# ADAPTIVE BANDWIDTH APPROACH ON DTC CONTROLLED INDUCTION MOTOR

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***ABSTRACT***

*Induction motors are most commonly used motor type in industrial applications because of its well-known advantages like robust structure, cheaper prices etc. Today, field oriented control (FOC) and direct torque control (DTC) methods, also called vector control, are most famous control methods in high-performance applications. The main structural and behavioural differences between the both methods can be summarized as: the FOC has parameter dependence while the DTC has high torque ripples. In this study, a new adaptive bandwidth approach was presented to reduce torque ripples in DTC controlled induction motor drives. With the proposed method, instead of fixed bandwidth, adaptive bandwidth approach was investigated in hysteresis controllers on the DTC method. Both the conventional DTC(C-DTC) method and adaptive bandwidth DTC (AB-DTC) for induction motor were simulated in MATLAB/SIMULINK and the results were presented and discussed to verify the proposed control. The comparisons shown that, torque ripples were 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. This is because they have simple and rugged design, also low-cost, and low maintenance beside direct connection to an AC power sources of IMs[1].

About 4-5 decades ago, IMs were used limited constant speed applications because of speed adjustment on IMs were not only hard to realize but also need high costs. It means, DC motors were the optimum option for the variable speed applications. But today, depending on developments in power electronics and semiconductor technology, IMs also be controlled like the DC motor through vector control method.

The 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 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].

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The DTC was originally developed for induction motors, but it has also been applied other motor types like PMSM and BLDC [5-6].

In literature, many kind of studies can be found about improve performance of the DTC. 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 or neural networks 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 structure has presented to improve the dynamic torque performance of the DTC controlled IM. To illustrate the effect of the proposed system, conventional and proposed systems were simulated in Matlab/Simulink environment and results were analyzed. Simulation studies were proved that this method reduces the torque ripple of the DTC method.

## 2. BASICS OF DTC

In the DTC stator flux linkage and electromagnetic torque are directly controlled by inverter voltage vectors, 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, hysteresis controllers keep the amplitude of the flux and the torque errors within acceptable limits [14]. In Fig. 1., the rotation of the stator flux vector and an example of the effects of the applied inverter switching vectors were given. 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].

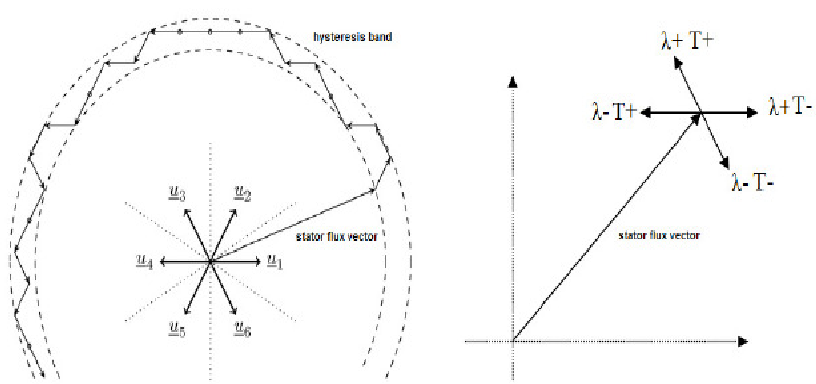



Figure 1. The rotation of the stator flux vector and an example for the effects of the applied inverter switching vectors [16].

