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MATRIX CONVERTERS: A REVIEW OF RESEARCHES IN FORMER SOVIET SOYUZ AND RUSSIA

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Abstract. In the last years many papers about research on matrix converters have been published in the Western hemisphere [1]. However, the papers of the former Soviet and Russian contributors are not considered. In our report the review of the publications for matrix converters in former Soviet Soyuz up to 1991 and in Russia up to the present time is made. The new results on the development of control algorithms and schemes of matrix converters are included, too.

Keywords: Matrix converters, Control, Semiconductor Devices

1. HISTORY

Single stage variable frequency converters
The single-stage AC/AC converter for variable frequency is known since the thirties of the last century. At first this converter type was composed of ionic devices (thyratrons, fig. 1), as gas discharge devices which could be fired (in switching mode operation, as a turn-on device, in contrary to linear (amplifier mode) vacuum valves).

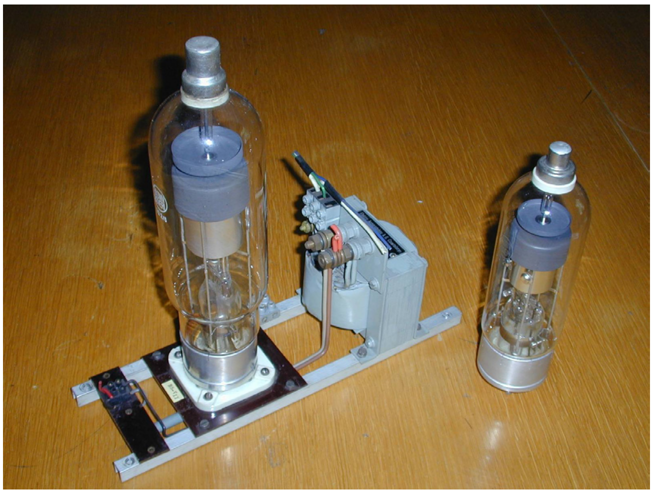

Fig. 1. Thyratron ("current gate")

Since the sixties of last century, thyristors (fig. 2) as the semiconductor realization of a switching device (turn-on device) are used.

Fig. 2. Thyristor ("thyratron + transistor")

In the Western hemisphere the single-stage AC/AC converter has obtained the name "cyclo-converter", and in the Soviet Soyuz this type of converter was called "frequency converter with direct coupling". This name is quite close to the German language expression "Direktumrichter" = "direct converter".

2. BASICS OF CYCLO-CONVERTERS

The advantages of cyclo-converters are as follows:

- Single energy conversion step;
- Ease of yielding a recuperation mode;
- Absence of additional reactive components (no reactor L, no capacitor C);

- Capability of turn-off in emergency (or fault) operation.

The disadvantages of cyclo-converters are the following: (as they are stipulated by natural commutation):

- The maximum output frequency could not exceed the frequency of the input voltage;
- Low input power factor
- High and varying reactive power (modulation reactive power) on the line side (input)

3. CYCLO-CONVERTER IMPROVEMENT

In order to eliminate these disadvantages, Zavalishin D. A.. [2] proposed to supplement cyclo-converters by artificial commutation (this means without line commutation, turn-off is accomplished internally and the instant of turn-off of a switch can be selected arbitrarily) already in 1939. This direction has received intensive attraction and development in the Soviet Soyuz in the sixties and seventies in connection with appearance and availability of thyristors as very rugged and cost-effective switching devices.

Three concepts of control were developed with reference to cyclo-converters with appropriate devices of artificial commutation:

1. Concept of cyclical control
   For cyclical control see [3-7]. Here the frequency of the output voltage was determined by a difference in frequency of control of thyristors and frequency of input voltage of the converter.

2. Concept of a pulse-width modulation similar to standard PWM in voltage source inverters
   The development was received by the schemes of converters oriented to the rectangular law of pulse-width modulation [8,9] and on the sinusoidal law [10,11]. The first algorithm required usage of common units of artificial commutation, for the second individual units became necessary. The advantage of algorithms of pulse-width modulation was the high value for the input power factor of the converter. Thus the shift factor of an input current referred to the voltage (cos phi) was equal practically to unity.

