TORQUE RIPPLES MINIMIZATION ON DTC CONTROLLED INDUCTION MOTOR WITH ADAPTIVE BANDWIDTH APPROACH

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ABSTRACT

Field oriented control (FOC) and direct torque control (DTC), also called vector control, are most famous control methods in high-performance motor applications. If we want to specify the basic handicaps of both methods: the FOC has parameter dependence while the DTC has high torque ripples. This paper proposes a new adaptive bandwidth approach to reduce torque ripples in DTC controlled induction motor drives. With the proposed method, instead of fixed bandwidth, adaptive bandwidth approach is investigated in hysteresis controllers on the DTC method. Both the conventional DTC(C-DTC) method and adaptive bandwidth DTC (AB-DTC) for induction motor are simulated in MATLAB/SIMULINK and the results are presented and discussed to verify the proposed control. The comparisons have shown that, torque ripples have been reduced remarkably with the proposed AB-DTC method.

KEYWORDS

Direct torque control, Adaptive hystresis controller, Induction motor control, Vector control

1. INTRODUCTION

Three-phase induction motors (IMs) are the most common motors used in industrial control systems and commercial applications. Simple and rugged design, low-cost, low maintenance and direct connection to an AC power source are the main advantages of IMs[1].

In the past, IMs were preferred only constant speed applications because of speed adjustment on IMs were not only hard to realize but also need high costs. So, DC motors were the optimum option for the variable speed applications. But over the years, this situation has changed depending on developments in power electronics and semiconductor technology. As a result, many kinds of IM variable speed driver have been produced and now the IMs are very good alternative for variable speed applications.

Today, vector controlled drivers are the most popular variable speed driver for the IMs and vector control methods can basically be grouped under two headings: FOC and DTC. The FOC was first introduced by Blaschke [2] in the 1970's. It was unrivalled in industrial induction motor drivers until DTC was introduced by Takahashi [3] in the middle of the 1980's. It was a good alternative

Jan Zizka et al. (Eds) : DBDM, CICS, CCNET, CSIP - 2015
pp. 41–48, 2015. © CS & IT-CSCP 2015 DOI : 10.5121/csit.2015.50704

to FOC due to some well-known advantages, such as simple control structure, no need much motor parameters so independency of parameter changes, fast dynamic response. Besides these advantages, DTC scheme still had some disadvantages like high torque and current ripples, variable switching frequency behaviour and implementation difficulties owing to necessity of low sampling time [4].

Despite, the DTC was originally developed for induction motor drives, it has also been applied other motor types like PMSM and BLDC [5-6]. When we look at the recent studies about the DTC, we can see that many kinds of approaches have been investigated to overcome the high torque and current ripple problems on DTC method.

In these studies, researchers proposed different ways. Some studies suggest using different switching techniques and inverter topologies [7-8], in another group of researchers, different observer models have been suggested [9-10]. On the other hand, intelligent control methods like fuzzy logic have been explored by several researchers for its potential to improve the speed regulation of the drive system. [11-12]

In this paper, a new hysteresis controller algorithm is presented to improve the dynamic torque performance of the DTC controlled IM. To illustrate the effect of the proposed system, conventional and proposed systems are simulated in Matlab/Simulink environment and results have been analyzed. Simulation studies have proved that this method reduces the torque ripple of the DTC method.

2. BASICS OF DTC

Direct torque control (DTC) directly controls the flux linkage and electromagnetic torque, considering the motor, voltage source inverter, and the control strategy at the system level. A relationship is established between the torque, the flux and the optimal inverter switching so as to achieve a fast torque response. It exhibits better dynamic performance than conventional control methods, such as vector control, is less sensitive to parameter variations, and is simpler to implement [13].

The DTC bases on the selection of the optimum voltage vector which makes the flux vector rotate and produce the demanded torque. In this rotation, the amplitude of the flux and the torque errors are kept within acceptable limits by hysteresis controllers [14]. The rotation of the stator flux vector and an example of the effects of the applied inverter switching vectors are given in the Fig.

1. The DTC allows for very fast torque responses, and flexible control of the induction motor. The flux and torque errors are kept within acceptable limits by hysteresis controllers [15].

