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"AREA BASED" CONTROL ALGORITHM FOR MATRIX CONVERTER

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ABSTRACT

A matrix three phases converter is a very simple structure incorporating nine bi-directional switches, able to convert input voltages into output voltages of any shape and frequency. However, commutation problems and complicated control algorithms keep it from being utilized on a large scale. This paper shows a new control scheme for the matrix converter, based on an "area" approach, which is easy applicable using any simple microprocessor controller. The scheme is then applied to manage matrix converter working as an interconnection between two power systems.

KEY WORDS

Matrix converter, Power flow, Current control, Voltage transfer

1. INTRODUCTION

The three phases to three phases matrix converter is an array of nine bi-directional switches (Fig. 1), able to convert three phase input voltages into three phase output voltages of different amplitude, phase and frequency than the input ones. This conversion is done without the use of a DC current circuit or any energy storage elements between the converter input and the output.

Recently, due to its simplicity, the matrix converter (MC) has received a lot of attention. The main problems in large scale industry application are complexity of control schemes, large amount of low order harmonics in converter currents and their non-continuity [2].

In this paper, the application of the MC in power system as a connector or the element of FACTS device was considered. Following properties of MC in this application were recognized:

1. The MC should be symmetrical with respect to both sides (possible power flow in both directions)
2. Currents on both sides should be continuous
3. No short-circuits are expected to occur at the input or output side
4. The MC should be able to work without (or with a very small) interference on transmission system

Several control strategies were investigated for the proposed application of the MC taking under consideration stated requirements of the power system, necessary symmetry of connector and optional MC work without interfering with the power system.

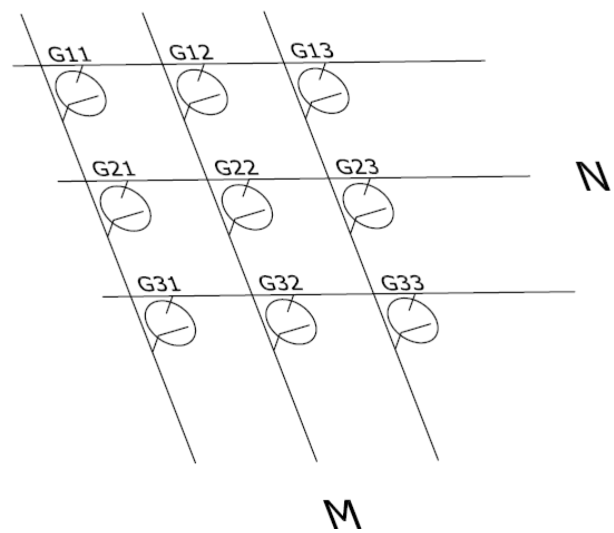

FIG.1. The structure of NxM matrix converter

The control strategy proposed in this paper is based on a so called "area based" approach [1]. This control scheme is based on a geometrical representation of the states of switches on the plane where the values on X axis represent phase of the input voltage, and corresponding values on Y axis represent phase of the output voltage. Both input and output functions are assumed to be periodical, and then the entire problem can be narrowed to the $((0,2\pi),(0,2\pi))$ space. The $(0,2\pi)$ interval on the X axis represents the phase of the input voltage, and the corresponding interval on Y axis represents the phase of the output voltage.

Over this space functions $G_{n,m}$, which describe the state of the switches are defined. These functions assume values 1 when the switch is conducting and 0 when the switch is open respectively and can be stated as:

$$G_{n,m} = \sum_{r=-\infty}^{\infty}\sum_{s=-\infty}^{\infty} \mathrm{G}_{r,s}\, e^{jr[\omega_1 t-(n-1)\varepsilon_N]} e^{js[\omega_2 t-(m-1)\varepsilon_M]}$$

Where: ω_1 and ω_2 represent frequencies at both sides of MC, $\varepsilon_N = 2\pi/N$ and $\varepsilon_M = 2\pi/M$.

After substitution :

$$x = \omega_1 t \text{ and } y = \omega_2 t$$

functions of the switch condition can be rewritten as:

$$G_{n,m} = G\left(x-(n-1)\varepsilon_N ,\, y-(m-1)\varepsilon_M\right)$$

and interpreted as two-periodical functions over the space $((0,2\pi),(0,2\pi))$.