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

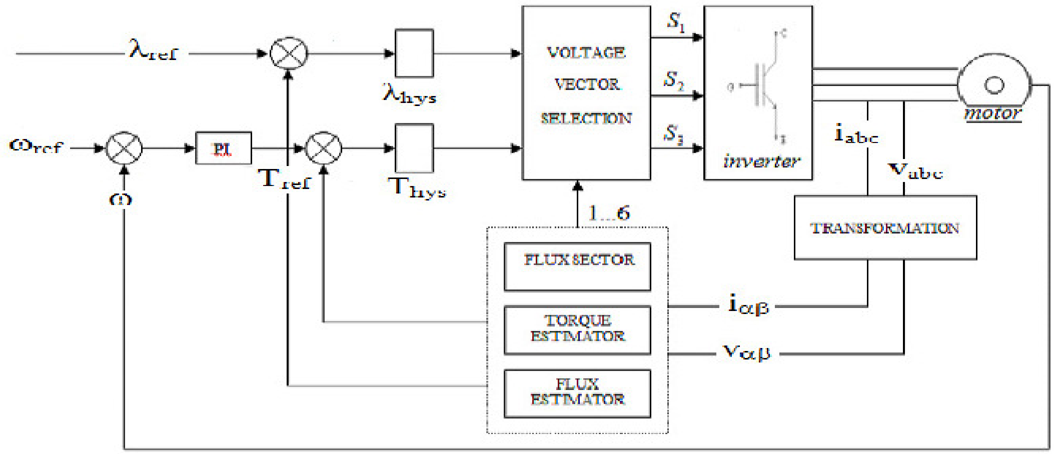



Figure 2. The block diagram of the conventional DTC

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, $\lambda_\alpha$ - $\lambda_\beta$ are stator fluxes, $i_\alpha$ - $i_\beta$ are stator currents, $V_\alpha$ - $V_\beta$ 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. as flux and torque regions.

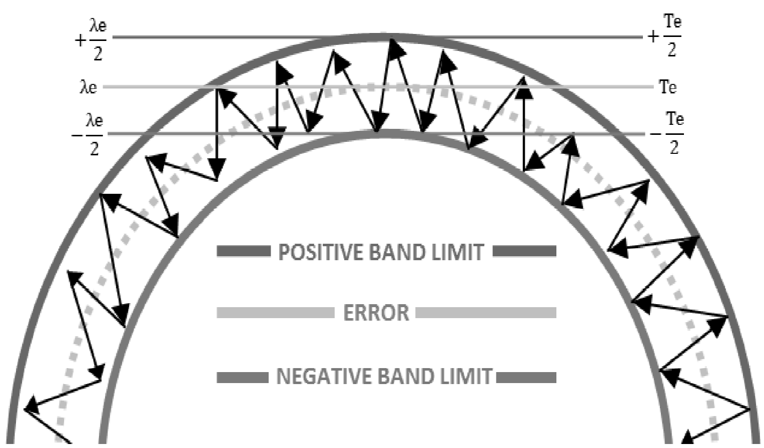



Figure 3. Adaptive hysteresis bandwidth

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 [20].

