2011 International Conference on Signal, Image Processing and Applications
With workshop of ICEEA 2011
IPCSIT vol.21 (2011) © (2011) IACSIT Press, Singapore

Comparison between 3-Level Classical Method and 7-Level Proposed Method of an Induction Machine by Using Direct Torque Control - Matrix Converter

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Abstract. Direct Torque Control (DTC) for induction motors using Matrix Converter (MC) is becoming one of the most popular control methods. This paper is aimed to give a contribution for a detailed comparison between 3-Level classical and 7-Level proposed control techniques, emphasizing advantages and disadvantages. Torque ripple and output THD is one of the most important drawback of DTC-MC classical method .By using new standard look up table and new hysteresis comparator with seven levels for use of all voltage vector selection table of DTC-MC proposed method is improved in order to reduce electromagnetic torque ripple and output current THD. The analysis has been carried out on the basis of results obtained by simulation.

Keywords: Direct torque control, Matrix converter, Induction motor.

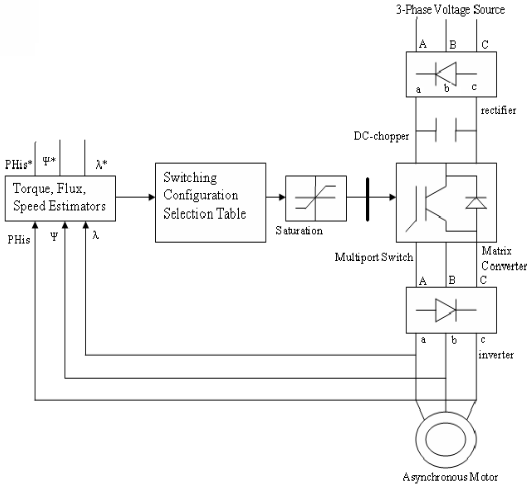
1. Introduction

DTC-MC proposed is a high dynamic and high performance control technique. The real development of Matrix Converter starts with the work of Venturini and Alesina published in 1980. The Matrix Converter with only nine switches can be effectively used in the vector control of an induction motor with high quality input and output current. The main aim of this paper is to give a fair comparison between the two schemes (classical and proposed) in a realistic numerical simulation of the drive. In both cases the results obtained emphasizes which one of the two schemes can be effectively employed in the various applications that today require torque control and finally gives the effectiveness of the proposed drive system. Yaskawa Company has implemented a commercial Matrix Converter and Eupec Company has developed a new technology for integrating the whole Matrix Converter power devices in a single package integrated power modules.

In this control scheme the motor flux and torque are the reference quantities which are directly controlled by the applied inverter voltage vector. DTC main features are as follows: Direct control of flux and torque, indirect control of stator currents and voltages, approximately sinusoidal stator fluxes and stator currents, high dynamic performance even at stand still. DTC –MC main advantages: Fast torque and flux responses in a wide speed range, Low switching losses, low THD, low torque ripple, long life, Sinusoidal input/output waveforms, Bidirectional power flow, Robust construction Unnecessary use of regeneration converter, Capable of converting AC-AC, Providing generation of load voltage with arbitrary amplitude and frequency, Operation with unity input power factor, Minimizing the stray inductance and the size of the power devices, no need of capacitors. Disadvantages of classical DTC-MC : Possible problems during starting, Requirement of torque and flux estimators, Inherent electromagnetic torque and stator flux ripple, High noise level at low speed. DTC-MC proposed scheme can overcome the disadvantages obtained by classical. The current deviations and the torque ripple of the motor can be effectively reduced by using DTC-MC proposed. In this paper a new control Matrix Converter is proposed which allows the generation of the voltage vectors required to implement the DTC of induction machines. By selecting the most appropriate voltage vector the new look-up table and new hysteresis comparator with seven levels output the system will differentiate between small, medium and large torque errors and consequently reduce the electromagnetic torque ripple and output current THD. Simulation results demonstrate the effectiveness of the proposed scheme.

