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Novel DTC induction machine drive improvement using controlled rectifier for DC voltage tuning

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ABSTRACT

The application of the direct torque control strategy for induction machine drives is mainly characterized by torque and flux distortions caused by voltage vector limitation. The goal of this paper is to perform the conventional DTC induction machine drives and reduce ripples of both flux and torque response. The proposed contribution is based on the control of the DC output side of the rectifier feeding the voltage source inverter by means of PI controller in order to adapt the voltage vector used in typical DTC switching table. Mathematic models are built using MATLAB Simulink and programming environment; the simulation results show the difference between the proposed method and classical DTC.

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1. INTRODUCTION

Variable speed applications based on induction machine drives require an efficient control scheme, in order to achieve this requirement, many control methods has been developed, One of the commonly used control strategy for induction motor is Field Oriented Control (FOC) [1], it is inspired from the similarity of an induction motor and a separate exited DC motor control strategy [2]. Compared to FOC control, the direct torque control technique (DTC) proposed by I. Takahashi [3] and M. Depenbrock [4, 5] in the mid-eighties have been recognized recognized to be an alternative solution to achieve a precise and quick torque response, it is based on the direct flux and torque controlling using the adequate switching states for a three phase voltage source inverter VSI [3, 4, 6].

Moreover, the DTC is a simple control strategy without current loop control and PWM strategy [7], however, its simplicity, high torque and stator flux ripples is the main drawbacks of conventional DTC drives [6, 8-10].

Overcoming this problem is the aim of the presented approach, such as many other proposed strategies by means of extended switching tables [10], space vector modulation SVM [11], fuzzy logic controllers [12] or multilevel inverters [13, 14], our solution is based on the control of the DC voltage input of the voltage source inverter VSI using a controlled rectifier. The DC voltage value is selected with a PI controller according to the torque error, and then the required firing angle is calculated and used for the rectifier power switches control.

Starting with a review and modelling of DTC applied for IM, then a detailed description of our contribution, finally simulation results and comparative study are performed among the proposed approach and standard DTC, results are simulaire to other recently developed approchs [10, 14, 15].

2. DTC REVIEW AND DESCRIPTION

The direct torque control method Figure 1 is based on the direct control of stator flux linkage and the electromagnetic torque [16].

The desired stator flux and torque modules are compared with their estimated values [14], the errors are processed through hysteresis-band controllers [17, 18], then dividing flux plane into six sectors, the adequate voltage vector is selected according to the hysteresis-band outputs value and the stator flux position with a switching table (table 1) [18, 19]. Referred to stationary frame (α, β), the mathematical model of induction motor is used to calculate flux and torque values [11, 13, 19].

Using the voltage vector and internal stator resistance of the motor, two stator flux components, sector position and electromagnetic torque are estimated, the DTC algorithm processing uses the estimation given the equations 1, 2 and 3 [10, 11] as a result the action on the voltage vector controls directly the flux and the torque values of the motor.

DTC systems use estimated flux and torque feedback signals, they can be obtained from the IM stator frame reference (α, β), by the following equations [20]:

$$\hat{\varphi}_{s\alpha}(t) = \int \left(V_{s\alpha} - R_s i_{s\alpha}\right) dt \tag{1}$$

$$\hat{\varphi}_{s\alpha}(t) = \int \left(V_{s\alpha} - R_s i_{s\alpha}\right) dt \tag{2}$$

$$\hat{T}_e = \frac{3}{2} P(\varphi_{s\alpha} i_{s\beta} - \varphi_{s\beta} i_{s\alpha}) \tag{3}$$

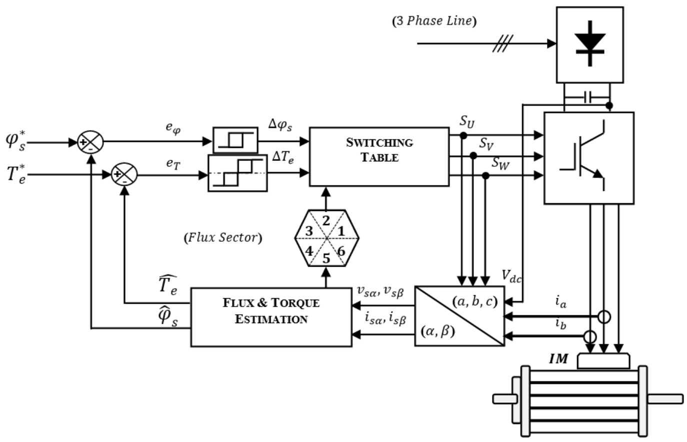

Figure 1. DTC block diagram applied for induction machine

The differences between estimated and reference controlled variables are processed through hysteresis comparators; the corresponding outputs are used together

with six angular sectors by the switching table designed to select the appropriate voltage vector can easily control both flux and torque, taking into account that the influence of R_s in (1) and (2) is too small [18, 19].

