Case Study In Direct Torque Control Strategy Of Induction Motor

Manish Kurre[1], Dhananjay Chandrakar[2]

[1]Lecturer , Parthivi college of Engineering and Management,
Bhilai 3, Chhattisgarh , India
kurremanish@gmail.com

[2]M.E Scholar (Power System), Dr. C V Raman University,
Bilaspur, Chhattisgarh, India
dcelex102@gmail.com

ABSTRACT: - ***Direct Torque Control of inverter-fed Induction Machine allows high dynamic performance by means of very simple control schemes. In this paper the basic evolution of direct torque control from other drive types is explained. The basic concepts behind direct torque control are clarified. An explanation of direct self-control and the field-orientation concepts implemented in the adaptive motor model block is presented. The reliance of the control method on fast processing techniques is stressed. The theoretical foundations for the control concept are provided in summary format. Information on the ancillary control blocks outside the basic direct torque control is given. The implementation of special functions directly related to the control approach is described. Finally, performance data from an actual system are presented.***

Keywords: - AC adjustable-speed drives, direct torque control, motor control, sensor less vector control.

Introduction:-

Advanced control of electrical machines requires an independent control of magnetic flux and torque. For that reason it was not surprising, that the DC machine played an important role in the early days of high performance electrical drive systems, since the magnetic flux and torque are easily controlled by the stator and rotor current, respectively. The introduction of Field Oriented Control [1] meant a huge turn in the field of electrical drives, since with this type of control the robust induction machine can be controlled with a high performance. Later in the eighties a new control method for induction Machines were introduced: The Direct Torque Control (DTC) method is characterized by its simple implementation and a fast dynamic response. Furthermore, the inverter is directly controlled by the algorithm, i.e. a modulation technique for the inverter is not needed. However if the control is implemented on a digital system (which can be considered as a standard nowadays); the actual values of flux and torque could cross their boundaries too far [2] [3], which is based on an independent hysteresis control of flux and torque.

1. Different Controlling Schemes

There are many types of controlling schemes are present for controlling of induction motors in which Direct torque control represents a recent step in mix improvement. Fig. 1 shows drive evolution as a basic four-step process. This viewpoint is simplistic, but useful for comparison purposes.

1.1 Dc Drive

Torque is directly proportional to armature current in the dc motor. By using an inner-current control loop, the dc drive can directly control torque. Likewise, the constant magnetic field Orientation, which is achieved mechanically through commutator action, makes direct flux control a given.

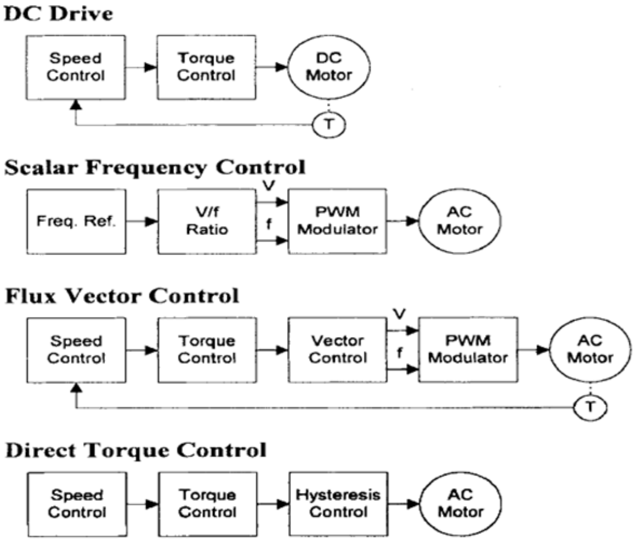

Figure1: Evolution of drive control technique

1.2 Scalar Frequency Control

All of the ac drives compared here allow the use of economical, robust ac induction motors. Scalar frequency control also offers the advantage of operation without an encoder. On the negative side, torque and flux are neither directly nor indirectly controlled. Control is instead provided by a frequency and voltage reference generator with constant volts per hertz output, which then drives a pulse width-modulated (PWM) modulator. Although simple, this arrangement provides limited speed accuracy and poor torque response. Flux and torque levels are dictated by the response of the motor to the applied frequency and voltage and are not under the control of the drive.

