# IMPLEMENT DIRECT TORQUE AND FLUX CONTROL (DTC) INDUCTION MOTOR DRIVE MODEL: A REVIEW

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**Abstract**- Direct torque control ( DTC ) is considered one of the modern control methods, which wildly used in industrial variable speed drive systems to govern behaviors of induction motors. The main objective of this paper is to introduce a comprehensive study of a conventional direct torque of three phase induction motors. Moreover, the paper also aims to enhance and improve the transient response of the conventional DTC by proposing a novel design of its switching table, which considered as an essential component of DTC control circuit. At first, Space Vector theory was implemented to derive a mathematical model of a three-phase induction motor. Second, the model was simulated by using Matlab Simulink software due to its simplicity. The conventional DTC and proposed DTC were applied on the computer model of the motor at no-load and when the motor shaft is loaded respectively. It was observed from the results that the transient response of the proposed DTC is better than the response of the conventional one. The paper concluded with number of important results, which obtained from the computer model of the two DTC control methods. Ripple

**Keywords**- Direct Torque Control, Induction Motors, Transient Response, Switching Table.

## INTRODUCTION

Mechanical energy is needed in the daily life use as well as in the industry. Induction motors play a very important role in both worlds, because of low cost, reliable operation, robust operation and low maintenance. There are two main types of induction motors which are the wounded rotor and squirrel-cage design and both of them are in widespread use. Squirrel-cage rotor winding design is considered of the two more reliable and cheaper to make. When induction motors are operated without a proper control (drive), the motors are consuming large energies and the operating costs are high. In last few decades, power electronics has emerged, Digital signal Processing (DSP) and microcontrollers are now well established, motion and I-V sensors are ubiquitous allowing improved the performance. The contribution of power electronics in driving the AC motors which is so called “adjustable speed drives”, is characterized by the three phase mains voltages being converted to DC through conventional rectifier circuits to a DC rail. Next to the DC rail is inverted to AC but with both a different voltage and different frequency, VOUT (fOUT). Because the motor speed depends on the applied frequency, speed control is facilitated. The DC to AC inverter is usually built using Pulse Width Modulation (PWM) methodology to piecewise simulate the desired V (f). DSP is considered a very important component in recording and analyzing the PWM I-V data from motion and I-V sensors and to compare it with the desired conditions in the motor controller. Dynamic models (mathematical models) are employed in to better understand the behavior of induction motor in both transient and steady state. The dynamic modeling sets all the mechanical equations for the inertia, torque and speed versus time. It also models all the differential voltage, currents and flux linkages between the stationary stator as well as the moving rotor. My mathematical model will be done using MATLAB/Simulink which will represent the three phase induction motor including a three phase to d-q axis transformations. The main benefit with MATLAB Simulink is that in the electromechanical dynamic model can be accomplished in a simple way and it can be simulated faster using function blocks. Hasse in 1969 and Blaschke in 1972 proposed the concept of the vector control method or so called Field Orientation method of AC motors, based on making the well-established separately excited dc machine. Here the torque is defined as the cross vector product of the magnetic field from the stator poles and the armature current. To a good approximation the two are perpendicular, thus the maximum torque can be achieved and independent control of the motor facilitated. This is why vector control is often called “decoupling control”. Direct Torque Control concepts were proposed by Takashi and Noguchi in 1986. The idea of this method is based on comparing the measured stator flux and torque with the theoretically desired bands. The vector differences will control the subsequent switching sequence of the SVPWM inverter voltage based on the switching logic table. However, however restricts the means the stator flux and torque to fall in the pre-established bands.