The sub-areas of the $((0,2\pi),(0,2\pi))$ space over which values of the functions G are equal to 1 are called the conduction areas of the switches. These conduction areas are created for every switch and are different for every control strategy. The shapes of the conduction areas are theoretically arbitrary, but in real application they are determined by several conditions. Some of these conditions are necessary to assure proper converter working settings and some depends on control strategy.

2. THE CONTROL ALGORITHM

For the 3x3 MC, the planes containing the $((0,2\pi),(0,2\pi))$ spaces, each containing a conduction area for the specific switch can be positioned one over another (FIG.2) to create nine corresponding layers. The plane perpendicular to the set of layers and crossing through each layer, generate on each layer line called the trajectory. The line is generated within a modulo 2π constrain along both axis i.e. if 2π in X or Y direction is reached, the next point of the trajectory is shifted backwards by 2π along corresponding direction (FIG.3). The common parts of the trajectory and the conduction areas generate the switch's conduction pattern.

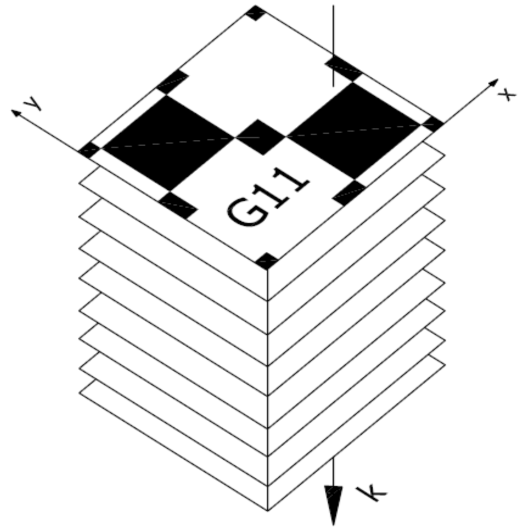

FIG. 2. The layers representing the conduction areas

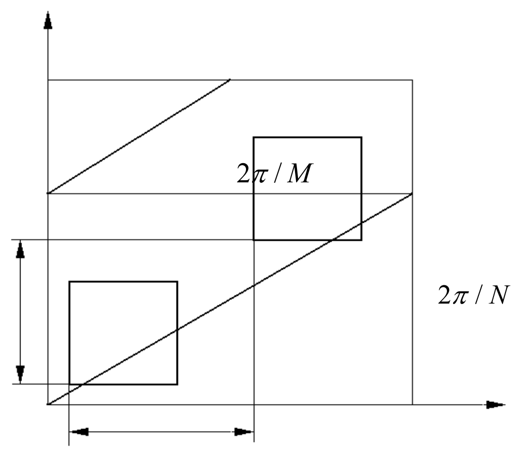

FIG.3. Single plane with trajectory

If the input and output voltages assume the form of sinusoidal functions with the mean value during the period equal to zero (zero offset), the conduction areas for every switch cannot be determined arbitrary, but have to be shaped according to the following rules:

1. They have to have the same shape for every switch
2. The area corresponding to the conduction area of the first switch (G_{11}) is symmetrical in relation to the diagonals of the $((0,2\pi),(0,2\pi)))$ space
3. For N input and M output phases the areas of the following conduction areas are obtained by repeatedly shifting the base conduction area (G_{11}) by $2\pi/3$ along X axis and by

$2\pi/3$ along Y axis (3x3 switches) modulo 2π along each axis

4. To avoid a short-circuit at the input any cross-section of every conduction area along X axis cannot be longer than $2\pi / 3$
5. Any cross-section of every conduction area along Y axis cannot be longer than $2\pi / 3$ to avoid a short-circuit at the output

Furthermore, the conduction areas should cover the $((0,2\pi),(0,2\pi))$ area two or three times, what corresponds to two or three switches conducting at the same time. If this shall not happen, and only one switch is conducting at the time, no current flow through MC is possible.