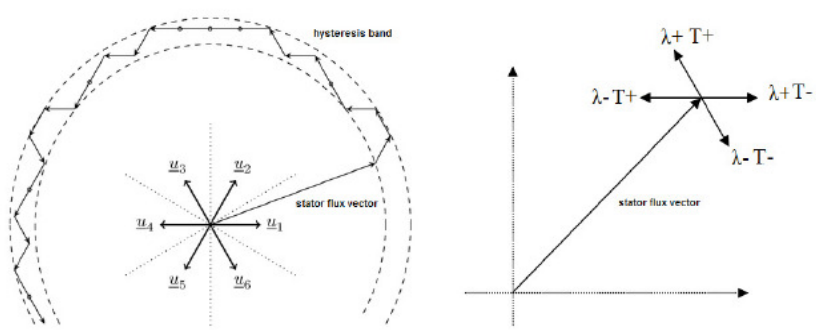

Figure 1. The rotation of the stator flux vector and an example for the effects of the applied inverter switching vectors [16].

The block diagram of the conventional DTC controlled motor is given in Fig. 2.

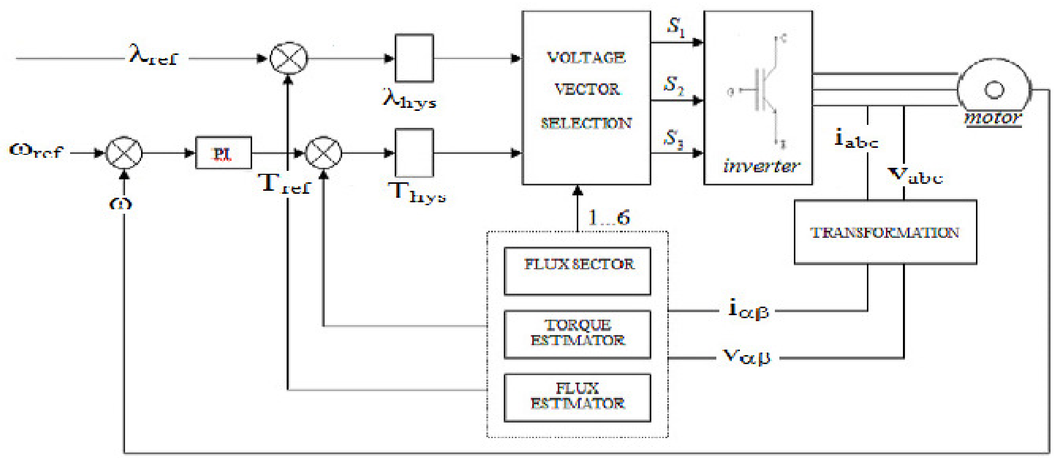

Figure 2. The block diagram of the conventional DTC

The DTC algorithm controls the stator flux and the torque by using measured currents and voltages.

The instantaneous values of the flux and torque can be obtained by using the transformation of the measured currents and the voltages of the motor. The stator flux is calculated as given in Eq.1-3 in a stationary reference frame.

$$\lambda_\alpha = \int (V_\alpha - R_s i_\alpha) dt \tag{1}$$

$$\lambda_\beta = \int (V_\beta - R_s i_\beta) dt \tag{2}$$

$$\lambda = \sqrt{\lambda_\alpha^2 + \lambda_\beta^2} \tag{3}$$

Where, λ_α - λ_β are stator fluxes, i_α - i_β are stator currents, V_α - V_β are stator voltages, $\alpha - \beta$ components and R_s is the stator resistance. Motor torque can be calculated as given in Eq.4.

$$T_e = \frac{3}{2} p(\lambda_\alpha i_\beta - \lambda_\beta i_\alpha) \tag{4}$$

Where, *p* is the motor pole pairs. The stator flux vector region is an important parameter for the DTC, and it can be calculated as given in Eq.5:

$$\theta_\lambda = \tan^{-1}\left(\frac{\lambda_\beta}{\lambda_\alpha}\right) \tag{5}$$

The torque and flux errors, which are obtained by comparing the reference and observed values, are converted to control signals by hysteresis comparators. The switching table is used to determine the optimum switching inverter states, and it determines the states by using the hysteresis comparator outputs and the flux region data [17].

3. ADAPTIVE BANDWIDTH APPROACH

Hysteresis control is one of PWM methods used for generating pulses to order the power switches of the inverter. Among the various current control techniques, it is widely used due to the fast response, simple implementation, negligible tracking error, inherent robustness to load parameter variations and proper stability [18].

In DTC method, two different hysteresis controllers are used to determine the changes in stator flux and electromagnetic torque. In constant bandwidth approach, small bandwidth values results in a higher switching frequency. So, it results in low harmonic copper losses in the motor while switching losses in the inverter are high. Conversely, in a large bandwidth values case, switching losses decrease in the inverter while the harmonic copper losses increase in the motor [19]. So selection of optimum amplitude of flux and torque hysteresis band is important for the drive but there are no certainties to determine optimum amplitude of hysteresis bandwidth.