1.3 Flux Vector Control

Flux vector control reestablishes one of the advantages of the dc drive through implementation of direct flux control. In this case, field orientation is controlled electronically. The spatial angular position of rotor flux is calculated and controlled by the drive, based on a relative comparison of the known stator field vector to feedback of rotor angular position and speed. The motor's electrical characteristics are mathematically modeled with microprocessor techniques to enable processing of the data. Torque control is indirect because of its position in the control algorithm prior to the vector control process; however, good torque response is achieved nonetheless. Inclusion of the pulse encoder insures high-performance speed and torque accuracy. The biggest disadvantage of flux vector control is the mandated inclusion of the pulse encoder. Another minor disadvantage is that torque is indirectly, rather than directly, controlled. Finally, the inclusion of the PWM modulator, which processes the voltage and frequency reference outputs of the vector control stage, creates a signal delay between the input references and the resulting stator voltage vector produced.

2. Direct Torque Control Scheme

Direct torque control has its roots in field-oriented control and direct self-control. Field-oriented control uses spatial vector theory to optimally control magnetic field orientation. It has been successfully applied to the design of flux vector controls and is well documented. Direct self-control theory is less well known. It is a patented concept developed in Germany by Manfred Depenbrock and has been described in several papers [2], [3] which he has published. The fundamental premise of direct self-control is as follows. Given a specific dc-link voltage (Edc) and a specific stator flux level (Ψref) is unique and represents the half-period time of the frequency of operation (ωe). Since the operational frequency (ωe) is established without a frequency reference, this operational mode is referred to as direct self-control. Output frequency is, thus, not requested, but rather, is self-controlled via the actual frequencies present. Once sensed, whether the frequency increases or decreases depends on what the torque reference from the speed regulator requests. Differential changes to operational frequency are determined by the torque request. Nominal operating frequency is self-determined via the sensed feedbacks. Direct torque control combines field-oriented control theory, direct self-control theory, and recent advances in digital signal processor (DSP) and application specific integrated circuit (ASIC) technology to achieve a practical sensor less variable frequency drive. Fig.2 shows the basic functional blocks used to implement the core of the direct torque-control scheme. The relationship of this core to the complete control will be described in a subsequent section. Three key blocks interact to provide the primary control required:
1) torque/flux comparators; 2) optimal switching logic.

2.1 Torque/Flux Comparator

The torque comparator and the flux comparator are both contained in the hysteresis control block. These function to compare the torque reference with actual torque and the flux reference with actual flux. Actual levels are calculated by the adaptive motor model. When actual torque drops below its differential hysteresis limit, the torque status output goes high. Likewise, when actual torque rises above its differential hysteresis limit, the torque status output goes low. Similarly, when actual flux drops below its differential hysteresis limit, flux status output goes high, and when actual flux rises above its differential hysteresis limit, the flux status output goes low.

2.2 Optimal Switching Logic

Processing of the torque status output and the flux status output is handled by the optimal switching logic contained in the ASIC block. The function of the optimal switching logic is to select the appropriate stator voltage vector that will satisfy both the torque status output and the flux status output. In reality, there are only six voltage vectors and two zero-voltage vectors that a voltage-source inverter can produce. These are shown in Fig. 3. The analysis performed by the optimal switching logic is based on the mathematical spatial vector relationships of stator flux, rotor flux, stator current, and stator voltage. These relationships are shown as a vector diagram in Fig. 4. The torque developed by the motor is proportional to the cross product of the stator flux vector (Ψs) and the rotor flux vector (Ψr) the magnitude of stator flux is normally kept as constant as possible, and torque is controlled by varying the angle (γ) between the stator flux vector and the rotor flux vector.