It should be noted, that by covering the $((0,2\pi),(0,2\pi))$ space by the conduction areas corresponding to the state of the switches, a certain switching pattern is created. If this pattern is synchronized with a zero crossing of the input voltages, it corresponds to the algorithm which creates output voltage at the given instant from the available input voltages. Several different control schemes are possible depending on the shape of the conduction areas and trajectory positioning. The output of the 3x3 MC can resemble the output of a rectifier, a six pulse converter or a cycloconvertor. The additional advantage of this algorithm is the fact that, it is easy to implement it into digital control, and easy to use in the micro-controller based MC handling device.

3. DIGITAL APPLICATION OF THE PROPOSED CONTROL SCHEME

For the application of the proposed MC control scheme, the $((0,2\pi),(0,2\pi))$ area was divided into 360x360 squares (one degree by one degree each), what corresponds to the resolution of $\Delta t = 55 \cdot 10^{-6}[s]$ and requires only 129.600 bites of memory to map a single conduction area over the $((0,2\pi),(0,2\pi))$ space. The control algorithm was then developed for three phases to three phases (9 switches) MC.

Two approaches were considered: one where the states of the switches were obtained from the conduction area of the first switch, the second one where the memory address is a direct pointer to the 9 bites word, which determines the state of all switches. The first approach requires small size memory, but the calculations are longer. The second approach requires larger memory, but calculations are limited only to the determination of the actual memory address.

The first proposed technique uses calculation of the states of the switches on the basis of only one conduction area, the one for the G_{11} switch. The construction of all other conduction areas are done by shifting this area by $\varepsilon_N = \frac{2\pi}{3}$ *and* $\varepsilon_M = \frac{2\pi}{3}$ respectively, along X and Y axis. The relativity of the movement between the conduction areas and the trajectory allows the problem to be reversed - constant trajectory and area movement is equivalent to trajectory movement and constant area. Only one base conduction area and 9 trajectories, each shifted by an angle corresponding to the base area shift are created. The common parts of the trajectories and base area create the time intervals of the conduction of the switches. The method requires only 129600 bits of the data memory, but 9 different trajectories have to be calculated and 9 times the $((0,2\pi),(0,2\pi))$ space has to be searched to create the 9 bit output signal necessary to set the switches. This control technique is easy to implement using any type of 8-bit micro-controllers, but for the required speed of operation (new set of the 9 bits determining the position of the switches every $\Delta t = 55 \cdot 10^{-6}[s]$, it can be too slow.

The second technique is a direct memory search technique. The memory is organized in a 360x360 cluster of 16 bit words or 360x720 8 bit words. The address, corresponding to a certain input voltage phase, is calculated in the form [y x], from a given x and trajectory equation. The values of x and y are combined into one 18 bit memory pointer (values x and y are 9 bit, modulo 360). The 9 bit value under this address is sent directly into processor port. If a 16 bit processor is utilized, only the first 9 bits are used. For 8 bit systems, two addresses are required to store necessary information (360x720 address space). The hardware is already available- for example the 8 bit 8051 based processors with 20 bit addressing capability and 1MB memory 8 bit chips.

4. MATLAB SIMULATION OF MC WORKING UNDER PROPOSED CONTROL

The proposed control procedure, with the conduction area as described in FIG.2, was written in Matlab Simulink as S- function and implemented in the simulation. The schematic of the simulation circuit is shown in FIG.4. The simulations were undertaken under different load conditions. At first, LR load was applied and phase of the output voltage was shifted by 25 degrees (compare to the input voltage) for the same output frequency. The resulting output voltage waveform can be seen in FIG.5.