3. Concept of combined control algorithms for the converter
   For combined control algorithms see [12-15]. In this case the algorithms for a direct approximation of a curve of output voltage of the converter to a given curve were selected in a special way.

4. CYCLO-CONVERTERS WITH TURN-OFF DEVICES

Matrix converters in the West
The appearance of power transistors and GTO-thyristors has considerable increased the competitiveness of cyclo-converters in contrast to frequency converters with a DC link. DC-link converters are commonly using direct current (current source inverter) or direct voltage (voltage source inverters) in the DC link. In the West, transistor cyclo-converters composed of gate controlled turn-off devices (bipolar transistors, GTO thyristors, now IGBTs and IGCTs) got the "new" name matrix converters [1] in the eighties.

Matrix converters in the East
But in Russia this title was offered in the sixties already. [7,8]. In Russia the power transistors were available only at the beginning of the nineties, therefore the main objective of this paper further-on will concern the review of results of the Russian activities on matrix converters for the last decade. The outcomes of researches on these converters in Russia, especially at MEI (Moscow), are reflected in a doctoral thesis of G. Mychyk (2001), have again not been analyzed thoroughly in the West.

5. NEW RESULTS AT MATRIX CONVERTERS

Two possible directions for the improvement of matrix converters appear. The first direction is the modification of the power schemes of matrix converters. After that the development of control algorithms, directed towards an increase of the first harmonic of the converter output voltage and obtaining a high value of input power factor cos phi, including a value close to unity (cos phi = 1) is being considered.

Modification of Power Schemes
The modification of the schemes of matrix converters happened in two consecutive directions. First, it was accomplished on the basis of the application of the known approach used in other types of converters also at matrix converters. This concept applies a controlled reactive voltage in series to the voltage component, this means without an own power source and - as a consequence of it - with a phase shift of the current of a cell referenced to it's voltage of 90 degrees. For the type of the cell of the autonomous voltage, usually a voltage source inverter is used [16-18], although realizing a cell, an autonomous current source inverter is possible, too.

This method gave an impulse in the development of active filters [16,17] and new regulators for alternating voltage [18, 19]. The replacement of key units in matrix converters by cells of reactive voltages results in modified schemes of matrix converters [20,21]. A simple version of a modified scheme is displayed in fig. 1, with a, b, c being the line (input) side and x, y, z being the load (output) side. Thus the voltage source inverter on an output (quasi-inverter with separated sources of power for each arm of the inverter) can be derived from the basic design with three cells disposed in one vertical column.

