Simplified Matrix Converter Fed Induction Motor Drive

Vinod Battu, Grandhi Ramu

Abstract—Matrix converter (MC) consists of an array of bidirectional switches, which are used to directly connect the power supply to the load without using any dc-link or large energy storage elements. These highly attractive characteristics are the reason for the tremendous interest in this topology. One of the biggest difficulties in the operation of this converter was the commutation of the bidirectional switches. This problem has been solved by introducing intelligent and soft commutation techniques, giving new momentum to research in this area. . The aim of this paper is to propose a scalar matrix converter modulation equivalent to the SVM ones in order to obtain the same electrical characteristics with a simple approach. Then, the proposed symmetrical carrier-based PWM, equivalent to the SVM, is applied to control the induction motor.

Index Terms— Matrix converter,Space vector Modulation, Carrier based SVM, Induction Motor..

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1 INTRODUCTION

The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub harmonics; it has inherent bi-directional energy flow capability; the input power factor can be fully controlled. Last but not least, it has minimal energy storage requirements, which allows to get rid of bulky and lifetime- limited energy-storing capacitors.

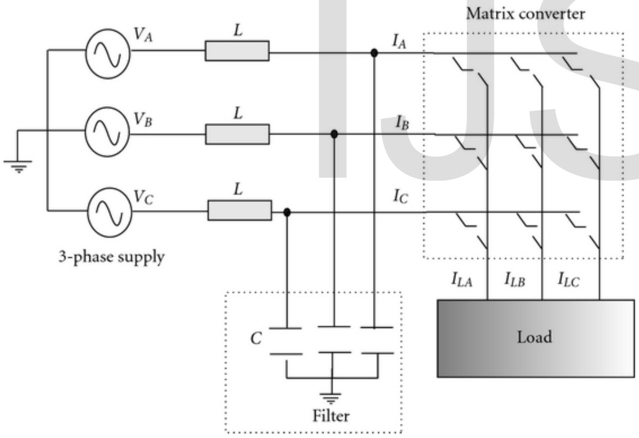

Fig.1 Matrix coonverter

The matrix converter consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. The circuit scheme is shown in Fig.1.The input terminals of the converter are connected to a three phase voltage-fed system, usually the grid, while the output terminal are connected to a three phase current- fed system, like an induction motor might be. The capacitive filter on the voltage- fed side and the inductive filter on the current- fed side represented in the scheme of Fig.2.1 are intrinsically necessary. Their size is inversely proportional to the matrix converter switching frequency [2]. It is worth noting that due to its inherent bi-directionality and symmetry a dual connection might be also feasible for the matrix converter: a current- fed system at the input and a voltage- fed system at the output

With nine bi-directional switches the matrix converter can theoretically assume 512 (29) different switching states combinations. But not all of them can be usefully employed. Regardless to the control method used, the choice of the matrix converter switching statescombinations (from now on simply matrix converter configurations) to be used must comply with two basic rules. Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short-circuited and the output currents should not be interrupted. From a practical point of view these rules imply that one and only one bi-directional switch per output phase must be switched on at any instant. By this constraint, in a three phase to three phase matrix converter 27 are the permitted switching combinations.

One of the biggest difficulties in the operation of this converter was the commutation of the bidirectional switches. This problem has been solved by introducing intelligent and soft commutation techniques, giving new momentum to research in this area.It is therefore relevant to propose simple, but efficient modulation schemes like the three phase VSI modulation, with the well-known symmetrical carrier-based modulation. Thus, an interesting scientific and industrial approach is to propose a symmetrical carrier based modulation to greatly simplify this implementation and its understanding. The aim of this paper is to propose a scalar matrix converter modulation equivalent to the SVM ones in order to obtain the same electrical characteristics (same logic state at each time, same constraints, same efficiency…), with a simple approach. Then, the proposed symmetrical carrier-based PWM, equivalent to the SVM, creates, without any additional calculation, the nine logic control signals of the matrix converter switches by using the matrix [M]. This modulation process can be extended to other PWM strategies.

