Investigations on Matrix Converter for Induction Motor Drive during Abnormal Conditions

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ABSTRACT
The matrix converter connects the three-phase power supply with the three-phase load directly through a switching matrix composed of four-quadrant switches. In order to evaluate and improve the performance of matrix converter, some experimental tests in typical abnormal conditions have been carried out. The basic topology of Matrix Converter (MC) consists of a three-phase MC consists of nine bidirectional switches, which allow pulse width modulation (PWM) control of input currents and output voltages. The maximum line–line output voltage of the matrix converter must not be greater than the minimum line–line input voltage. An often-cited drawback to the matrix converter is the theoretical voltage conversion limit of 0.86. When high dynamic performance and precision control are required for an induction motor in a wide speed range, the speed must normally be measured. In contrast, in the case of medium and low performance applications, sensorless control without measuring the motor speed is desirable as they tend to reduce system reliability when working in hostile environments. This also describes the working principle, space vector modulation strategy of matrix converter, characteristics of fuzzy control, and the basic principle of adaptive fuzzy PID. The use of fuzzy makes the control of matrix converter more reasonable. Combining fuzzy control and closed-loop control can effectively improve the input and output waveforms of matrix converter.

Keywords
Matrix converter, Induction Motor Drive, Abnormal Conditions, Space Vector Modulation, Fuzzy PID controller.

1. INTRODUCTION
The matrix converter (MC) is fully regenerative and has low total harmonic distortion (THD) input currents with unity power factor. Since the concept of MC topology, a forced commutated direct AC-to-AC converter [1], its characteristics have been widely discussed. The matrix converter (MC) stability under abnormal conditions is an important issue, which attracts high attentions these years. Using this type of converter decreases the instability problems, owing to the absence of an intermediate dc-link with energy storage capability and to the reduced size of the input filters. In this case any input voltage disturbance is reflected on the output voltages determining low order harmonics. It is possible to compensate these effects by monitoring the input voltages and, employing intelligent technique for reckoning the duty-cycles necessary to generate balanced and sinusoidal output voltages. Also, high performance of MC fed induction motor drive could be obtained over a wide operating range, if some compensation techniques are used in abnormal conditions [2]. In this way, constant power operating conditions are in general achieved.

In order to overcome this problem a different filter structure will be considered. It has been observed that the use of a digital low pass filter to the input voltages increases the matrix converter stability, leading to a sensible improvement of the maximum output power. It can be seen that by applying a digital low-pass filter to the input voltages, and using these filtered voltages for calculating the duty-cycles of the matrix converter switching configurations, it is possible to improve the system stability, with no additional hardware. Initial simulation reveals that the use of a digital low pass filter to the input voltages increases the matrix converter stability, leading to a sensible improvement of the maximum output power. Further, a novel switching strategy is contemplated to reduce input current harmonics for ac-ac matrix converter based system.
Fig. 1 shows the basic topology of a MC [3]. A three-phase MC consists of nine bidirectional switches, which allow pulse width modulation (PWM) control of input currents and output voltages. It does not involve intermediate dc link and the associated capacitive filter. An understanding of the commutation procedure from one switch to another is very important for practical PWM control. The commutation between bidirectional switches should be carefully controlled under the following constraints: 1) avoiding input line-to-line short circuits and 2) avoiding output open circuits. Several multistep commutation strategies were introduced which obey these constraints [2].

2. MATRIX CONVERTER POWER STAGE [4]
The maximum line–line output voltage of the matrix converter must not be greater than the minimum line–line input voltage. An often-cited drawback to the matrix converter is the theoretical voltage conversion limit of 0.86 [5]. This limit is due to the fact that the maximum output voltage can never be higher than the greatest difference between the line-to-line input voltages. The objective of any matrix converter modulation strategy is to obtain the target output voltages and sinusoidal input currents at a controlled input power factor subject to the constraints of not open circuiting any output phase and of not short circuiting any two input phases [6].