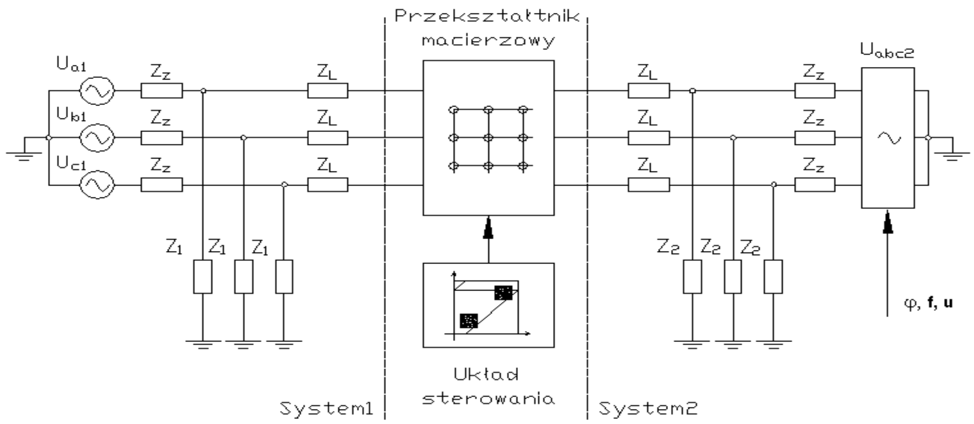

FIG.4. The schematic for the simulation

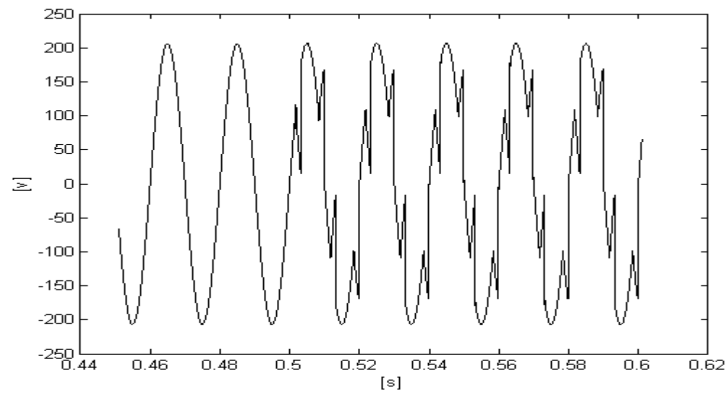

FIG.5. Output voltage of the MC for $U_{abc2} = 0$. At instant of 0.5s phase shift 25 degrees was applied

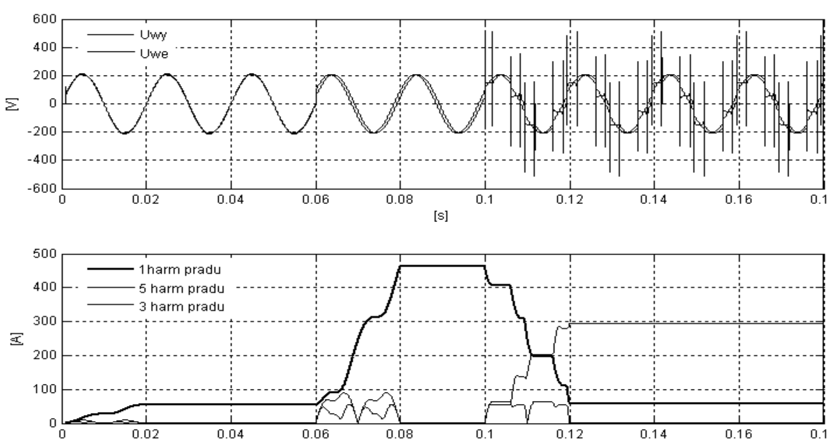

FIG.6. Voltages and currents of MC

In the second example of the simulation (FIG.6), MC acted as an interconnection device between two power systems. At the instant of 0.06s the phase of the system2 voltage source was shifted by 30 degrees, resulting increase of the current. At 0.1s the phase of the output voltage of the MC was shifted by 28 degrees, what caused the first harmonic of the intersystem current to decrease. The current, however contains a large dose of low order harmonics.

During the simulations of MC work in two way powered systems, it was noticed that after the voltage phase shift in the system 2, the MC is not always able to depress the amplitude of first harmonic of the current to the value equal to the one from before the disturbance.

