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Study of Induction Motor Drive (IMD) with Direct Torque Control Scheme (DTCS) and Indirect Field Oriented Control Scheme (IFOCS)

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Abstract

Induction motors are the starting point to design an electrical drive system, which is widely used in many industrial applications. In modern control theory, different mathematical models describe induction motor according to the employed control methods. Vector control strategy can be applied to this electrical motor type in symmetrical three-phase version or in unsymmetrical two-phase version. The operation of the induction motor can be analyzed similar to a DC motor through this control method. With the Joint progress of the power electronics and numerical electronics it is possible today to deal with the axis control with variable speed in low power applications. With these technological projections, various command approaches have been developed by the scientific community to master in real time, the flux and the torque of the electrical machines, the direct torque control (DTC) scheme being one of the most recent steps in this direction. This scheme provides excellent properties of regulation without rotational speed feedback. In this control scheme, the electromagnetic torque and stator flux magnitude are estimated with only stator voltages and currents and this estimation does not depend on motor parameters except for the stator resistance. In this paper, we present about direct torque control scheme (DTCS) and indirect field oriented control scheme (IFOCS).

Keywords: *DTC, IFOCS, Vector Control, Induction Motor*

1. Introduction

The induction motor (IM) thanks to its well-known advantages of simple construction, reliability, ruggedness, and low cost has found very wide industrial applications. These advantages are superseded by control problems when using an IM in industrial drives with high Performance demands. Using direct torque control (DTC) or direct self control (DSC) it is possible to obtain a good dynamic control of the torque without any mechanical transducer on the machine shaft. Thus direct torque control (DTC) and direct self control (DSC) can be considered as "sensor less type" control techniques. Direct self control (DSC) is preferable in the high power range applications where a lower inverter switching frequency can justify higher current distortion. Direct torque control (DTC) is more suitable in the small and medium power range application [1].The basic concept of direct torque control of induction motor drives is to control both stator flux and electromagnetic torque of the machine simultaneously. The direct torque control (DTC) based drives do not require filling the coordinate transformation between stationary frame and synchronous frame in comparison with the conventional vector controlled drives [2].The name direct torque control (DTC) is derived by the fact that on the basis of the error between the reference and the estimated values of the torque and flux, it is possible to directly control the inverter states in order to reduce the torque and flux error within band limits. Space vector modulation (SVM) is incorporated with direct torque control (DTC) for induction motor (IM) drives to provide a constant inverter switching frequency. In this paper, we discusses the induction motor drive with direct torque control and indirect field oriented control scheme.

2. Direct Torque Control of Induction Motor

In recent years “induction motor control techniques” have been the field of interest of many researchers to find out different solutions for induction motor control having the features of precise and quick torque response, and reduction of the complexity of field oriented control. The Direct torque control (DTC) technique has been recognized as the simple and viable solution to achieve this requirements [3-7]. DTC is one of the most excellent and efficient control strategies of induction motor. This technique is based on decoupled control of torque and stator flux and today it is one of the most actively researched control techniques where the aim is to control effectively the torque and flux.

2.1 Conventional DTC scheme

The conventional DTC scheme is a closed loop control scheme, the important elements of the control structure being: the power supply circuit, a three phase voltage source inverter, the induction motor, the speed controller to generate the torque command and the DTC controller. The DTC controller again consists of torque and flux estimation block, two hysteresis controllers and sector selection block, the output of the DTC controller is the gating pulses for the inverter. The DTC scheme does not require coordinate transformation as all the control procedures are carried out in stationary frame of reference. So this scheme does not suffer from parameter variations to the extent that other control techniques do. Also there is no feedback current control loop due to which the control actions do not suffer from the delays inherent in the current controllers, no pulse width modulator, no PI controllers, and no rotor speed or position sensor. So it is a sensorless control technique which operates the motor without requiring a shaft mounted mechanical sensor. Here on-line torque and flux estimators are used for closing the loop. Here the torque and stator flux are controlled directly by using hysteresis comparators. Fig.1 shows the basic block diagram of conventional DTC scheme [8] [9].

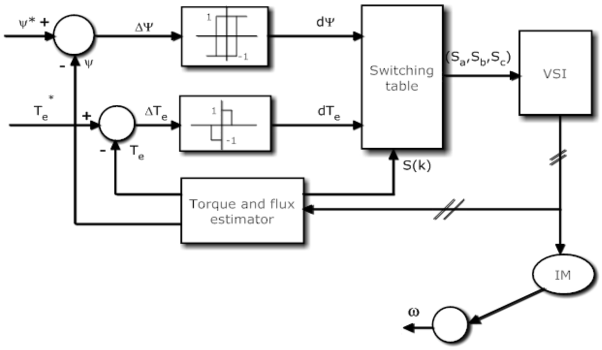

Figure 1: Block diagram of conventional DTC scheme for IM drives

2.2 Principle of DTC scheme

The basic principle of DTC is to directly select stator voltage vectors according to the torque and flux errors which are the differences between the references of torque and stator flux linkage and their actual values. The governing equation for torque for this scheme is due to the interaction of stator and rotor fields. Torque and stator flux linkage are computed from measured motor terminal quantities i.e. stator voltages and current. An optimal voltage vector for the switching of VSI is selected among the six nonzero voltage vectors and two zero voltage vectors by the hysteresis control of stator flux and torque.