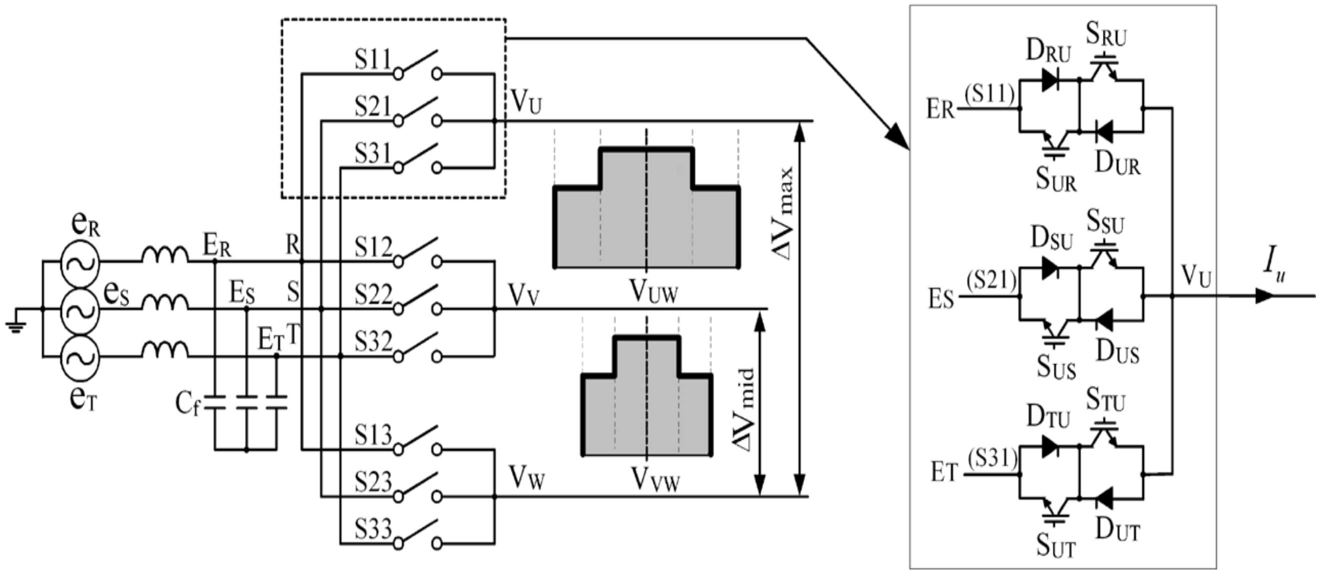

Fig. 1. Topology of Matrix Converter

However, in applications where there is a design choice on the machine voltage, this ratio is not an important consideration [6]. The matrix converter, as presented in Fig. 2(a), uses the traditional 12 bidirectional semiconductor switch topology, [a total of 24 common-emitter-connected insulated-gate bipolar transistors (IGBTs)]. An example of the implementation of the required bidirectional switches is shown in Fig. 2b, each bidirectional switch comprising of two IGBTs and series diodes in a back-to-back arrangement [5]. The switching devices required by the matrix converter can be compared to the fifteen switching devices needed for a typical controlled rectifier/voltage source inverter with the same functionality [4].

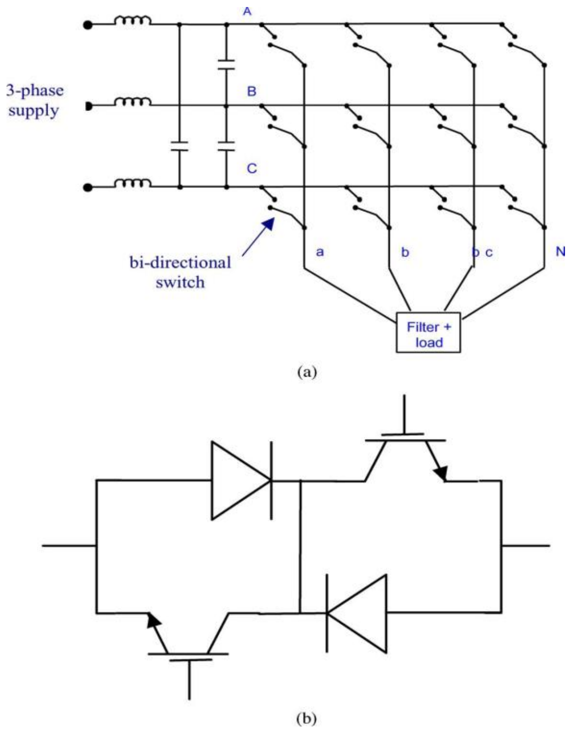

Fig. 2. (a) Basic matrix converter circuit, (b) Example of a bidirectional switch configuration [4]