Table 1. DTC switching-vector look-up table

$\Delta\varphi_s$	N / ΔT_e	I	II	III	IV	V	VI
1	1	U_2	U_3	U_4	U_5	U_6	U_1
	0	U_7	U_0	U_7	U_0	U_7	U_0
0	1	U_3	U_4	U_5	U_7	U_1	U_2
	0	U_0	U_7	U_0	U_7	U_0	U_7

3. DTC WITH DC BUS ADJUSTMENT

Conventional DTC induction machine drives present torque and flux ripples in addition to current waveform distortion, this major drawbacks is due to the use of hysteresis comparators and switching table, only eight switching combination are possible. In most cases, overcoming this problem is based on new voltage selection methods together with Space vector modulator [7, 8]. The output voltage of the VSI used to drive the IM is function of the continuous voltage E. Presented in figure 3, our proposition adapts the voltage vector module selected in typical DTC by acting on the DC voltage value using a three phase controlled rectifier.

The desired voltage victor is produced with a three phase VSI represented in figure 2, for each leg the three converter switching functions SU, SV, and SW take 0 or 1 values [17], the resulted six active voltage vectors and the two zero voltage vectors are selected by the switching table [4, 11]. The output voltage produced by the VSI is function of switching states and the DC voltage E:

$$V_s = \sqrt{\frac{2}{3}} E \left[S_U + S_V e^{j2\pi/3} + S_W e^{j4\pi/3} \right] \tag{4}$$

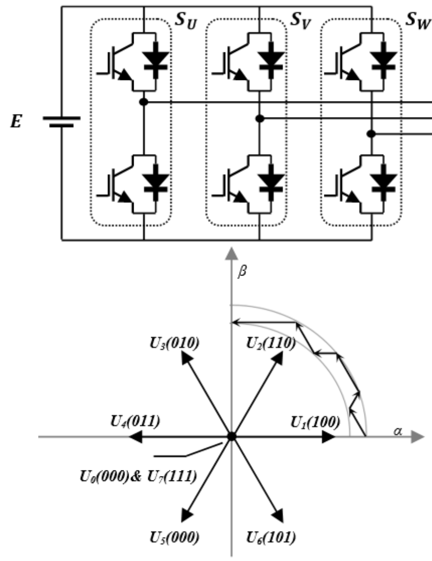

Figure 2. Three phase VSI voltage vector presentation

The proposed strategy performs the corresponding voltage vector by means of PI controller. The electromagnetic torque error is processed through the controller that selects an adequate DC voltage value necessary to adapt the VSI output vector and consequently reduces torque and flux ripples;

Firing angles are calculated according to the required DC voltage.

A closed loop speed controller is used to found the reference torque value.

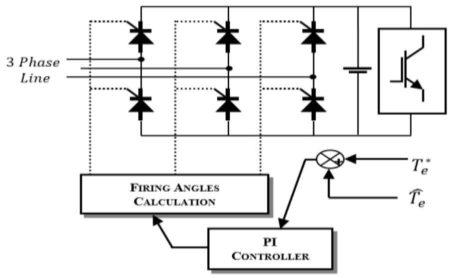

Figure 3. DC voltage control using controlled rectifier

4. SIMULATION RESULTS

Using the block diagrams in Figure 1 and 3, a mathematic model of the proposed control strategy and typical DTC has been developed in MATLAB Simulink environment. As a result a comparison of both control methods is performed with the same settings; the motor parameters are given in Table 3. The motor speed responses are presented in figure 4, for the proposed strategy the speed actives their reference value (1000 rpm) with a negligible overshot and an excellent response time. Compared to conventional DTC, The motor current waveform is improved; it takes the sinusoidal form as indicated in figure 5. The figure 6 shows the comparison of the electromagnetic torque, the torque follows the torque load value (10 Nm) for the two presented methods. In our approach, resulting from the soft voltage vector selection, the torque distortions are greatly reduced. Similar to the torque, for the studied variant the stator flux follows the desired value that's demonstrated in Figure 7, their waveform is also performed, and consequently the ripples are significantly decreased. Then, the flux trajectory behavior takes a circular shape with a diameter equal to the reference stator flux value (1.2 Wb).

Comparaison of above performences with other results in recently published paper [7, 13, 16, 21], demonstrats the significative current improvement and torque and flux ripples reduction.

