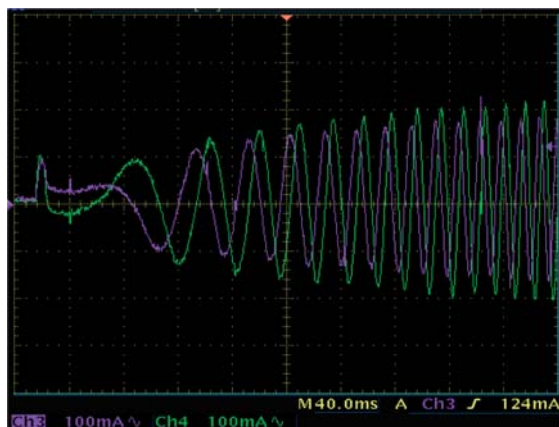


Fig. 11 Real stator currents of two-phase induction motor during start-up

From Fig. 11 we can see that the amplitudes of the stator current are not the same because the two-phase induction machine was unsymmetrical. Maximum efficiency of the proposed two-phase two-stage converter is nearly 94% at switching frequency 5kHz (in first-stage) and 10kHz (in second-stage).

6. Conclusion

The article shows a new concept of an electric drive system for electric vehicle and industrial application. It consists of the two-stage converter created by the single-phase converter and two single-phase matrix converters commutated by HF-AC input voltage, and two-phase induction TPIM or synchronous motors with PM. Simulation and experimental results showed good agreement between simulated and real output time waveforms. If this type of inverter is used to supply two-phase drive, high efficiency and very good mechanical parameters can be achieved (by two-phase – orthogonal supply of two-phase motor – TPIM, drive develops maximum torque). The maximum efficiency of the proposed two-phase two-stage converter is nearly 95% at switching frequency 1kHz (in first-stage) and 2kHz (in second-stage).

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