3. SENSORLESS DTC-SVM FOR MATRIX CONVERTER DRIVES

3.1 Speed-Sensor less DTC-SVM for Matrix Converter Drives

Adjustable-speed drives are widespread electromechanical systems suitable for a large spectrum of industrial applications. When high dynamic performance and precision control are required for an induction motor in a wide speed range, the speed must normally be measured. In contrast, in the case of medium and low performance applications, sensor less control without measuring the motor speed is desirable as they tend to reduce system reliability when working in hostile environments. As a consequence, a great deal of research has been carried out in sensor less drives over the last few decades. Adaptive observer based sensor less schemes seem attractive as they are relatively simple to implement [7].

A new adaptive estimator using a parameter estimation technique is proposed. It is assumed that only the stator currents and voltages are measurable, and that the stator currents are assumed to be bounded. The state estimation problem is converted into a parameter estimation problem assuming that the rotor speed is constant [8]. The speed and parameter adaptation laws are designed such that the estimated stator currents converge to the measured ones. Some stability properties are provided on the basis of Lyapunov analysis. In addition, the stator resistance can also be estimated within the same framework. A modified direct torque control with space vector modulation (DTC-SVM) scheme using an overmodulation strategy for matrix converter drives is employed, which enables minimizing torque ripple and obtaining a unity input power factor, while maintaining constant switching frequency and fast torque dynamics [9]–[11]. Fig. 3 shows the whole control block diagram of a DTCSVM matrix converter drive, which consists of a modified DTC with an overmodulation strategy, the detection of input voltage angle, indirect space vector modulation (ISVM), an adaptive estimator for speed and flux estimation, and compensation of nonlinearities of the matrix converter [12].

3.2. Novel Unified DTC-SVM for Matrix Converter Drives

The basic DTC method for matrix converter drives allows for the generation of the voltage vectors required to implement the DTC of the induction motor under a unity input power factor constraint [8]. However, the switching frequency varies according to the motor speed and the hysteresis bands of torque and flux, a large torque ripple is generated in a low speed range because of the small back EMF of an induction motor, and high control sampling time is required to achieve good performance [13]. To cope with these problems, a new DTC is proposed. The proposed scheme consists of a deadbeat controller with an overmodulation strategy and a detector of the input voltage angle.

4. THE SPACE VECTOR MODULATION FOR MATRIX CONVERTER

The modulation strategy is also named indirect conversion method or AC-DC-AC equivalent transformation. Assume AC-AC conversion of matrix converter is made up of rectifying and inverting, which respectively adopts high table to adjust parameters Fig. 4[15]. The kernel of fuzzy control design is to summarize technological knowledge and actual experience of engineering technicians. A fitting fuzzy rule table is set up to get a fuzzy control table for respectively setting three parameters-KP, KI, and KD [14].

