# Switching Algorithms for Single Phase Matrix Converter with Input Capacitance

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***Abstract* – This paper describes the switching algorithms for single phase matrix converter (switching logic for matrix converter). There is shown two basic methods of the control of the switches in the matrix converter and these modifications (and combining algorithm). First method needs the knowledge of the polarity of the output current of the converter and the second method needs the knowledge of the polarity of the input voltage.**

***Keywords - Single phase matrix converter; Control algorithms; Commutation in power electronic***

## I. INTRODUCTION

Matrix converter (MC) is a modern type of power semiconductor converter and it will be very progressive type of converter (in future). Using of matrix converter is very universal (with AC or DC input resp. output). Main branch it's using is as AC/AC frequency converter.

Nowadays as common frequency converter is used indirect frequency converters with DC-link (and the most used type of these frequency converters use DC-voltage link with big capacitance). These indirect frequency converters have three parts: rectifier, inverter and DC-link (with big values of passive component of this filter) between them. Direct converter theoretically has only one part.

Using of direct converter (namely for matrix converter) will bring these advantages:

1) Reduction of size of converter – namely reducing of passive components (direct converter has not DC-link and has not big capacitance on this place)

2) Reduction of power losses on semiconductors (in direct converter currents flow directly thru only 2 devices – but in indirect converter thru 4 devices, possibility of reducing of switching frequency with the same value of ripple of output current)

3) Reduction of negative influence of input part to supply grid (because many indirect frequency converter has only non controlled diode rectifier with very non-sinusoidal current but matrix converter can to realize approximately sinusoidal current)

4) Reduction of negative influence output part (because commonly used indirect frequency converter has 2-stage voltage sourced inverter with big capacitance and it yield with very high value of derivation of output voltage – *dv/dt*)

5) Easy possibility to realize recuperation regime (from braking motor etc. to supply grid) without some additionally devices

But using of matrix converter brings these disadvantages:

1) Nowadays atypical type of converter, yet

2) More complicated control algorithms

3) High influence of faults (for example voltage sags of supply voltage cannot been compensated by big filter's capacitance in DC-link)

4) Using of special types of semiconductor elements (i. e. IGCT, RB-IGBT or combination or classical IGBT with additionally diode)

5) Many applications do not use braking regime, for these applications it is used of simple and cheap indirect converter without recuperation is

6) Basic type of matrix converter cannot generate full value of voltage (it depend on practical realization of converter)

Nowadays solution of converters is 3-phase to 3-phase for general application (for example for supply 3-phase AC-machine from 3-phase grid). Figure 1 shows the example of 3/3-phase matrix converter with switches which internal capacitances. These internal capacitances reduce the overvoltage produced in parasitize inductances during commutation. Internal capacitances bring the complication on realization. This paper solves the matrix converter without internal capacitances – i.e. with external capacitances in input side of converter (see for example Figure 2).

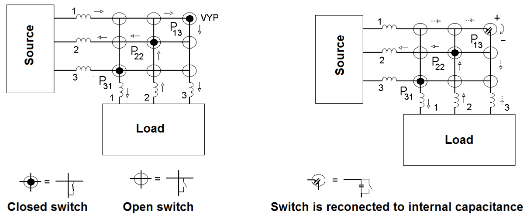


Figure 1. 3/3-phase matrix converter with internal capacitances

This paper devoted to problematic of realization of special type of converter – 1-phase to 1-phase matrix converter. This special 1/1-phase matrix converter can

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be used as an input converter in electric vehicles supplied from AC-trolley (25kV 50Hz or 15kV 16.7 Hz). This special high voltage converter can to change input low-frequency (50Hz or 16.7Hz) of supply voltage to medium frequency AC-voltage for purpose to supply medium frequency transformer. Medium frequency transformer bring chance to minimize the mass (and power losses) of locomotive transformer (in comparing with the standard nowadays solution without input high voltage converter and low frequency transformer for trolley frequency only 16.7Hz). Other methods of using of MFT for this purpose see [1], [2] or [3].