Further investigation revealed, that the phase shift of the MC output voltage is, for chosen control algorithm, accompanied by the output voltage change FIG.7. The voltage transfer of MC decreases from 1 at phase shift 0 degrees to 0.82 for phase shift 60 degrees. For 3x3 MC the situation repeats every 120 degrees

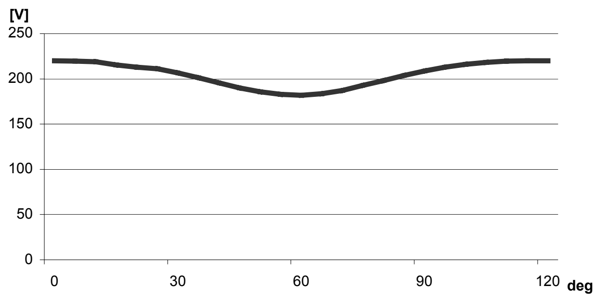

FIG.7. Voltage transfer of the PM for the proposed control scheme

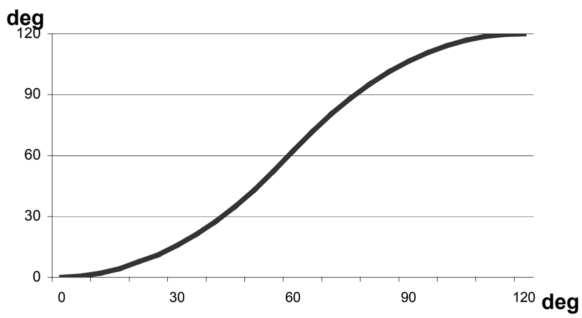

FIG.8. The phase of the output voltage versus trajectory shift

For control purposes it is also necessary to know how the phase of the output voltage changes as a response to the trajectory shift, for the proposed control scheme. The relation shown in FIG.8 is strongly non-linear and must be included in the control algorithm if the phase of the output voltage of PM is intended to be controlled.

The next group of simulations includes the change of the output frequency. The interconnections in the power systems, which can operate between the sources of different frequency, are commonly used to couple renewable energy sources to the network. The waveforms of the conversion of 50 Hz voltage to the 120 Hz voltage can be seen in FIG.9.

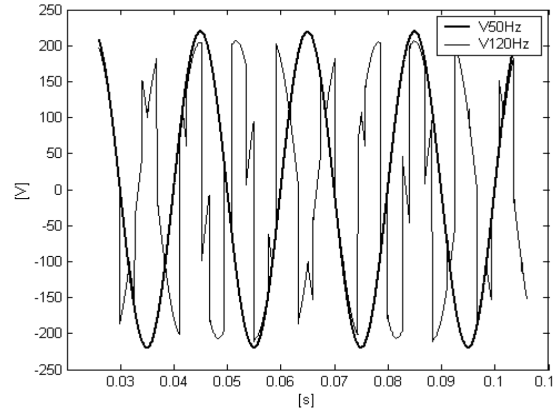

FIG.9. The conversion 50Hz voltage to 120 Hz waveform for RL load

5. CONCLUSION

The matrix converter as the inter-system connector was supposed to control constant current flow from one system to another, to avoid power flow oscillations after disturbances. The proposed control strategy has several advantages: during the steady state operation, when the reaction of MC is not required three switches G_{11}, G_{22}, G_{33} are permanently switched on connecting respectable phases, the input and output currents are always continuous (expect commutation times). The strategy is easy to implement and the change of the control algorithm requires only the change of the shape of the conduction areas. The change of the phase and frequency of the output can be done continuously, by simply shifting the position of the trajectory.

However, due to the fact that the strategy operates over the envelope of the waveform of input voltages (which is not constant line), the output voltage can be created only from the voltages available at the input at the same instant. This fact causes the output voltage transfer to become a function of the input-output phase shift. It is possible to implement voltage increasing transformer at the input, but in this case the possibility of a non invasive work and symmetry of the MC is lost. Other, then based on areas shown in FIG.2, control schemes were investigated and revealed better voltage transfer, but at the cost of current discontinuity or a short-circuits at the output.

The three phases to three phases matrix converter produces a large amount of low order harmonics in input and output currents (FIG.6) that are difficult to remove. The main cost for the proposed application for 3x3 MC will be not associated with converter itself, but with the filters [4]. The filters have to be designed in such way that, they should not only filter lower harmonics, but also not influence the converter work.

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