The main idea of adaptive hysteresis bandwidth approach as given in Fig. 3.

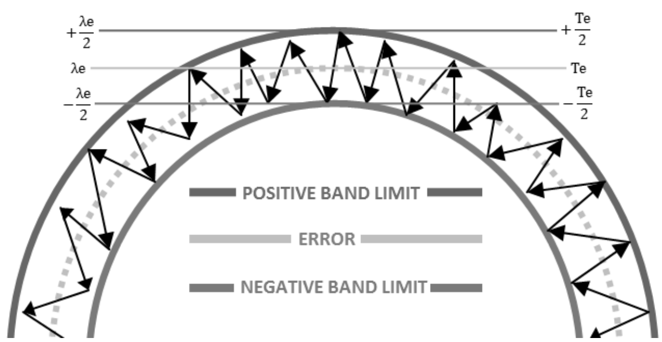

Figure 3. Adaptive hysteresis bandwidth

In this approach hysteresis bandwidth is determined by error values in the previous step for stator flux and electromagnetic torque. So, for the next step of the control process, hysteresis bandwidth is adapted with change in error. It means, if error on flux / torque is high, hysteresis bandwidth will be extended, on the contrary, if error on flux / torque is low, hysteresis bandwidth will be reduced. In this way, hysteresis bandwidth is designed to be flexible and the control algorithm tries to minimize previous step errors at every step. In other words, flux and torque errors are associated with each other with this approach.

4. SIMULATIONS AND RESULTS

The C-DTC and the proposed AB-DTC drive systems have been developed using Matlab/Simulink and the AB-DTC system with the Simulink blocks is shown in Fig. 4.

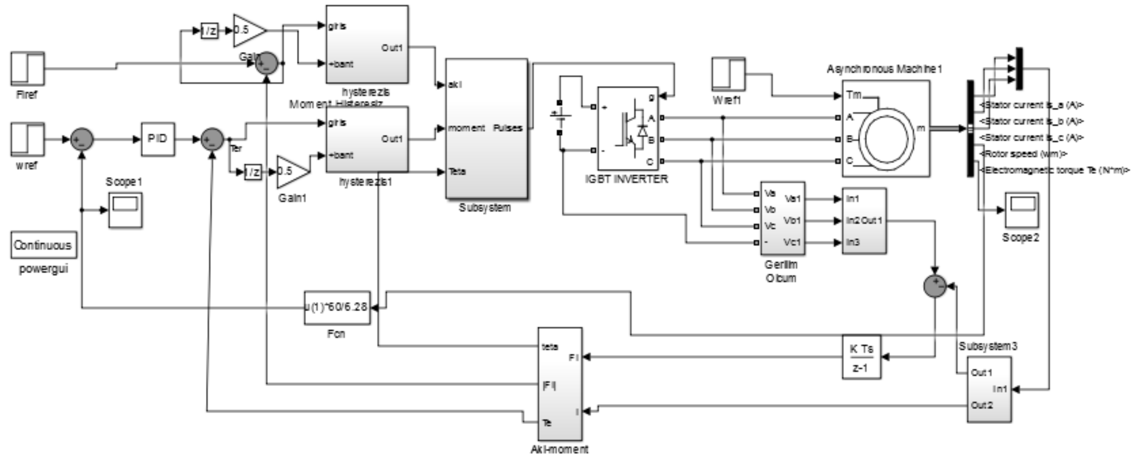

Figure 4. The proposed AB-DTC system with the Simulink blocks

The both control systems have been simulated in order to demonstrate the validity of the proposed AB-DTC system. The sampling interval is 50 µs. The magnitudes of the torque and flux hysteresis bands in the C-DTC are 0.1 Nm and 0.02 Wb, respectively. The nominal motor parameters are mentioned in Table.

Table. Specifications and parameters of the IM

Symbol	Quantity	Value
P	Power (kW)	1.1
V_n	Line to Line voltage (V)	230
p	Number of poles	2
f	Frequency(Hz)	50
R_s	Stator resistance(Ω)	8
Lm	Mutual inductance (H)	0.55
L	Inductance (H)	0.018

To investigate and compare the performances of the C-DTC and the AB-DTC algorithms, unloaded and rated loaded (3 Nm) working conditions are employed. The speed reference is set at 2800 rpm for both conditions. The electromagnetic torque responses of motor for unloaded and loaded conditions are shown in Fig. 5 and Fig. 6., respectively.