3. Indirect Field oriented control of Induction Motor

Scalar control such as the “V/Hz” strategy has its limitations in terms of performance. The scalar control method for induction motors generates oscillations on the produced torque. Hence to achieve better dynamic performance, a more superior control scheme is needed for Induction Motor [14]. With the mathematical processing capabilities offered by the micro-controllers, digital signal processors and FGPA, advanced control strategies can be implemented to decouple the torque generation and the magnetization functions in an AC induction motor [13]. This decoupled torque and magnetization flux is commonly called rotor Flux Oriented Control (FOC) [10].

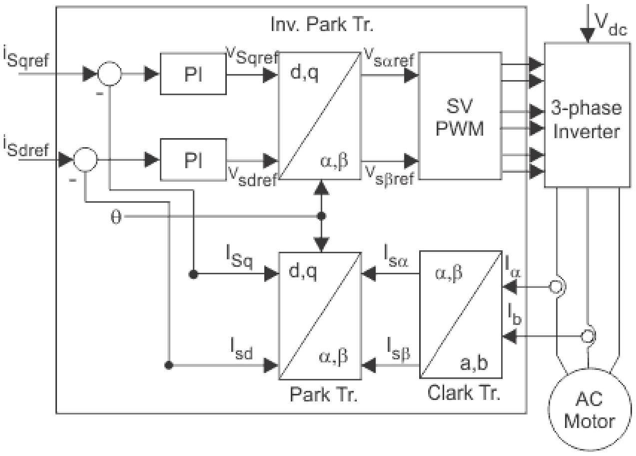

Figure 2: Simplified Indirect FOC

Field Oriented Control describes the way in which the control of torque and speed are directly based on the electromagnetic state of the motor, similar to a DC motor. FOC is the first technology to control the “real” motor control variables of torque and flux. With decoupling between the stator current components (magnetizing flux and torque), the torque producing component of the stator flux can be controlled independently. Decoupled control, at low speeds, the magnetization state of motor can be maintained at the appropriate level, and the torque can be controlled to regulate the speed. “FOC has been solely developed for high-performance motor applications which can operate smoothly over the wide speed range, can produce full torque at zero speed, and is capable of quick acceleration and deceleration” [11]. The field oriented control consists of controlling the stator currents represented by a vector. This control is based on projections that transform a three phase time and speed dependent system into a two coordinate (d and q frame) time invariant system. These transformations and projections lead to a structure similar to that of a DC machine control. FOC machines need two constants as input references: the torque component (aligned with the q coordinate) and the flux component (aligned with d coordinate). The three-phase voltages, currents and fluxes of AC-motors can be analyzed in terms of complex space vectors. If we take i_a, i_b, i_c as instantaneous currents in the stator phases, then the stator current vector it defined as follow:

$$\vec{\imath}_s = i_a + i_b e^{j2\pi/3} + i_c e^{j4\pi/3}$$

Where, (a, b, c) are the axes of 3 phase system. This current space vector represents the three phase sinusoidal system. It needs to be transformed into a two time invariant coordinate system. This transformation can be divided into two steps: (a, b, c) → (α, β) (the Clarke transformation), which outputs a two coordinate time variant system. (a, β) → (d,q) (the Park transformation), which outputs a two coordinate time invariant system. The (a, b, c) → (α, β) Projection (Clarke transformation**),** in this process, 3-phase quantities either voltages or currents, varying in time along the axes a, b, and c, can be mathematically transformed into two-phase voltages or currents, varying in time along the axes α and β by the following transformation matrix:

$$i_{\alpha\beta o} = 2/3 * \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

Assuming that the axis a and the axis α are along same direction and β is orthogonal to them, we have the following vector diagram:

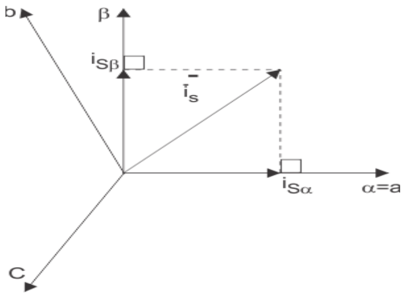

Figure 2: Space vectors in Stationary Reference Frame

The above projection modifies the three phase system into the (α, β) two dimension orthogonal system as stated below:

$$i_{s\alpha} = i_a$$
$$i_{s\beta} = i_a/\sqrt{3} + 2i_b/\sqrt{3}$$

But these two phase (α, β) currents still depends upon time and speed. The (α,β)→(d.q) projection (Park transformation) , this is the most important transformation in the FOC. In fact, this projection modifies the two phase fixed orthogonal system (α, β) into d,q rotating reference system. The transformation matrix is given below.

$$i_{dqo} = 2/3 * \begin{bmatrix} cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

Where, "θ" is the angle between the rotating and fixed coordinate system. If you consider the d axis aligned with the rotor flux,

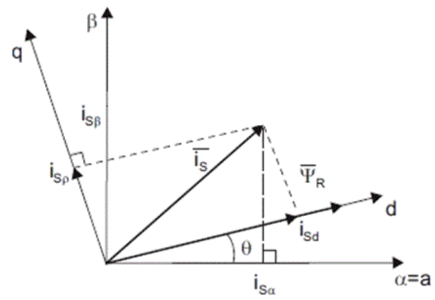

Figure 3: Space Vectors in Rotating Reference Frame

Where, "θ" is the rotor flux position. The torque and flux components of the current vector are determined by the following equations:

$$i_{sq} = i_{s\alpha}\sin\theta + i_{s\beta}\cos\theta$$
$$i_{sd} = i_{s\alpha}\cos\theta + i_{s\beta}\sin\theta$$

These components depend on the current vector (α, β) components and on the rotor flux position. If you know the accurate rotor flux position then, by above equations, the d,q component can be easily calculated. At this instant, the torque can be controlled directly because flux component (i_{sd}) and torque component (i_{sq}) are independent now. If the field angle is calculated by using terminal voltages and currents or flux sensing windings and rotor speed, then it is known as direct FOC. The field angle can also be obtained by using rotor position measurement and slip position by partial estimation with only machine parameters but not any other variables such as voltages or currents, this class of control scheme is known as indirect FOC. The rotor field angle is obtained by submission of rotor speed and slip frequency.

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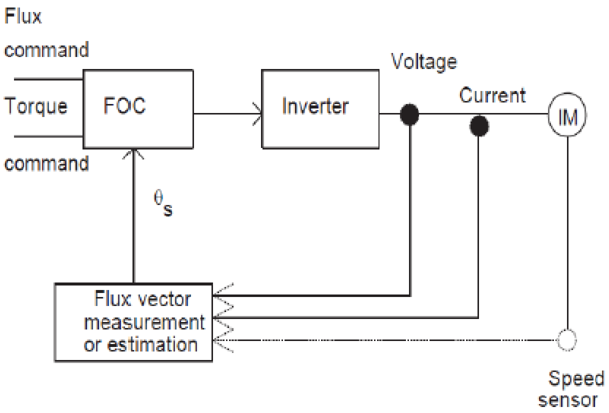

Figure 4: Simplified Direct FOC

4. Advantages and Disadvantages of Direct Torque Control and Indirect Field Oriented Control

4.1 Advantages of Direct Torque Control

- Absence of co-ordinate transform.
- Absence of voltage modulator block, as well as other controllers such as PID for flux and torque.
- Minimal torque response time, even better than the vector controllers.

4.2 Disadvantages of Direct Torque Control

- Possible problems during starting.
- Requirement of torque and flux estimators, implying the consequent parameters identification.
- Inherent torque and flux ripples.

4.3 Advantages of Indirect Field Oriented Control [12]

- Improved torque response.
- Torque control at low frequencies and low speed.
- Dynamic speed accuracy.
- Reduction in size of motor, cost and power consumption.
- Four quadrant operation.
- Short-term overload capability.

4.4 Disadvantages of Indirect Field Oriented Control

- Fact that a sensor is needed for determining the exact rotor position.
- An electro-mechanical sensor or a complex software algorithm (observer) is used.

5. Conclusion

From a high point of view, it can be argued that import vehicle control is very much needed, as it is a standard vehicle used in industrial vehicle control systems. Therefore, a well-designed simple, rugged, low-cost and low maintenance drive can therefore serve the desired purpose. This paper reviews various aspects of regulated direction in the field of induction motor including targets, segregation (direct and indirect FOC), and determination of vector flux status. Many authors have published numerous research papers on vector control techniques for induction motor. In addition, studying vector control techniques it is clear that the indirect vector control process takes a more precise vector control and is more widely used than the latest. Therefore, with continuous operation the adopted method of indirect vector control is the process. In this, we also discusses the advantages and disadvantages of DTC and Indirect FOC.

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