2. Classical DTC-MC Method

2.1. Block diagram of classical DTC-MC



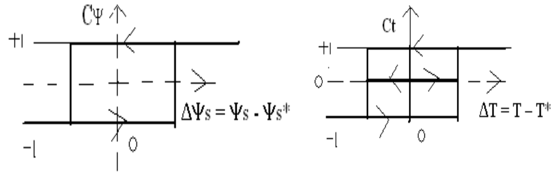


Fig. 1: Block diagram of classical DTC-MC Fig 2:3-level hysteresis comparator

In addition to stator flux and torque another additional third variable and average valve of the sine of the displacement angle is added. When instantaneous errors in flux magnitude and torque are generated, the control technique of the Matrix Converter selects at each sampling period, the proper switching configuration. The hysteresis 3 level comparator directly controls this variable shown in Fig 1. Assuming v1 is the output voltage vector. The magnitude and the direction of the corresponding output voltage vector depend on the input voltage vector. Among the 6 vectors, those having the same direction of v1 and the maximum magnitude are considered. If the input voltage vector lies in sector 1, +1and -3 are the switching configurations utilized.

Input current vectors lying on the directions adjacent to sectors 1 and 4.Then, if the average value of sin has to be decreased, the switching configuration -3 has to be applied. Otherwise +1 has to be applied to increase. The switching table based on these principles is shown in Table I. Depending on the output value of the hysteresis comparator, the left or the right sub column has to be used in selecting the switching configuration of the matrix converter. When a zero voltage vector is required from the zero configuration of the matrix converter, which minimize the number of commutations is selected. A schematic diagram of the classical drive system is represented in fig 1 .The reference values of torque and stator flux are compared with the estimated values. The output of the hysteresis comparators, together with the numbers of the sectors of the stator flux vector and input line to neutral voltage vector, are the input to the switching configuration selection algorithm of Table I.

Table I Selection Table of Matrix converter

	Sector of input phase voltage vector											
	❶		❷		❸		❹		❺		❻	
C_ψ	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1
$V_{1\text{-}vsi}$	-3	1	2	-3	-1	2	3	-1	-2	3	1	-2
$V_{2\text{-}vsi}$	9	-7	-8	9	7	-8	-9	7	8	-9	-7	8
$V_{3\text{-}vsi}$	-6	4	5	-6	-4	5	6	-4	-5	6	4	-5
$V_{4\text{-}vsi}$	3	-1	-2	3	1	-2	-3	1	2	-3	-1	2
$V_{5\text{-}vsi}$	-9	7	8	-9	-7	8	9	-7	-8	9	7	-8
$V_{6\text{-}vsi}$	6	-4	-5	6	4	-5	-6	4	5	-6	-4	5

Table II Small voltage vectors of proposed method

Sector	1	2	3	4	5	6	7	8	9	10	11	12
H_ψ	-	+	-	+	-	+	-	+	-	+	-	+
V_{1-vsi}	-2	2	1	-1	-3	3	2	-2	-1	1	3	-3
V_{2-vsi}	8	-8	-7	7	9	-9	-8	8	7	-7	-9	9
V_{3-vsi}	-5	5	4	-4	-6	6	5	-5	-4	4	6	-6
V_{4-vsi}	2	-2	-1	1	3	-3	-2	2	1	-1	-3	3
V_{5-vsi}	-8	8	7	-7	-9	9	8	-8	-7	7	9	-9
V_{6-vsi}	5	-5	-4	4	6	-6	-5	5	4	-4	-6	6

3. Proposed Dtc-Mc Method

3.1. Block diagram of DTC-MC proposed method

From Fig 4 the reference values of speed, flux and torque are given as an input to the estimator .In this estimator the reference values and motor output values, which are feedback to the estimator are compared. In the second stage the use of all voltage vector selection tables is used again to compare the torque estimator, voltage estimator and current discrete pll by using relay. Finally the matrix converter is used to take the most appropriate signal and then gives perfect output to the motor with reduction in torque ripples. By dividing the input voltage vector path into twelve sectors, according to Fig. 4 and using the new MC switching table for DTC presented in Table II&III, the DTC algorithm will be able to distinguish between small, medium and large vectors. In order to reduce the torque ripple, in addition to the large vectors of MC, the medium and small vectors can also be used. Thus the DTC scheme must be modified resulting in a new torque hysteresis comparator that will provide seven different levels instead of three levels to distinguish between small, medium and large positive and negative torque errors.