# 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.

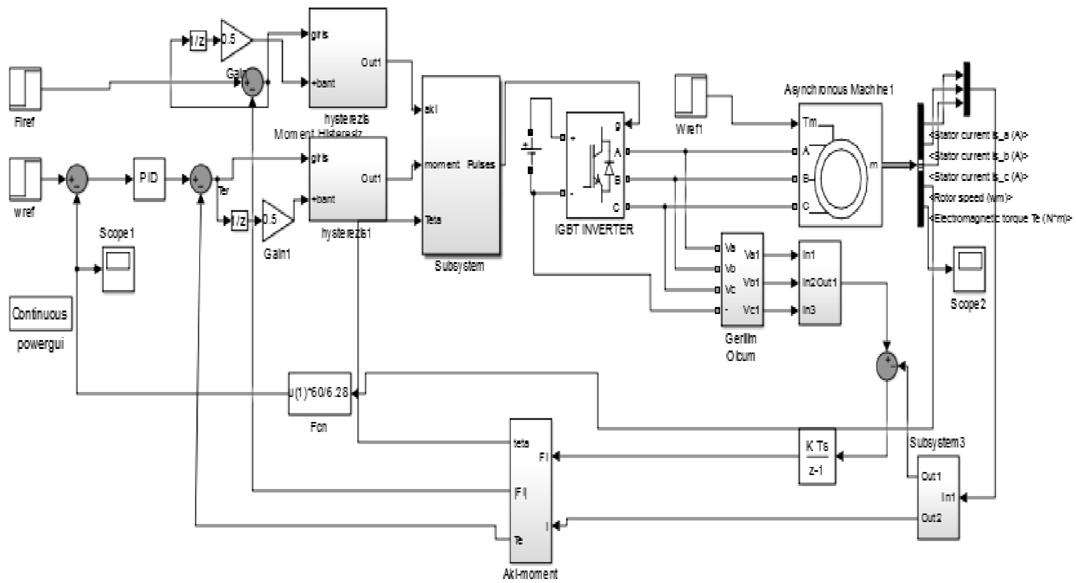



Figure 4. The proposed AB-DTC system with the Simulink blocks

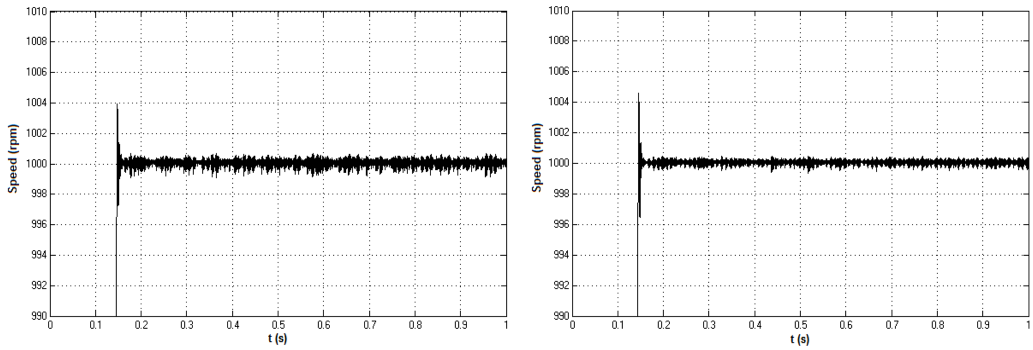
The both control systems were simulated in order to demonstrate the validity of the proposed AB-DTC system. The sampling interval was 50 µs. The magnitudes of the torque and flux hysteresis bands in the C-DTC were 0.1 Nm and 0.02 Wb, respectively. The nominal motor parameters were mentioned in Table.

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 |

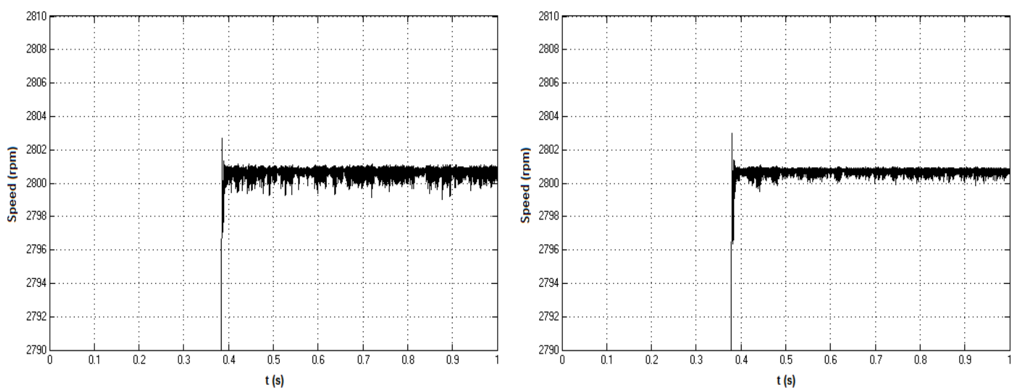
To investigate and compare the performances of the C-DTC and the AB-DTC algorithms, the speed and the torque responses of the motor were obtained for different references.

In the speed tests, the motor was tested 1000 rpm and 2800 rpm working conditions. The motor was unloaded along the speed tests. Detailed speed responses of the motor for both control methods were given in Fig. 5–6.




a b

Figure 5. Speed responses of the motor at 1000 rpm reference
a) C-DTC b) AB-DTC




a b

Figure 6. Speed responses of the motor at 2800 rpm reference
a) C-DTC b) AB-DTC

As it can be seen in Fig. 5–6, the speed ripples of the motor were reduced for both working conditions with the proposed AB-DTC method. It must be pointed out that, the response time of the motor was almost same (about 0.38 sec. in 2800 rpm) for the both methods.