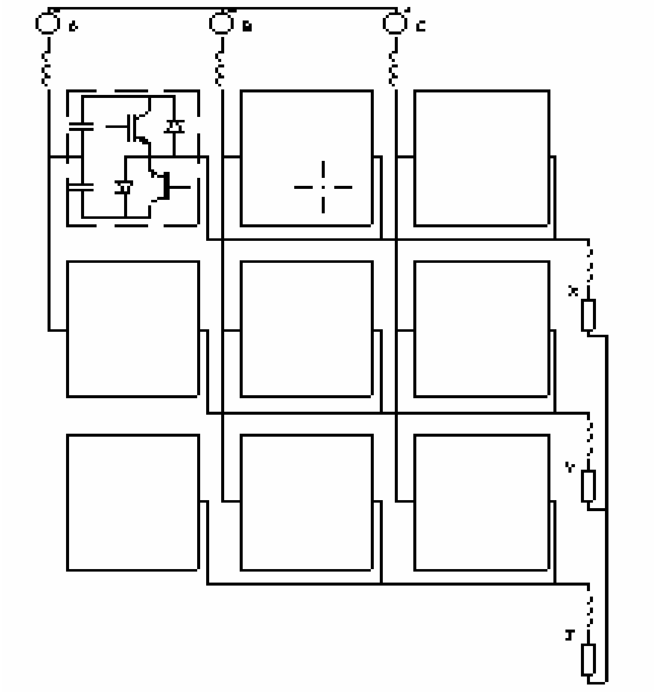

Fig. 1. Reactive voltage cell improved cyclo-converter, basic circuit topology

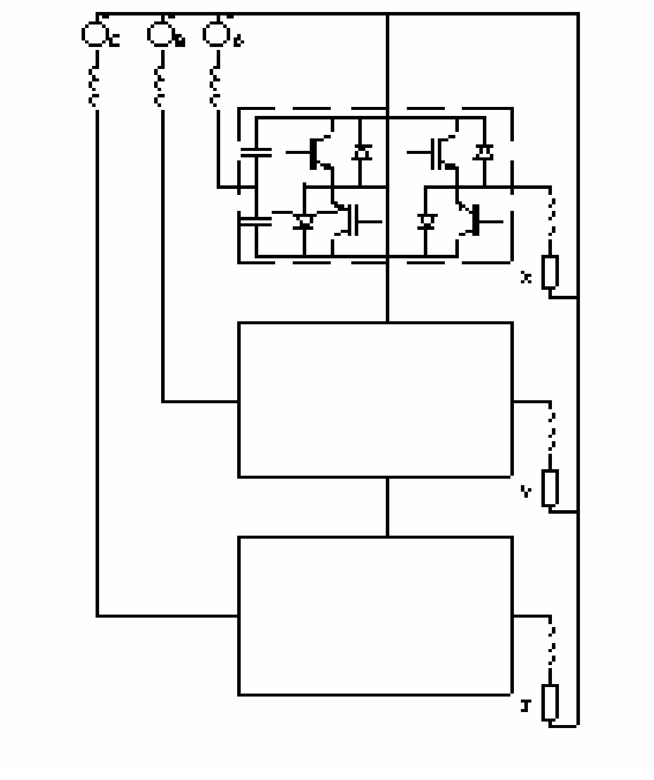

Fig. 2. Matrix converter composed of three single-phase cells

In a consecutive step, the output voltage of the matrix converter can be generated by a method of sine wave pulse-width modulation as in the classical voltage source inverter. Thus, if three cells located in one line of a matrix of cells of the converter will cope also in all phases of a input network and the continuous currents will proceed. At the application of these key cells of the inverter on bridge circuits the number of key cells grows twice while one half of capacitors can be removed from the circuit. Then the entrance current of a cell in shape and phase relation to the voltage, has to show - as a rule - sine wave, conterminous in phase with the input voltage [19].

Another variant of the direct converter which matrix structure is the two-stage three phase output converter for a three-phase input voltage with star point connection. This circuit is represented in fig. 2. As a matter of fact, this converter is composed of single-phase cells.

The internal operation of entrance and output stages of the converter from three single-phase cells provides ease of maintaining a symmetry on the three-phase voltage phases output, even at highly asymmetrical loading.

Controlled Energy Exchange

The second direction of updating the circuits of matrix converters is connected to the introduction of the concepts of controlled exchange of energy between reactive elements (reactors and condensers), into the circuits. In a similar way it was used originally in back-boost DC-DC converters. Recently this concept was published on AC-AC regulators and frequency converters [22-25].

The circuit of a direct frequency converter for converting a three-phase main voltage into a single-phase voltage is presented in fig. 3.

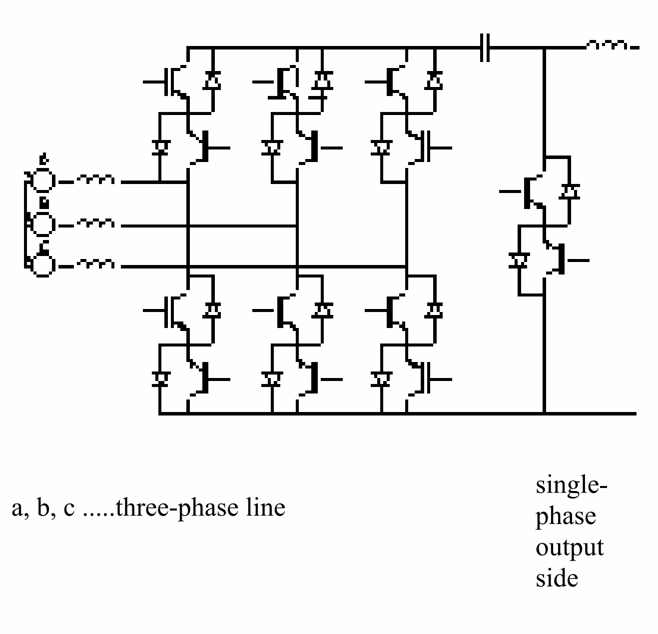

Fig. 3. Three-phase to single-phase matrix (direct) converter

These new types of cyclo-converters (matrix converters) are designed by the combination of usual frequency converter topology and the DC-DC Cuk' converter. Here an output voltage can be obtained by appropriate control of the exchange of energy between input reactors L and capacitor C which may be higher or lower than the input voltage. In addition, the input currents of this converter described can have practically sine wave form by PWM control and can be in phase related to the input voltage. Three-phase output is produced at three similar cells.