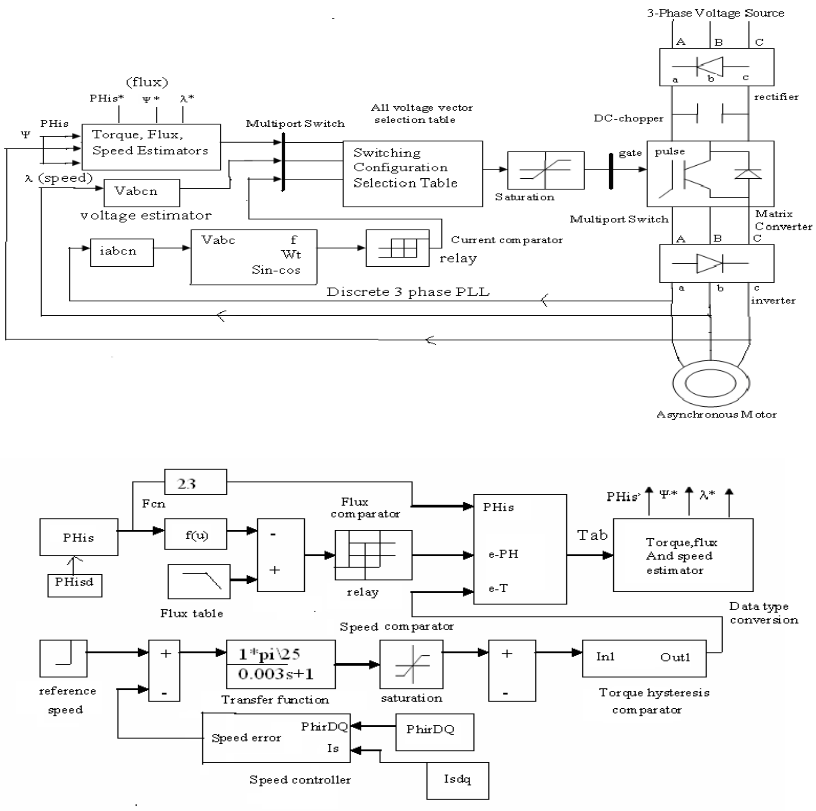


Fig .4: Block diagram of DTC-MC Proposed method

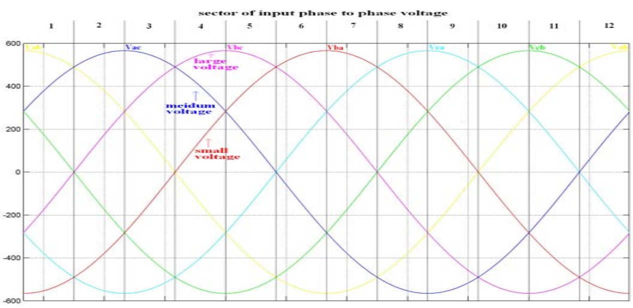


Fig.5: Small, medium & large input line voltage comparator

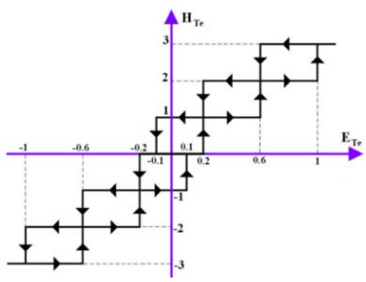


Fig.6: Seven level Hysteresis

If the ideal value of Cψ for power factor hysteresis comparator can't be found in one input voltage sector, then the other vector in the same sector can be selected from Table IV to control the unit input power factor.

When the absolute value of torque error Ete is equal to or greater than 0.6,and less than 1, the value of The is +2,the medium voltage vector table error is selected and Ete will decrease until the absolute value of Ete is equal to 0.2. When the absolute value of torque error Ete is equal or greater than 1, the value of The is +3, the large voltage vector table is selected and Ete will decrease until the absolute value of Ete is equal to 0.6. When the absolute value of torque error Ete is equal to or greater than 0.2, and less than 0.6, the value of Hte is +1, the small voltage vector table is selected and Ete will decrease until the absolute value of Ete is equal to 0.1.