In the torque tests, unloaded and 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. 7 and Fig. 8, respectively.

As it can be seen if Fig. 7, 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 ripples were reduced about 65% with the proposed DTC method for unloaded working conditions.

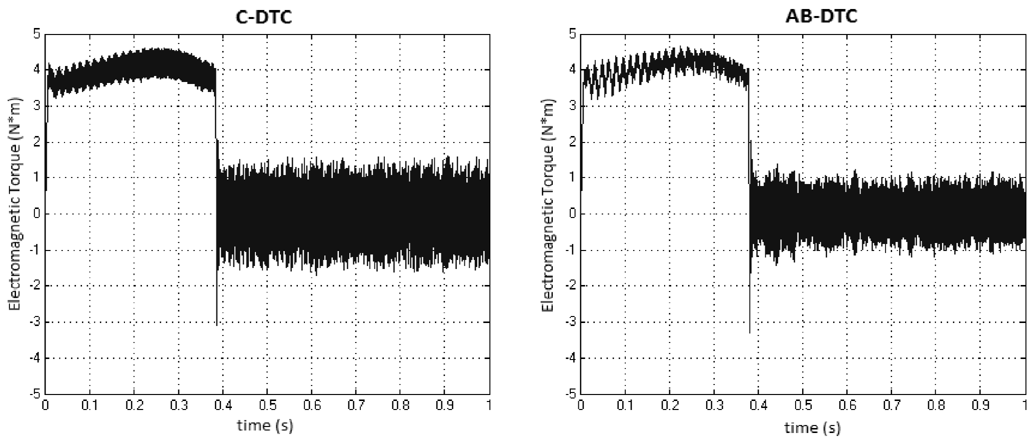



Figure 7. Electromagnetic torque responses at unloaded working conditions

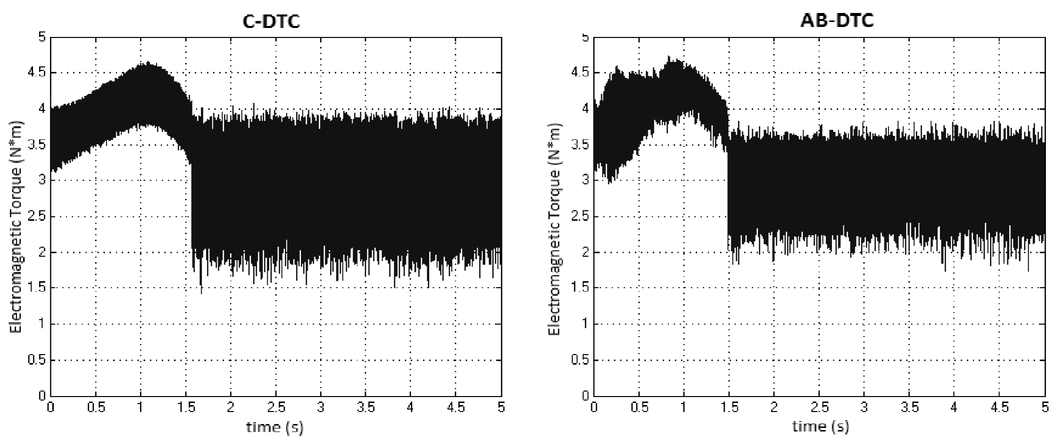



Figure 8. Electromagnetic torque responses at loaded working conditions

If we need to investigate loaded working conditions, as it can be seen in Fig. 8., 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 vector control methods have gained great importance because of the control abilities on the induction motors. The DTC method is an option on the vector controlled drivers. The second option is the FOC. The conventional DTC has several important advantages such as faster dynamic performance and robust controller structure compared to the FOC for IMs. However, most faced problem in the conventional DTC is high torque ripples. In this paper, an adaptive control approach on hysteresis controllers which are directly effect on system performance has been presented. 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 numerical simulations and the speed and the torque responses obtained and compared for the proposed method. The obtained results shows that the proposed DTC approach can reduce the torque ripple about 60% and improve the driver performance.

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