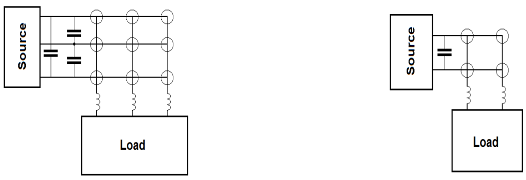

Figure 2. a) 3/3-phase b) 1/1-phase matrix converter with capacitances at input side

## II. Single Phase Matrix Converter

Figure 2b) shows 1-phase to 1-phase matrix converter with capacitances on input side. Actual switching combination of power elements of 1/1-phase matrix converter is possible to describe theoretically by matrix with 2 rows and 2 columns (but for practical situation is possible to describe by only one scalar value – with the values s=+1, s=0 or s=-1 see for example Figure 3).

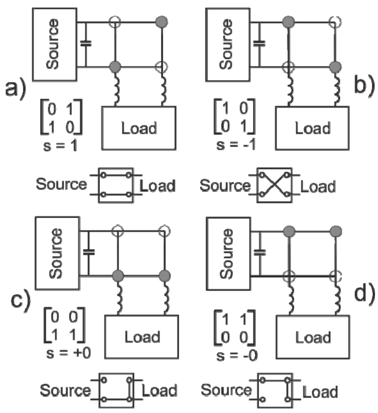

Figure 3. Practical switching combination for 1/1-phase matrix converter with capacitances at input size

## III. Commutation according to the Polarity of Input Voltage

Figure 4 shows basic type on 1/1-phase matrix converter. Let us to solve only situation for positive actual value of input supply voltage (for negative value it is symmetrical situation). For this situation we have the same situation as four-quadrant DC/DC-converter - let us to use labeling (see Fig.7), symbols and terms respondent these situation (H-bridge consist of left half-bridge and right half-bridge) – see for example [5], [6].

It is possible to solve theoretically 6 variants of commutation of whole matrix converter – i.e. from each of three switch combination (according to Figure 3) to another 2 switch combination). But it is possible to minimize this problem to only one type of commutation – for one general half-bridge (inversion commutation has the same situation but symmetrically - with opposite polarity of voltage). All variants of commutation of whole matrix converter are possible to solve as superposition of commutation of both half-bridges. Let us solve this generally type of commutation - for example only for right half-bridge from initial switching combination (according to situation on Figure 4a) to final switching combination (according to situation on Figure 4c).

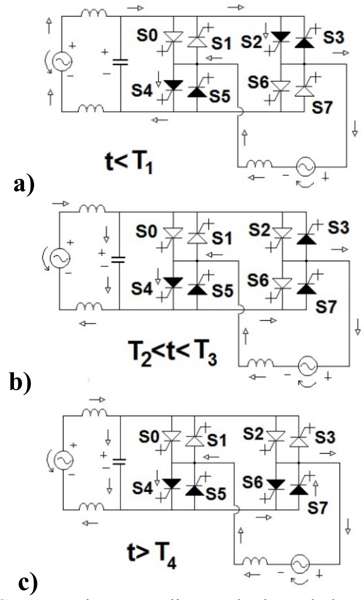

Figure 4. Commutation according to the knowledge of polarity on input supply-voltage

We must to turn off top elements S2 and S3, but current must to flow thru matrix converter (because disconnecting of output load-current make a big overvoltage on output inductance). Commutation has these four steps:

1) time T1 = turn on bottom element S7 (for preparing new way for load current), both elements S3 and S7 are open (but because input supply-voltage is positive this is not generate very danger short circuit – the same situation as freewheeling anti-parallel diodes in standard DC/DC-converter)

2) time T2 = turn off element S2 - if output load-current has positive direction according to Fig.4, the current start to flow thru newly open element S7 (for opposite direction of output load-current the current flow continually thru element S3) situation on

3) time T3 = turn on element S6 (danger element S2 is closed)

4) time T4 = turn off element S3 – after it, it is final situation (according to Figure 4c)

Figure 5 and 6 show switching sequence for this commutation – i.e. with this polarity of input supply-voltage. Symbols “X” and “!” are used for warning to danger combination S2 and S6 (element S2 must to be safely turn off before turn on of element S6). Thick line shows elements with current, thin line closed elements without current (difference between Figure 5 and Figure 6 depend on actual polarity of output load-current). It is possible to make some optimization of this algorithm (for example do not turn on element S3 for positive current etc.).

Very importance is aspect, that error on measure of polarity of input supply voltage (or long time delay between measurement and real commutation or big derivation of this value around the zero value) can to bring over-current between supply source (and its capacitance) and elements S7 and S3.