Table III. Table represents medium and large vectors for proposed method

MEDIUM VECTORS

Sector	1	2	3	4	5	6	7	8	9	10	11	12
H_ψ	+	-	+	-	+	-	+	-	+	-	+	-
V_{1-vsi}	-3	1	2	-3	-1	2	3	-1	-2	3	1	-2
V_{2-vsi}	9	-7	-8	9	7	-8	-9	7	8	-9	-7	8
V_{3-vsi}	-6	4	5	-6	-4	5	6	-4	-5	6	4	-5
V_{4-vsi}	3	-1	-2	3	1	-2	-3	1	2	-3	-1	2
V_{5-vsi}	-9	7	8	-9	-7	8	9	-7	-8	9	7	-8
V_{6-vsi}	6	-4	-5	6	4	-5	-6	4	5	-6	-4	5

LARGE VECTORS

Sector	1	2	3	4	5	6	7	8	9	10	11	12
H_ψ	-	+	-	+	-	+	-	+	-	+	-	+
V_{1-vsi}	1	-3	-3	2	2	-1	-1	3	3	-2	-2	1
V_{2-vsi}	-7	9	9	-8	-8	7	7	-9	-9	8	8	-7
V_{3-vsi}	4	-6	-6	5	5	-4	-4	6	6	-5	-5	4
V_{4-vsi}	-1	3	3	-2	-2	1	1	-3	-3	2	2	-1
V_{5-vsi}	7	-9	-9	8	8	-7	-7	9	9	-8	-8	7
V_{6-vsi}	-4	6	6	-5	-5	4	4	-6	-6	5	5	-4

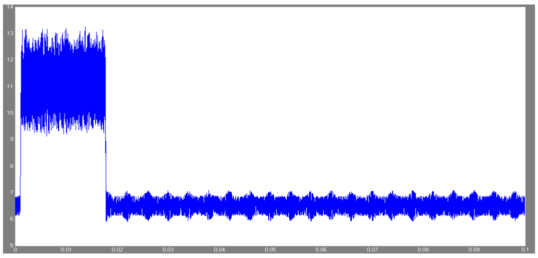
4. Simulation Results

The simulation model of this DTC-MC proposed adjustable speed system is set up with simulink using MOSFET switches. The parameters used are

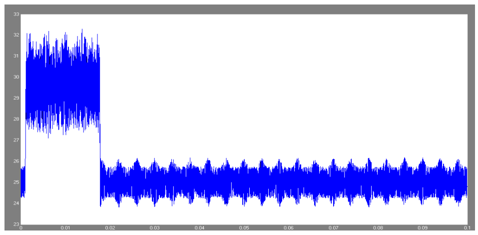
power=3.7kva, Vrms=460, poles=2, Rs=1.472, Rr=1.125, Lm=0.1853H, Ls=0.1906, Lr=0.1933.

The results obtained at speed 1000 rpm, torque 25n-m and at speed 500 rpm, torque 6.5n-m in terms of electromagnetic torque and output current THD are shown below From Fig 10 to 19.

The proposed DTC-MC reduces torque ripple and current THD by 40% when compared to classical method at speed 1000 rpm, and reduces 53% at speed 500 rpm.

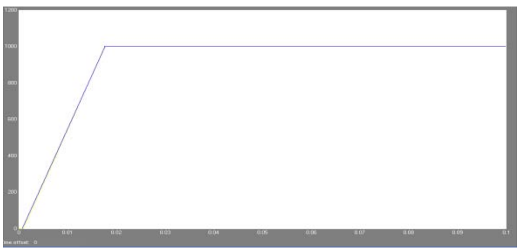


a) Proposed method



b) classical method

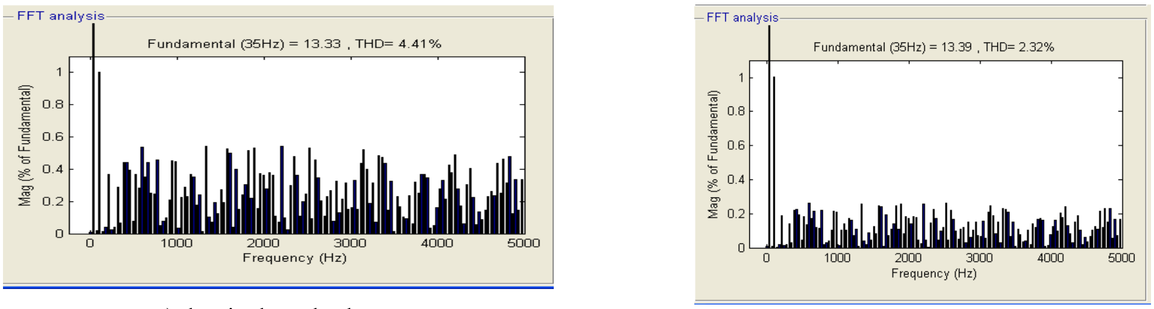
Fig.7: Torque ripples at 1000 rpm and t=0 to 0.1