As it can be seen if Fig. 5, for unloaded working conditions, the C-DTC torque ripple changes in ±1.5 Nm band while the AB-DTC changes in ±1 Nm. It means the motor torque ripple has been reduced about 65% with the proposed DTC method for unloaded working conditions.

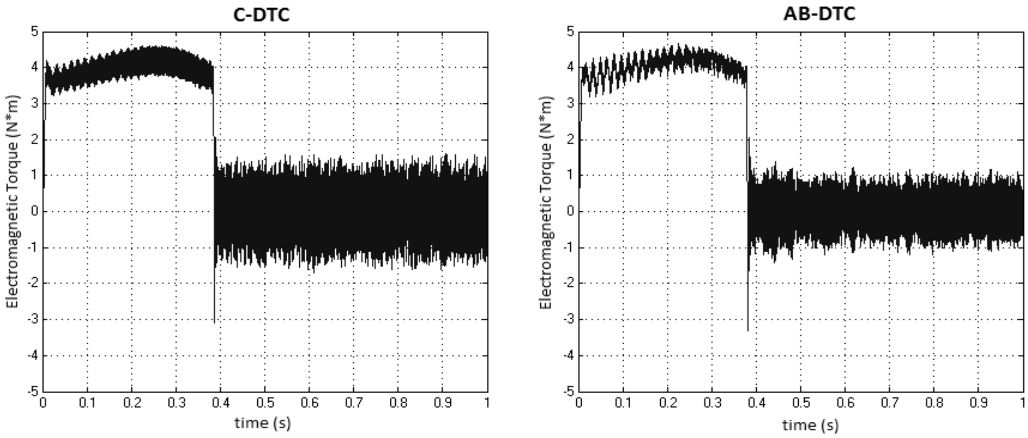

Figure 5. Electromagnetic torque responses at unloaded working conditions

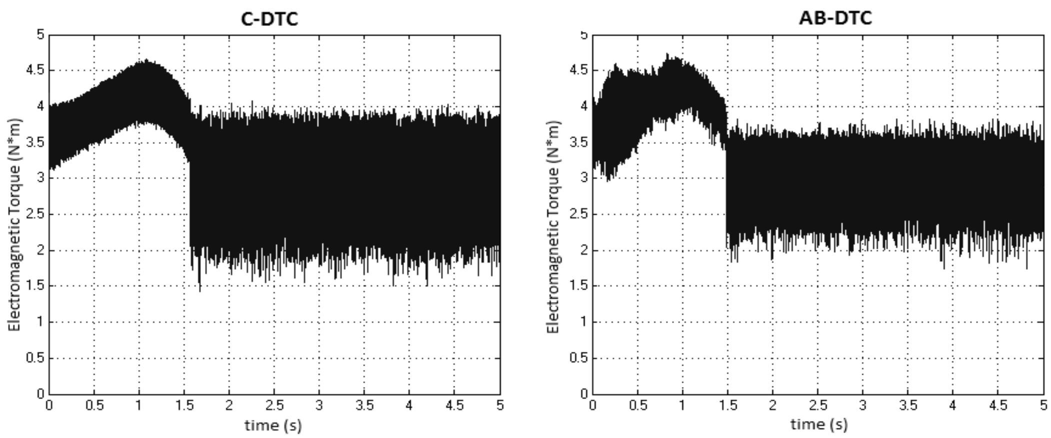

Figure 6. Electromagnetic torque responses at loaded working conditions

If we investigate loaded working conditions, as it can be seen in Fig. 6, the C-DTC torque ripple band changes between about 4 Nm /1.75 Nm (bandwidth 2.25 Nm) and the AB-DTC torque ripple band changes between about 3.6 Nm/2.25 Nm (bandwidth 1.35 Nm). It means the motor torque ripple has been reduced about 60% with the proposed DTC method for loaded working conditions. So, in general, it must be pointed out that the torque ripple of the motor has been reduced about 60% with the proposed DTC approach.

5. CONCLUSIONS

The conventional DTC offers several inherent advantages such as faster dynamic performance and robust controller structure compared to the Field Oriented Control for IMs. However, most faced problem in the C-DTC is high torque ripple. This paper presents an adaptive control algorithm on hysteresis controllers which are directly effect on system performance. In this approach hysteresis controller band limits are not constant and band limits are determined by error values in the previous step for stator flux and electromagnetic torque. The proposed approach is verified by the Matlab simulation and the obtained results shows that the proposed DTC approach can significantly reduce the torque ripple and improve the drive performance.

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