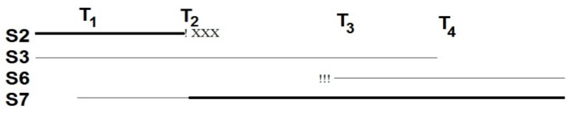


Figure 5. Switching diagram for commutation according to the knowledge of polarity on input supply-voltage (for positive input voltage and positive output current – according to Figure 4)

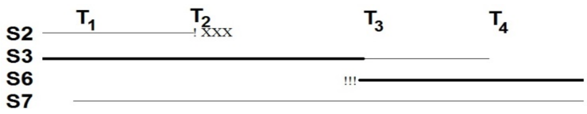


Figure 6. Switching diagram for commutation according to the knowledge of polarity on input supply-voltage (for positive input voltage and negative output current)

## IV. Commutation according to the Polarity of Output Current

Let us solve the same situation according to previous chapter but with one variance – when we do not know the polarity of actual value of voltage but we know the polarity of actual value of output load-current. Let us solve any generally commutation (for example for right half-bridge – it is the same situation, which was solved in previous chapter) from initial situation (according to Figure 7a) to final situation according to Figure 7c.

We must to turn off top elements S2 and S3, but input voltage cannot to connect to short circuit (because short circuit brings over-current between supply source and its capacity). Commutation has these four steps:

1) time T1 = turn off top element S2 without current (in next interval element S3 only will be closed alone in right half-bridge – but it is enough for this direction of output load-current)

2) time T2 = turn on bottom element S6 - if input supply-voltage has positive direction according to Figure 7, the current start to flow thru newly open element S6 (for opposite direction of input supply-voltage the current flow continually thru element S3)

3) time T3 = turn off element S3 (danger situation - element S6 must to be safely open, otherwise this step brings overvoltage produced by disconnection of current flow thru output load-inductance !!! )

4) time T4 = “useless” turn on element S7 – final situation (according to Fig.9c)), this element S7 can to conduct current only in situation, that current will change its polarity (for example long time after this commutation)

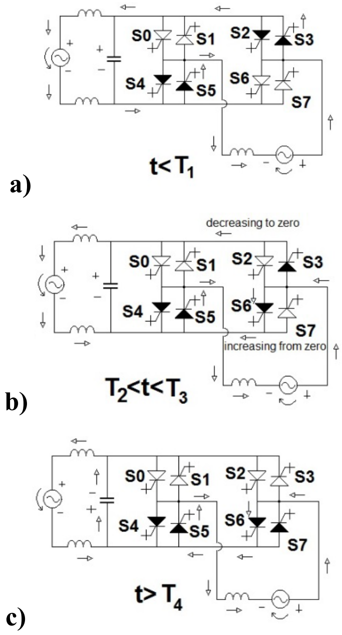


Figure 7. Commutation according to the knowledge of polarity on output load-current

Figure 8 shows switching sequence for this commutation – i.e. with this polarity of input supply voltage. Figure 9 shows situation for negative polarity of input supply voltage. It is possible to make some optimization of this algorithm (for example reducing of number of “useless” turn on elements etc.).

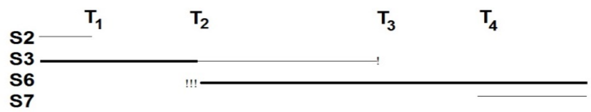


Figure 8. Switching diagram for commutation according to the knowledge of polarity on output load-current (for negative output current and positive input voltage – i.e. according to Figure 7)

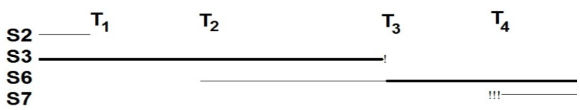


Figure 9. Switching diagram for commutation according to the knowledge of polarity on output load-current (for negative output current and negative input voltage)

Very importance is aspect that error on measure of polarity of output load-current (or long time delay between measurement and real commutation or big derivation of this value around the zero value) can to bring over-voltage, because disconnecting of output load-current make a big overvoltage on output inductance.

## V. Combining Algorithm

Previous chapters show, that both algorithms bring danger situation, that error in polarity of measured voltage (or current) bring over-current on short circuit in matrix converter (or over-voltage on output load-inductance).