## LITERATURE REVIEW

To ground this thesis, many prior art research papers have been read to distilled into three main topic points. First, understanding and modeling the performance of the uncontrolled induction motor, and especially the dynamic (mathematical) representation via MATLAB/ SIMULINK for the dynamic electromechanical coupled equations and studying the assumptions in the modeling procedure of Field Orientation Control (FOC). Finally, Direct Torque Control methodologies were studied using different analytic techniques. 3 The importance of the equivalent electrical circuit of three phase induction machine in dynamic modeling has been explained in [13] as well as the utility of the d-q transformations. Those transformations can be done in three main reference frames which are stationary at (start up), synchronous (at steady state) and rotor reference frame (during speed changes) as shown in [10]. Stationary and synchronous reference frames are the most common used. The representation of the mathematical model in different reference frames are explained as well as the step by step procedure of established MATLAB/SIMULINK rotational dynamic models illustrating the simplicity of using SIMULINK[12], [7]. The basic idea of Vector control for induction motor control is explained in both reference frames in [8] and [11]. The latter paper explains vector control concepts allowing the induction motor, to behave as a simple separately excited DC motor. It also details the established motor control method, the “scalar control method”, which controls only the magnitude of the voltage with a fixed frequency. This paper also derives the torque equations and then explains the two different ways of applying this control method in many different motor classifications. Finally, it compares actual and simulation results. A different approach, a fuzzy controller, was introduced in [11], where the of Vector Control method provided in differences between measured and simulated data for input to the PI controller in torque control loop. The disadvantage of the Field Orientation Control is that this method is sensitive to the changing dynamic parameters, being dependant on the rotor time constant [8]. FOC or, decoupling control, employs a clever mathematical coordinate transformation, to convert the three phase ac to two orthogonal dc components. The abc to d-q transformation, which is called Clarke Transformation, and vice versa, which is called inverse Clarke Transformation, are explained 4 and modeled using SIMULINK [9]. In this way one can decouple the stator flux and the torque so they can be separately controlled. Induction motor drives may be classified into two main control strategies. Scalar control, of the voltage magnitude and frequency is one. A second is controlling both the voltage vector and the frequency, which can be FOC or Direct Torque Control (DTC). In the research papers [16],[17] DTC principles are introduced, which allow keeping the flux and the torque falling in pre-established bands and using the hysteresis control via a switching table. The idea of Space Vector pulse Width Modulation (SV-PWM) which is used to defined the state of the inverter switching and the voltage vector. SVM is explained in detail in [14] and modeled using MATLAB. Another comparative study was conducted [15] to explore the difference between the conventional DTC and the DTC adding a PI controller, which is used in this thesis to get better reduction the ripple in the resultant flux and torque. One motivation for doing this thesis as a comparative study between FOC and DTC, is that few research papers were published on this topic as a comparative study and I judged it was ripe for a detailed study to explore future control approaches. As Many papers, on the other hand, were written about DTC and FOC individually and using many types of controllers trying to improve the performance of those methods of motor control. The other motivation is that all those papers and studies were done based on the performance comparison only assuming that everything is in normal operation which is not always the case. Therefore, two power quality issues are included in these comparison studies which are the voltage sag and short interruption. A theoretical comparative study between the DTC on one hand and other methods of motor drive has been done [18], explaining the basic principles of DC drive, scalar control, flux vector control, as well as direct torque control. Another comparative study between FOC and 5 DTC outlined the characteristics of the control algorithms, dynamic electromechanical response, and the sensitivity analysis of changing parameters in the implementation [19]. The latter paper uses Simulink in the comparison as was the inspiration for this thesis except this paper used the built in induction motor block which is different than what I used as a mathematical model to get more precise results in the case of unbalanced voltage and parameters changing. Finally the last prior work, [20], focuses on the similarities between FOC and DTC by reexamining the basic principles between both and studying how combine the two to make a both more accurate and faster control algorithm. Based on that, this study has been compared with the other.

## 3 METHODOLOGY

3.1. Block Diagram of Direct Torque Control The block diagram of the direct torque control (DTC) configuration with induction motor is shown in Figure 1. In understanding the control structure of DTC, it is better to begin with three-phase induction motor because single-phase induction motor is similar to three-phase induction motor. Although the control structure of those motor is similar, however, they have different voltage vector due to different topology of inverter used. In control structure three-phase induction motor of DTC has the stator flux and electromagnetic torque that been controlled independently by applying two-level and three-level hysteresis comparators as shown in Figure 1. An appropriate voltage vector is chosen from the look-up table based on the flux error and torque error status, in which the VSI to control the TPIM is activated in turn. The basic concept in DTC is to choose the optimal voltage vector based on the stator flux and the torque, and the flux angles rotate the flux to produce the desired output torque. The stator flux angle for the output voltage sector is separated equally by 6 sectors by 60° each. The DTC switching table generates a logic signal based on the three inputs which are Sa, Sb and Sc that are used to enable the switches in the VSI to operate the motor. The output from the three-phase VSI is the input for the induction motor stator. The VSI selects the stator vector based on the output of the hysteresis band and the stator flux band. The variation in stator flux is corresponding to the voltage vectors as the resistive voltage drop is relatively small. In order to obtain a circular stator flux, two active voltage vectors will be applied in each sector, either to increase or decrease the stator flux as shown in Figure 2. As depicted in Figure 2(b), in sector 1, V2 is applied to increase the stator flux whereas V3 is employed to decrease the stator flux. Both of V2 and V3 are capable to increase the electromagnetic torque. In order to decrease the torque, both V5 and V6 are applied. When decreasing the torque, V6 is activated to increase the stator flux while V5 is implemented to decrease the stator flux. A suitable voltage vector to satisfy the stator flux and electromagnetic demands is constructed in Table 1.