Table 3. Induction machine parameters

2 pairs of poles,	Rs =4.85Ω	Ls = 274 mH
220/380 V, 50Hz 6.4/3.7 A	Rr =3.805Ω	Lr = 274 mH
2 hp , 1420 rpm	Lm = 258 mH	
J =0.031 kgm2	f =0.00114 Nms	

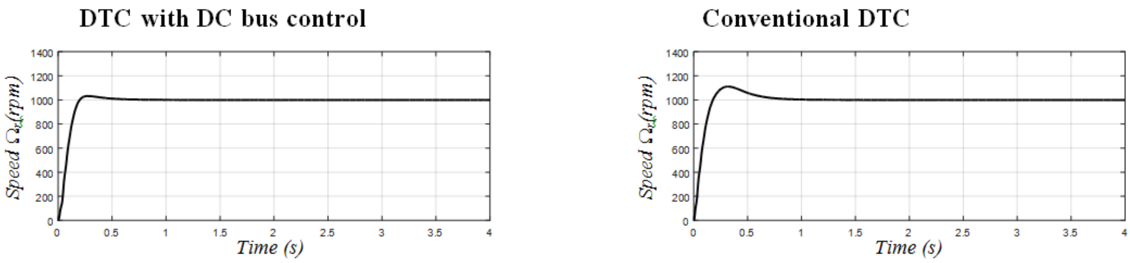

Figure 4. Motor speed responses for both methods

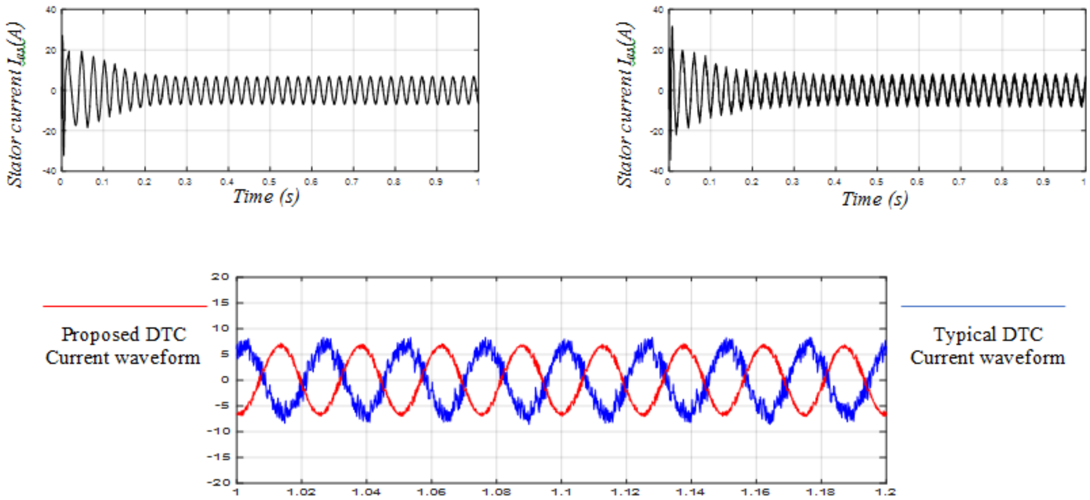

Figure 5. Motor current waveform comparison

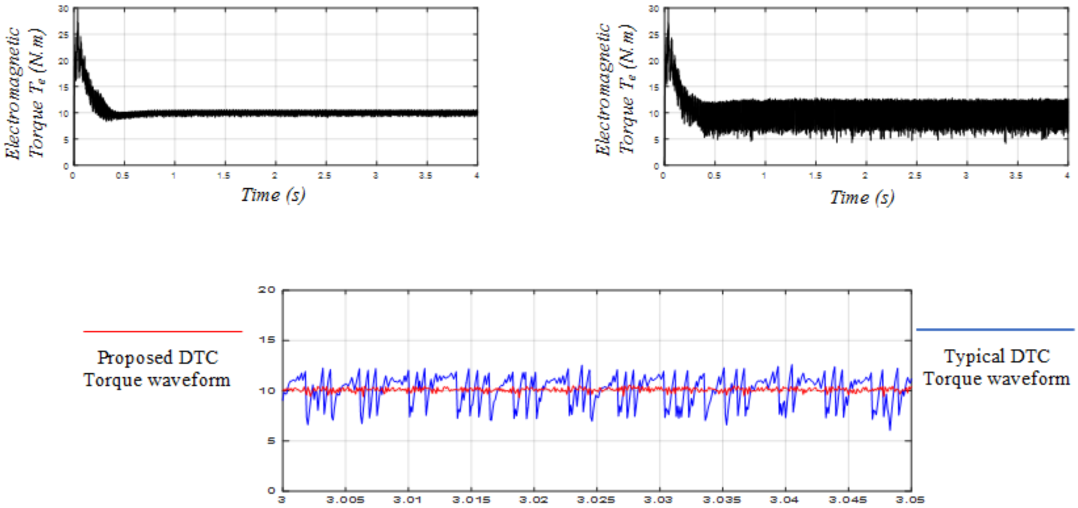

Figure 6. Electromagnetic torque performance comparison

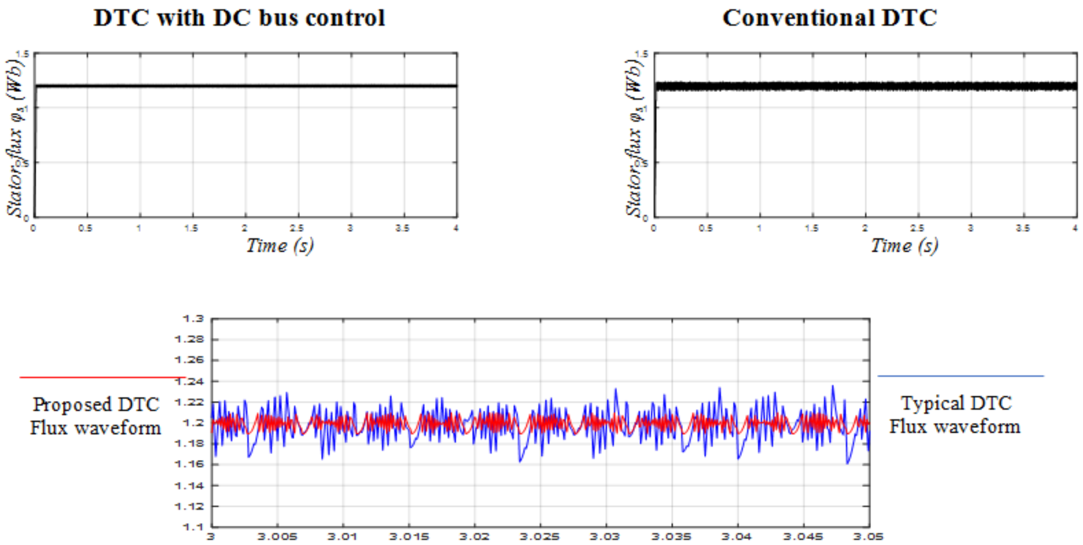

Figure 7. Comparison of stator flux waveforms

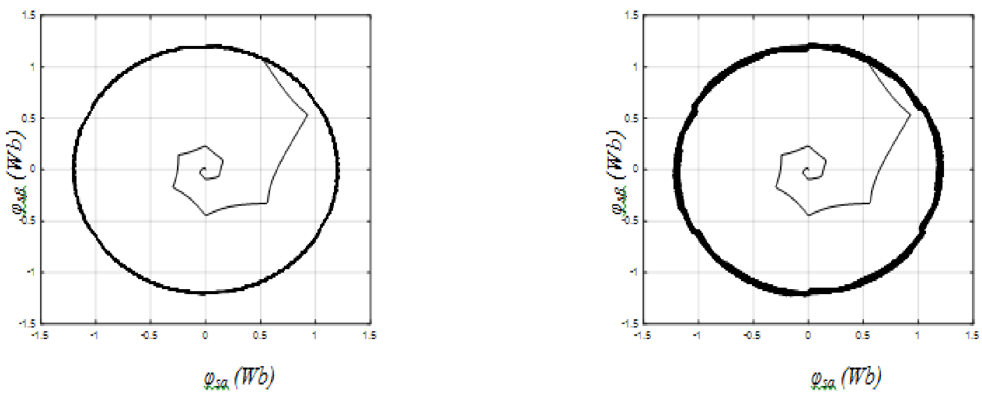

Figure 8. Comparison of stator flux trajectory

5. CONCLUSION

In the presented paper a controlled rectifier is used to perform a direct torque controlled induction motor drive, where a PI controller generates the desired DC voltage. This approach acts on the rectifier firing angles in order to adapt the selected voltage vector produced in conventional DTC switching table.

Through the simulation results comparisons cited and discussed above, we note a significant reduction in electromagnetic torque and stator flux ripples; we can clearly observe excellent current waveform amelioration and flux trajectory improvement. In conclusion, it had demonstrated by simulation the performances improvement of the controlling of the DC voltage for a DTC applied on induction machine drives.

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