Presently investigations are done on perfection of matrix converters for the purpose of wind power installations which are in development [26] and on a deepening of their study in the educational process on " to Fundamental of power electronics " [27,28].

In a part of development of control methods of matrix converters, the increase of the first harmonic of a output voltage of the converter is accomplished by the adaptation of a new algorithm of control of voltage source inverter with reference to the matrix converter [29]. Thus in the converter not phases but linear voltages are formed. That gives an increase of the output first harmonic on 15 % at better quality of a voltage (on 15 % less factor of harmonics) in comparison with known algorithms using the standard of an addition of the third harmonic.

The increase of input power factor is achieved at the expense of use not only extreme values of input voltages, but also their intermediate values. The diagrams of a output voltages and currents are shown in fig. 4.

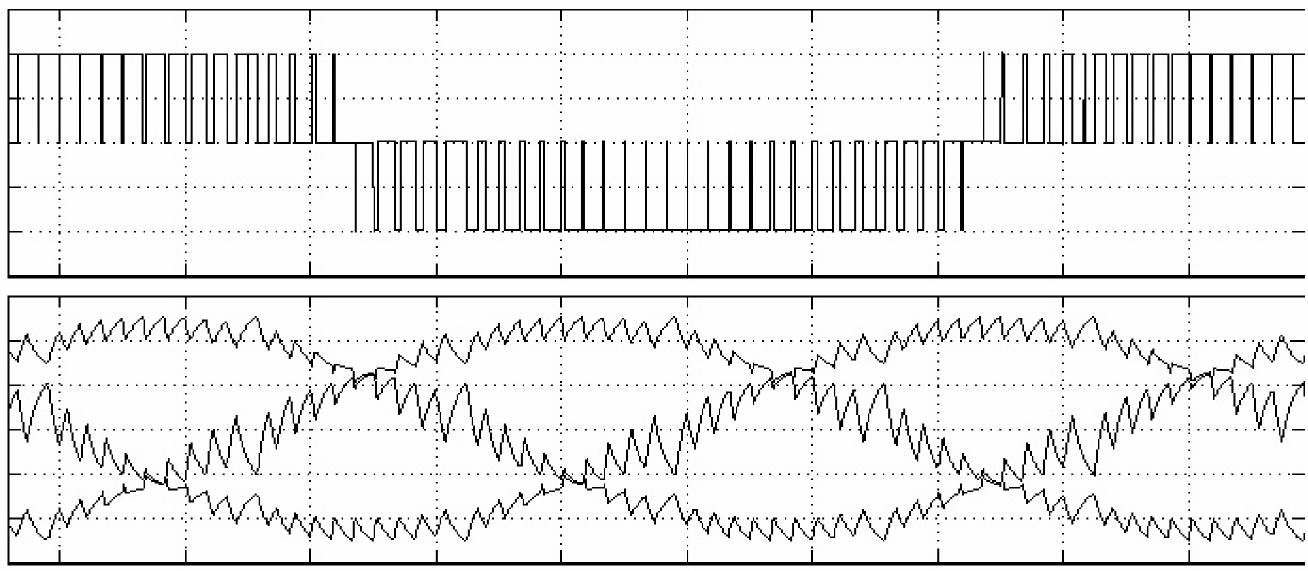

Fig. 4: Voltage (upper diagram) and currents (lower diagram) at a circuit with output voltage optimization.

6. CONCLUSION

Russia has an even longer history of developing matrix converters than the West. Two new types of matrix converters are intensively investigated in Russia presently. However, the introduction of vector control methods for converters and the creation of industrial products is running slowly only. Actually, activities into the direction of vector control of the matrix converter have appeared recently [30].

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