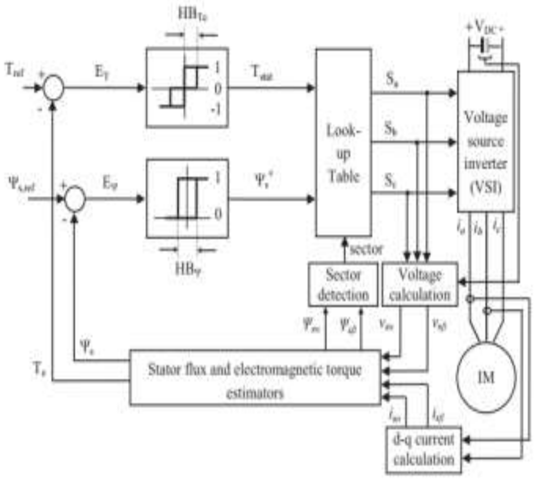


Figure 1. Direct Torque Control Structure

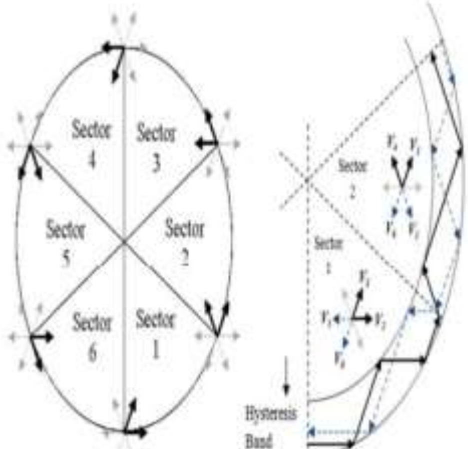


Figure 2. Active voltage vector(a) in each sector, (b) to control stator flux

**Table 1.** Look-up table of voltage vector for DTC

| Stator flux error status | Torque error status | Sector 1 | Sector 2 | Sector 3 | Sector 4 | Sector 5 | Sector 6 |
|---|---|---|---|---|---|---|---|
| 1 | 1 | V2 | V3 | V4 | V5 | V6 | V1 |
| | 0 | V0 | V7 | V0 | V7 | V0 | V7 |
| | -1 | V6 | V1 | V2 | V3 | V4 | V5 |
| 0 | 1 | V3 | V4 | V5 | V6 | V1 | V2 |
| | 0 | V7 | V0 | V7 | V0 | V7 | V0 |
| | -1 | V5 | V6 | V1 | V2 | V3 | V4 |

For any IM drives, Direct torque control is one of the best controllers proposed so far. It allows decoupled control of motor stator flux and electromagnetic torque. From the analysis it is proved that, this strategy of IM control is simpler to implement than other vector control methods as it does not require pulse width modulator and co-ordinate transformations. But it introduces undesired torque and current ripple. DTC scheme uses stationary d-q reference frame with d-axis aligned with the stator axis. Stator voltage space vector defined in this reference frame
control the torque and flux. The main inferences from this work are: 1. In transient state, by selecting the fastest accelerating voltage vector which produces maximum slip frequency, highest torque response can be obtained. 2. In steady state, the torque can be maintained constant with small switching frequency by the torque hysteresis comparator by selecting the accelerating vector and the zero voltage vector alternately. 3. In order to get the optimum efficiency in steady state and the highest torque response in transient state at the same time, the flux level can be automatically adjusted. 4. If the switching frequency is extremely low, the control circuit makes some drift which can be compensated easily to minimize the machine parameter variation. The estimation accuracy of stator flux is very much essential which mostly depends on stator resistance because an error in stator flux estimation will affect the behavior of both torque and flux control loops. The torque and current ripple can be minimized by employing space vector modulation technique

## 4. CONCLUSION

The results show the comparisons of torque and current behavior between the DC battery and the supercapacitor. It can be concluded that the supercapacitor has the better instantaneous reaction to improve the dynamic performance of torque response. However, after the dynamic operation, it started to become unstable and started creating ripple in the torqueis.

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