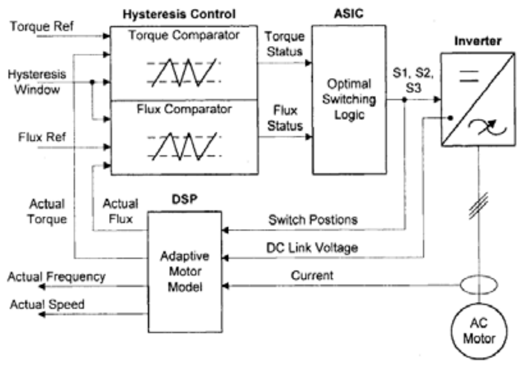

Figure 2 : Basic torque control scheme

2.3 Adaptive Motor Model

With reference to Fig. 2, it can be seen that the adaptive motor model is responsible for generating four internal feedback signals: 1) actual flux (stator); 2) actual torque; 3) actual speed; and 4) actual frequency. The first two values, which are critical to proper direct torque control operation, are calculated every 25 s. The latter two values, which are used by outer loop controllers, are calculated once per millisecond. Dynamic inputs to the adaptive motor model include: 1) motor current from two stator phases; 2) link voltage; and 3) power switch positions. Static motor data is also utilized in making calculations. The static data come from two sources: 1) user input data and 2) information determined automatically from a motor identification run that occurs during commissioning. The user input data include motor nominal voltage, motor nominal current, motor nominal frequency, motor nominal speed, and motor nominal power. The data collected during the motor identification run include motor

2.4 Torque Production

The estimated air-gap torque (Te) produced by the drive is shown in Fig.5.The periods during which torque has a positive slope, such as the region indicated as T+ in Fig. 5, indicate intervals where an active stator voltage vector is causing torque to increase. The periods during which torque has a negative slope, such as the region indicated as T0 in Fig. 5, indicate intervals where a zero-voltage vector has been selected. During most periods, either a simple positive slope or simple negative slope is indicated. During these periods, a single stator voltage vector selection has been able to satisfy both the torque status and the flux status output. However, during some periods, such as the region near the the identifier, a dual slope is present. This is indicative of an interval during which, after one voltage vector has been chosen, and although additional torque still needs to be developed (i.e., the torque status output is not satisfied), a change in the flux status output has occurred that requires selection of another stator voltage vector. Normally, switching occurs whenever torque drops below Tref-ΔT1 or exceeds Tref+ΔT1 in the special case where torque exceeds Tref+ΔT2, the optimal switching logic selects a stator voltage vector (Ux) that forces a decrease in torque by causing a reduction in the angle ϒ) between the stator flux vector and the rotor flux vector.

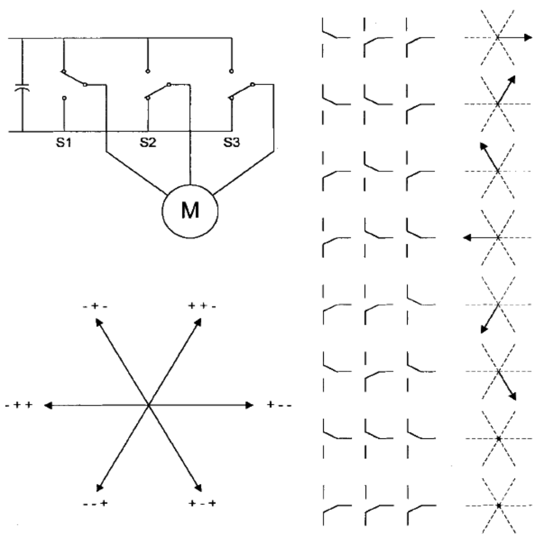

Figure 3 : Available state voltage vector

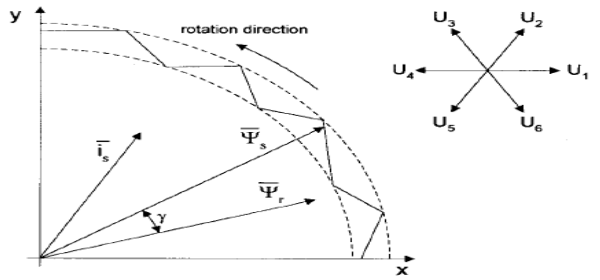

Figure 4: Stator spatial vector relationship

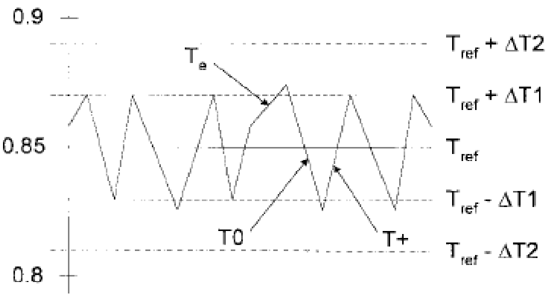

Figure 5: Estimated air gap torque with hysteresis control

2.5 Initial Starting

The statement that the operational frequency (ωe) is established without using a frequency reference, or otherwise directly controlling frequency, was made at the beginning of this section. This followed from the fact that direct torque control utilizes direct self-control as a part of its control scheme. Subsequent discussion has described how this is accomplished in a running system. The issue of system initialization, however, has not been addressed. How the drive can establish a correct start mode, when feedback data is not available for the adaptive motor model, is a valid question. In reality, the drive does not initially know what frequency to operate at. Only after the adaptive motor model analyzes the current and switch position feedbacks can a determination of flux, torque, speed, and frequency be made. To obtain the initial feedbacks, a low-level dc flux is established in the motor. This level is low enough that over current tripping and inappropriate torques are not created and high enough that meaningful feedback data is received. Once valid feedback data is available, operation proceeds as previously described.