2 INDUCTION MOTOR MODEL

In the control of any power electronics drive system(say a motor), to start with a mathematical model of the plant is required. This mathematical model is required further to design any type of controller to control the process of the plant. The induction motor

$$u_d = R_1 i_d + \frac{d\psi_d}{dt} - \omega_1 \psi_q$$

$$u_q = R_1 i_q + \frac{d\psi_q}{dt} - \omega_1 \psi_d$$

$$u_{dr} = R_2 i_{dr} + \frac{d\psi_{dr}}{dt} - (\omega_1 - \omega)\psi_{qr}$$

$$u_{qr} = R_2 i_{qr} + \frac{d\psi_{qr}}{dt} - (\omega_1 - \omega)\psi_{dr}$$

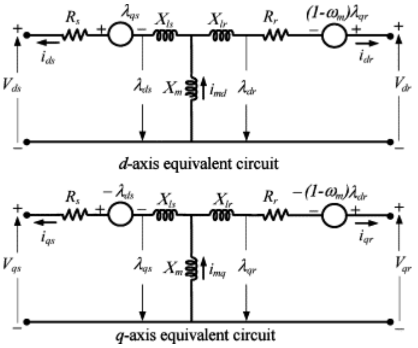

Fig.2 Equivalent circuit of induction motor in *d -q* fram model is established using a rotating (*d*, *q*) field reference (without saturation) concept.. The equivalent circuit used for obtaining the mathematical model of the induction motor is shown in the Fig. 2. An induction motor model is then used to predict the voltage required to drive the flux and torque to the demanded values within a fixed time period[9]. This calculated voltage is then synthesized using the space vector modulation. The stator & rotor voltage equations are given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{L_m}{L_r}\left(i_{qs}\lambda_{dr} - i_{ds}\lambda_{qr}\right).$$

where u_{sd} and u_{sq}, u_{rd} and u_{rq} are the direct axes & quadrature axes stator and rotor voltages. The squirrel-cage induction motor considered for the simulation study in this paper, has the *d* and *q*-axis components of the rotor voltage zero. By superposition, i.e., adding the torques acting on the *d*-axis and the *q*-axis of the rotor windings, the instantaneous torque produced in the electromechanical interaction is given by

3 CARRIER BASED SVM

In this part, the basic knowledge of the SVM applied to matrix converter is introduced to highlight the proposed modulation objectives. The well-known matrix converter Space Vector Modulation (SVM) [1]-[4] approach leads to define three vector families:

- First family: 6 rotating vectors (each phase input is connected to a different phase output).
- Second family: 3 null vectors (free wheeling ie a switches configuration leading to zero voltage on the load) called *Oi* with i = 1, 2 or 3.
- Third family (the remaining ones): 18 active vectors called *Aj* (with a fixed angular position, and proportional to one input phase-to-phase voltage), where j is an integer between 1 and 18.

Matrix SVM modulations use only the two last families to create output voltages and input currents [17], [18], as the first one has a vector position varying with the time, which is not useful for building the references with the space vector approach.

The general matrix SVM sequence, shown in Fig. 2, uses four active vectors Ak (among the six vectors nearest to the output voltage reference vector), and one to three null states Ok to complete the PWM period. This specific sequence allows having only one switching when a vector is changed.

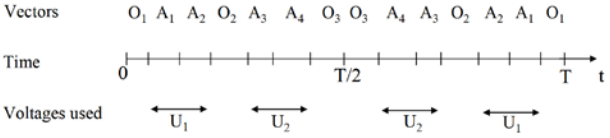

Fig. 3. General SVM sequence for the matrix converter

In classical SVM methods, only the two greatest phase-to-phase input voltages (U1 and U2 in Fig. 2) and also a null voltage (free-wheeling state) are connected to outputs (u, v, w) during a PWM period (T) [19]-[21].

The null vector O2 automatically involves at the output the common potential to U1 and U2, which is in fact the highest input phase potential in absolute value. A particular modulation can be defined by only using this null state O2, which generates a discontinuous modulation (DPWM) [19]. This terminology is proposed here, as this specific choice allows blocking one of the three "switching cells" of the matrix converter, in the same way as one inverter leg is blocked when using discontinuous PWM in VSI. This particular modulation, presented in Fig. 3, reduces the number of switching and increases the converter efficiency compared to the general SVM sequence (Fig.2.).