a) Speed at 1000rpm

b) speed at 500 rpm

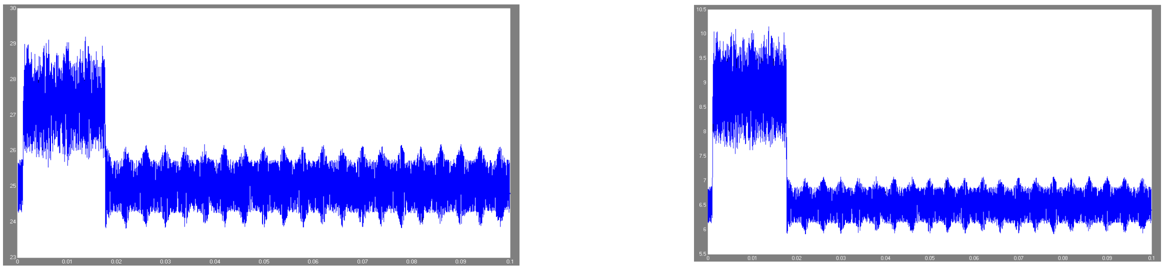
Fig.8: Showing steady and transient speeds from t=0 to 0.1



a)classical method

b) Proposed method

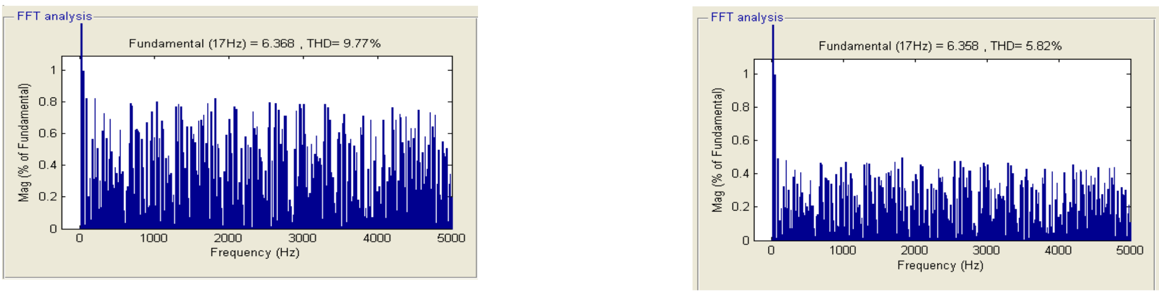
Fig.9: Current THD AT T = 2.5N.M AND N=1000



a) Classical method

b) Proposed method

Fig.10: Torque ripple at 500 rpm and t=0 to 0.1



a) Classical method

b) Proposed method

Fig.11: output current THD AT T=6.5 N-M and N=500 rpm

5. Conclusion

The aim of the paper was to give a fair comparison between classical and proposed DTC-MC techniques, to allow the users to identify the more suitable solution for any application that requires torque control. The new look up table for DTC-MC is designed for the small, medium and large matrix converter output voltage vectors. Furthermore, the torque error hysteresis comparator is modified in order to distinguish between small, medium and large positive and negative torque errors and to reduce torque ripple, in more percentage when compared to classical. The conclusion is that whole performance of the two schemes is comparable. DTC-MC classical might be preferred for high dynamic applications, but on the other hand shows higher current and torque ripple .This drawback can be partially compensated by the new DTC-MC proposed scheme. The DTC-MC proposed scheme is simpler to implement and require a very small computational time. The implementation of DTC-MC proposed technique not only reduces the torque ripple 40%more than classical but also reduces the output current THD 53% more than classical DTC-MC.

6. References

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