3. The Complete Drive

Circuitry, in addition to that shown in Fig. 2 and described in Section 2, is required to build a complete drive. Fig. 6 shows the block diagram for a complete direct torque control drive. Blocks for speed control, torque reference control, flux reference control, and switching frequency control have been added. The speed control block is implemented with a traditional proportional integral and differential (PID) controller. The speed reference input is compared to the actual speed feedback from the adaptive motor model. The resulting output signal, torque (speed) reference, becomes the reference for the torque reference control. An inertia compensator is also included, although not shown. The compensator helps reduce control deviation due to acceleration or deceleration of system inertia. It also allows the speed control to be primarily tuned based on changes in static load. Automatic tuning is provided. The torque reference control has two inputs, the torque (speed) reference and absolute torque reference. When the drive functions as a speed control, only the torque (speed) reference is used. When the drive functions as a torque control, only the absolute torque reference is used. These references are never used simultaneously. The function of the switching frequency control is to vary the size of the hysteresis windows utilized by the flux comparator and torque comparator, such that power switching frequencies are maintained between 1.5–3.5 kHz. The output, hysteresis window, is processed by the direct torque control as described in Section II.

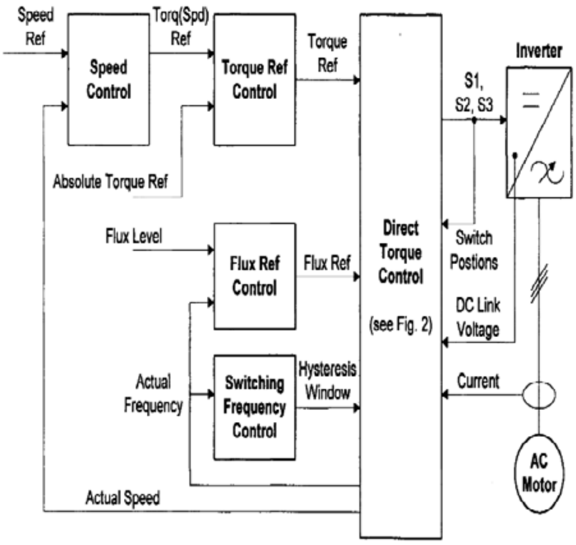

Figure 6 : Complete direct torque control drive.

4. Conclusion

Direct torque control combines the benefits of direct flux and direct torque control into a sensor less variable-frequency drive that does not require a PWM modulator. Recent advances in DSP and ASIC technology, plus the theoretical concepts developed for direct self-control, make this possible. Implementation of special functions such as flying start, flux braking, flux optimization, and power loss ride-through are all made easier, due to the control approach utilized. For many applications, exceptional performance can be realized without an encoder. Direct torque control represents a definite step forward in the mix of drive controls to choose from.

5. Reference

[1] Takahashi, I. - Noguchi, T: A new quick response and high-efficiency control strategy of induction motor, IEEE Trans. On IA, Vol.22, N°.5, Sept/Oct 1986, PP.820-827.

[2] P. Tiitinen, P. Pohjalainen, and J. Lalu, "The next generation motor control method—Direct torque control, DTC," in Proc. EPE Chapter Symp., Lausanne, Switzerland, 1994.

[3] M. Depenbrock, "Direct self-control (DSC) of inverter-fed induction machine," IEEE Trans. Power Electron., vol. 3, pp. 420–429, Oct. 1988.

[4] U. Baader and M. Depenbrock, "Direct self-control (DSC) of inverter fed induction machine: A basis for speed control without speed measurement," IEEE Trans. Ind. Application., vol. 28, pp. 581–588, May/June1992.

[5] Direct Torque Control, Induction Motor Vector Control Without an Encoder by James N. Nash, Member, IEEE.