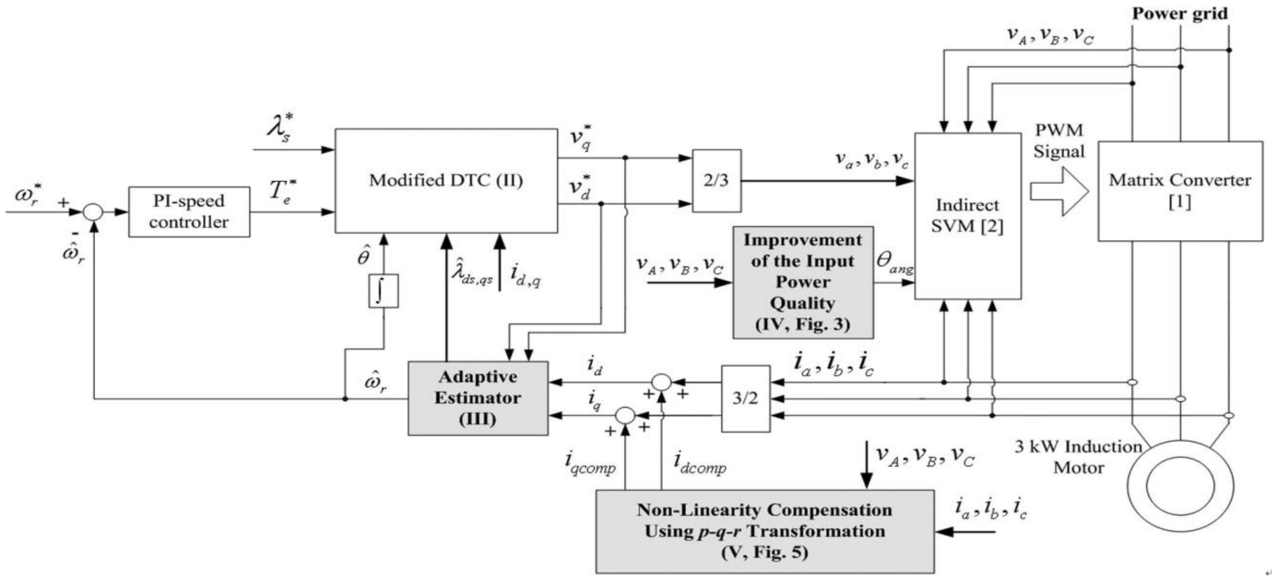

Fig. 3. Proposed sensor less DTC for matrix converter drives [8]

frequency rectifying and high frequency inverting PWM waveform composition technique [14]. Finally, the two processes are comprehended to get direct AC-AC transformation. Because the input currents and output voltages respectively have 6 basic effective space vectors, there are 36 kinds of switching combinations. Each of them corresponds to some three switches on in 9 switches [14-15].

Besides, there are three kinds of zero switching combinations in 9 switches. That is to say, the three switches connected by U, V, W three input lines are respectively switched on at the same time. In a PWM period, 5 comprehensive cycle ratios can be gotten from the modulation strategy. Correspondingly, there are 5 kinds of different switching combinations. So the control for matrix converter can be concluded to calculate 5 cycle ratios as well as the corresponding 5 kinds of different switching combinations

4.1. Adaptive Fuzzy PID Controller

On the basis of PID algorithm, it uses fuzzy rules to carry out fuzzy inference by calculating the error e and its variable rate etc. of the present system. Then we look up the fuzzy matrix

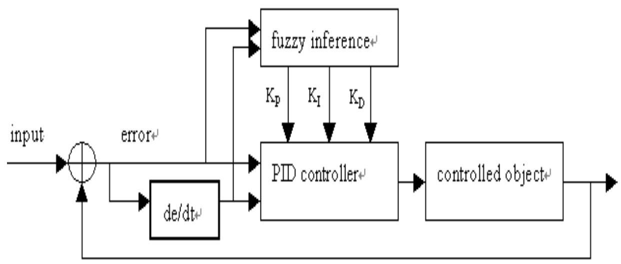

Fig.4 The controller structure of adaptive fuzzy PID [14]

Three simulated models have been set up [14]. They are opened-loop, closed-loop with common PID and adaptive fuzzy PID respectively. Simulation results revealed that the amplitude of three-phase input voltages is 1, 0.85 and 1.3, respectively for convenient analysis [14]. That is to say, they are under unbalanced input voltages. The input frequency is 50Hz; output frequency is 30Hz; modulation index is 0.80; switching frequency is 6kHz; bidirectional switches are ideal ones, the simulation time is 40ms. Simulation algorithm is ode15s. It has been concluded from the simulation waveforms that the output currents and output line-to-line voltages are gradually improved. Among them, the results of adaptive fuzzy PID are best. It is concluded that combining fuzzy control and closed-loop can effectively improve output waveforms under unbalanced input voltages.

5. CONCLUSION

Matrix Converter has many advantages that include bi-directional power flow, a size reduction, a long lifetime, and sinusoidal input currents. Furthermore, in connection with this technique, a novel insulated gate bipolar transistor (IGBT) with reverse blocking capability has been developed to improve the efficiency.

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