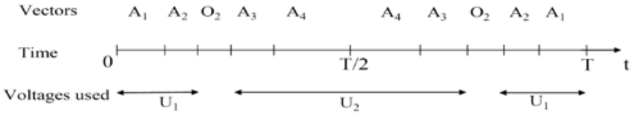

Fig.4. DPWM SVM sequence for the matrix converter

To generate this DPWM SVM, it is necessary to

- use the two greatest phase-to-phase input voltages to build the output voltages,
- use only the null state connected to the highest input phase potential in absolute value. In the SVM sequence, this particular null state is necessarily positioned in the medium part of the half PWM period.

The aim of the article is to propose a carrier based modulation method to obtain the SVM DPWM sequence, involving less calculation and thereby a simpler solution compared to the classical SVM implementation

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4 SPEED CONTORL OF INDUCTION MOTOR WITH MATRIX CONVERTER

An interesting and elegant protection scheme which might be used to prevent output side overvoltages due to hard shutdown of the converter was firstly proposed in [29] and more recently implemented in [30]. The method simply consists in a proper control strategy of the matrix unidirectional switches to be carried out after the emergency stop command has been set and before shutting-down the converter. The control strategy basically aims to create the same operating conditions of a traditional DC-link voltage converter at the shutdown. In traditional DC-link voltage converter (Fig.2.11), when all the switches are turned off, a static free-wheeling path to the motor currents is provided by the free-wheeling diodes. Through these paths the magnetic energy stored in the motor can be automatically transferred to the DC- link energy storage elements without any over voltages and over currents risk.

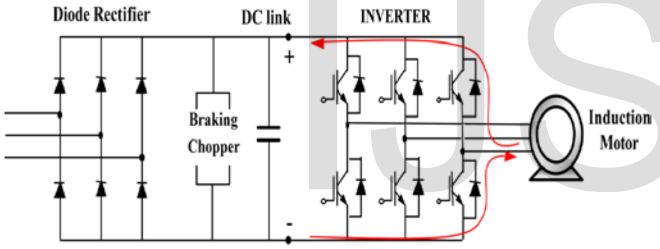

Fig. 5 Conventional control of Induction motor using DC link inverter and rectifier.

For the matrix converter, since no static free-wheeling paths are available, such operating condition must be actively imposed. The positive and negative DC rails are respectively substituted by the most positive and most negative input line-to-neutral voltage. For each output line current, the unidirectional switches of the matrix that provide a flowing path direct to and coming from the positive and negative rail respectively, have to be turned on.

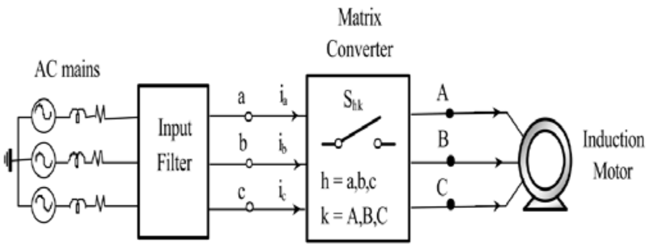

Fig. 6 Induction motor control using matrix converter.

5 SIMULATION RESULTS

The carrier based modulation has been implemented and used to control the induction motor. Proposed method has been simulated in MATLAB/Simulink and the simulation model is shown in figure 7. Simulation model of the matrix converter is shown in figure 8.

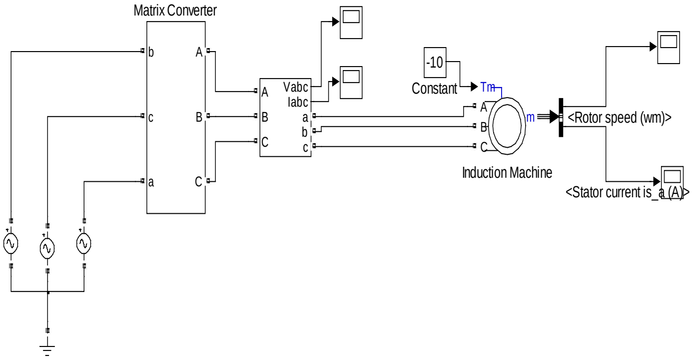

Fig 7. MATLAB/Simulink model of the matrix converter based induction motor control