Combining algorithm is “advanced” method (see Figure 11), which use either first basic algorithm according chapter III. (according to polarity of input supply voltage) or second basic algorithm according to chapter IV. (according to polarity of output load-current). Whole area of output voltages and output current is split up to 9 parts. High positive values of input supply-voltage are parts 1, 2 and 3. Approximately zero values of voltage are 4, 5 and 6. And high negative values of voltage are parts 7, 8 and 9. High positive values of output load-current are parts 3, 6 and 9. Approximately zero values of current are parts 2, 5 and 8. And high negative values of current are parts 1, 4 and 7.

We must to use inside part 2 and 8 first basic algorithm according chapter III. (according to polarity of input supply-voltage). Inside part 4 and 6 we must to use second basic algorithm according to chapter IV. (according to polarity of output load-current). Inside part 1, 3, 7 or 9 we can to use first or second basic algorithm (both values have enough value = it minimize the danger of errors described on final parts on chapter III. and chapter IV.).

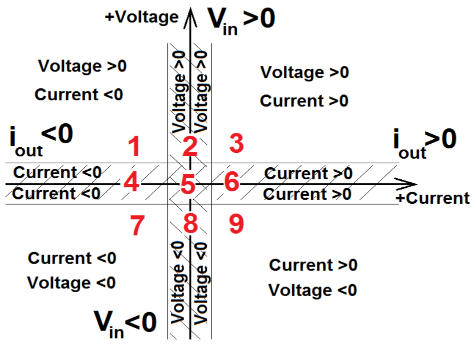


Fig.11 Combining algorithm for commutation

Central part 5 brings problems, because both current and voltage have a small value (and it means that this polarity can be estimated with big hazard of error). In this part is preferred the method according to higher value of current or of voltage (for example the absolute value of ratio of actual value divided by rated value or divided by accuracy of these sensors).

The 3/3-phase matrix converter can to choose two or three combination of non-zero actual values of voltage and the time of zero crossing of voltage and time of zero crossing of current is not the same (output current is phase current but input voltages are line to line - between two phases).

The 1/1-phase matrix converter (operated with high power factor – i.e. cosφ=1) has zero crossing of (both combination of) input voltage and zero crossing of output current at the same time.

Very small values (approximately zero value) of both current and voltage bring big hazard of error, but small value of voltage means a small value of “over-current” on short circuit via two closed semiconductor elements. And disconnecting of small value of output load-current make a small “overvoltage on output inductance (real matrix converter has passive capacitance and overvoltage protection).

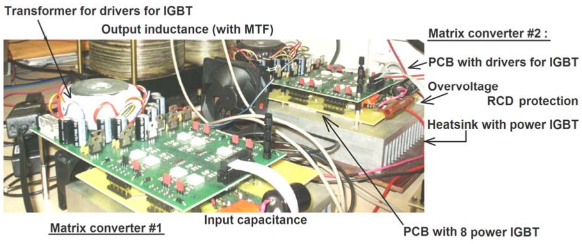


Figure 10. Two identical matrix converters (#1 and #2) realized in laboratory and controlled by joint DSP (Texas Instruments TMS320F2812).

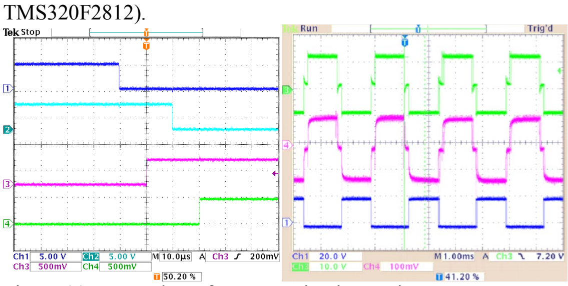

Figure 11. Examples of commutation in matrix converter
a) detail of used commutation time 4x10µs
b) extremely long-time 4x152µs (only for diagnostically purpose)

## VI. Conclusion

This paper presents the basic control algorithms for commutation of single phase matrix converter (i.e. the algorithm of commutation according to polarity of input supply-voltage, or according to polarity of output load-current or combining algorithm). These theoretical considerations, was been simulated on PC and successfully realized on laboratory model. These algorithms were implemented into DSP.

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