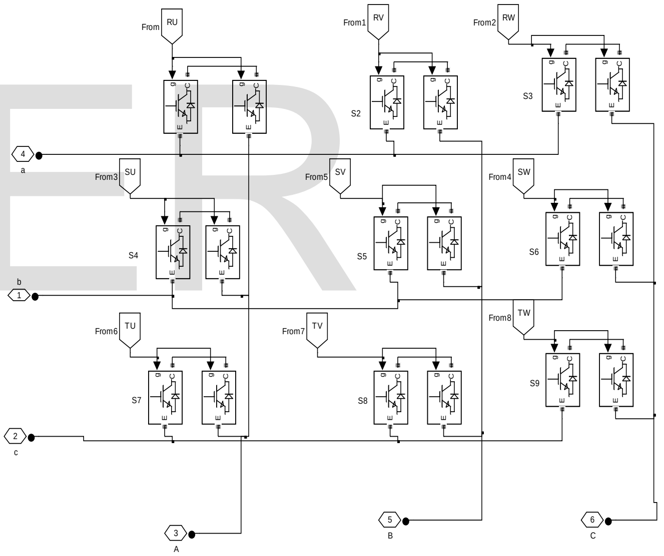

Fig 8.MATLAB/Simulink model of the matrix converter.-

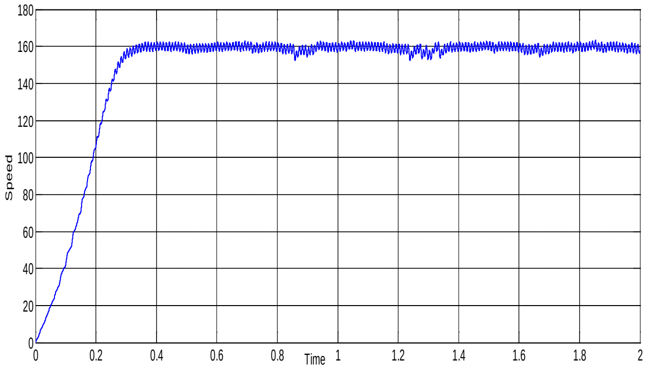

Fig. 9 Speed of the induction motor with paper title and editor)

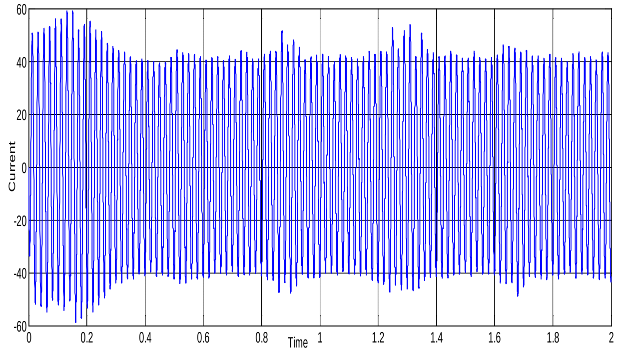

Fig. 10 Stator current supplied to the induction motor

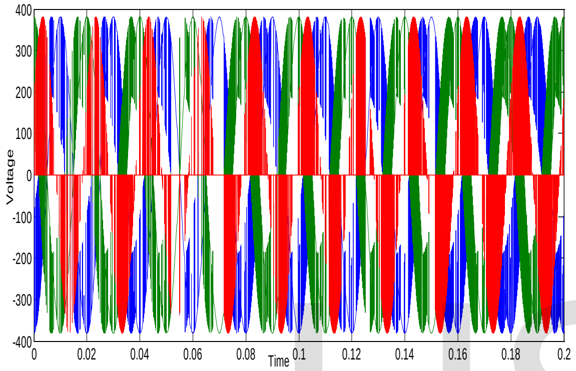

Fig. 11 Output voltages of the matrix converter

6. CONCLUSIONS

This paper has presented an original carrier-based modulator for matrix converters based on a "virtual matrix converter" concept. This choice limits to four the number of duty cycle calculations. The proposed carrier-based modulator creates the same instantaneous connexion matrix [S] as the SVM or the RIV (in the DPWM specific case here), but with less calculation and with a more synthesized and systematic approach. Therefore, this modulation is easier to implement compared to the previous ones. Speed control of Induction motor using matrix converter is presented in the paper and MATLAB/SIMULINK results are also presented.

7. REFERENCES

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