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Review on Direct Torque control of an Induction Motor

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Abstract

Induction motors are most widely used in various industrial sectors for various precise applications. Hence, controlling techniques plays a vital role and have received a lot of interest. An adequate method of induction motor control is the direct torque control (DTC). Direct torque control (DTC) is one of the most excellent control strategies of torque control in induction machine. It is considered as replacement to the field-oriented control (FOC) or vector control technique. These two control strategies are differing in the operation principle but their objectives are the same. They aim to control effectively the torque and flux. Controlling Technique of torque of an induction machine based on DTC strategy will be developed and a wide-ranging study of relevant parameters is presented in this paper.

KEYWORDS:- DTC, FOC. Drives.

I. INTRODUCTION

About sixty percent of the total electrical energy generated is converted into mechanical energy, which is required whenever physical activities such as process control, transportation, industrial process etc. takes place. Electric drives are used to convert Electrical Energy into Mechanical Energy. Thus the electric drives play a very important role in every industry. Industrial drive applications are generally classified into constant-speed and variable-speed drives. Traditionally, ac machines with a constant frequency sinusoidal power supply have been used in constant-speed applications, whereas dc machines were preferred for variable-speed drives.

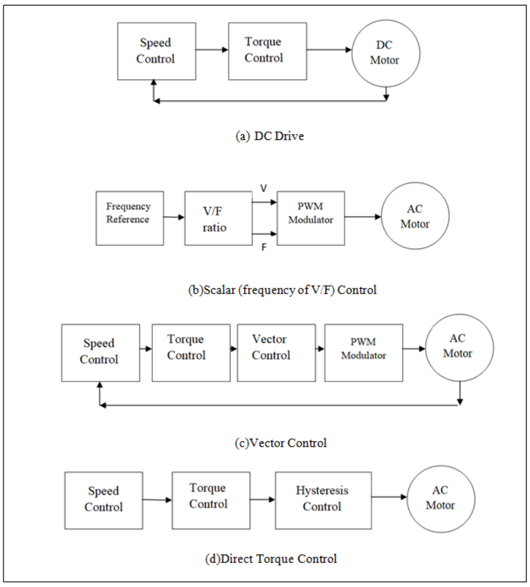

Figure 1: Evolution of Drive Control Techniques.

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. Direct flux control is possible by constant magnetic field orientation, which is achived mechanically through commutator action. DC
machine have the disadvantages of higher cost, higher rotor inertia, and maintenance problems with commutators and brushes. Commutators and brushes, in addition limit the machine and peak current, cause EMI problems, and do not permit a machine to operate in dirty and explosive environments.

AC Drive

Variable-speed ac drive have been used for over a hundred years. Because of their robustness, cheapness, high speed operation and less maintenance requirements, the induction motors (IM) are the most common type of electromechanical drive in industrial, commercial and residential applications. To reach the best efficiency of induction motor drive, many new techniques of control have been developed in the last few years.

In general, induction motor can be controlled by both open and closed loop control techniques. These are also known as scalar and vector control schemes.

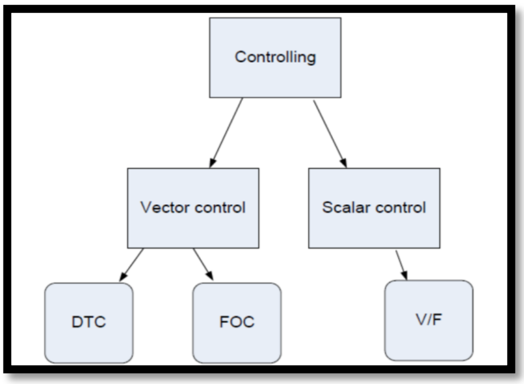

Figure 2: Comparison of Control Methods

The method use to control frequency comes under scalar control method. The method known as v/f control method also known as frequency control method. Whereas to control speed and torque parameters vector control method is used. Field oriented control (FOC) and direct torque and flux control (DTFC) are the vector control methods.

A. Scalar Control Technique

Scalar Control (V/f Control) is one common speed control technique for variable frequency drives (VFDs, frequency changers, frequency inverters) in the industry. In this type of control, the motor is fed with variable frequency signals generated by the Pulse Width Modulation (PWM) control from an inverter. Here; the V/f ratio is maintained constant in order to get constant torque over the entire operating range. Since only magnitudes of the input variables (frequency and voltage) are controlled, this is known as "scalar control". Generally, the drives with such a control are without any feedback devices (open-loop control). Hence, a control of this type offers low cost and is an easy to implement solution.

In such controls, very little knowledge of the motor is required for frequency is to control. So, scalar control is widely used. A disadvantage of scalar control is that the torque developed is load dependent, as it is not controlled directly. Also, the transient response of such a control is not fast due to the predefined switching pattern of the inverter. However, if there is a continuous block to the rotor rotation, it will lead to heating of the motor regardless of implementation of the over-current control loop. By adding a speed/position sensor, the problem relating to the blocked rotor and the load dependent speed can be overcome. However, this will add to the system cost, size and complexity.

Voltage source inverter fed induction motors are increasingly being used in general applications by varying the input voltage to the motor with frequency on open loop, is one of the popular methods of speed control. In this method V/f is held constant. In steady state operation, the machine air gap flux is approximately related to V/f. As the frequency approaches zero near zero speed, the magnitude of the stator voltage also tends to zero and this low voltage is absorbed by the stator resistance. Therefore, at low speed of operation the stator resistance drop is compensated by injecting an auxiliary voltage so that rated air gap flux and full load torque becomes available up to almost zero speed. At steady state operation, if the load torque is increased, the slip will increase within the stability limit and a balance will be maintained between the developed torque and the load torque. However, if the voltage to the inverter fluctuates, the air gap flux will vary. Furthermore, increase in the stator resistance due to temperature results in the variation of air gap flux. Hence, the air gap flux may drift and as a result the torque sensitivity with slip frequency (or stator current) will vary. If the V/f ratio is not maintained, the flux may weak (or saturate) and in the constant V/f control scheme if the air gap flux decreases, slip frequency will increase for the same torque demand, resulting into detoriation of machine response. Hence, a control scheme with independent control of torque and flux loop is desirable.

B. Vector Control Technique or Field Oriented (FO) Technique

Field Oriented Control (FOC) is by far the most widely accepted method of control in high performance ac drive domains. While FOC represents a single, unified control concept, the application strategies, complexity of implementation and drive. Responses vary with different drive motors. The principle behind the field oriented control or the vector control is that the machine flux and torque are controlled independently, in a similar fashion to a separately excited DC machine. The vector control technique decouples the two components of stator current space vector: one providing the control of flux and the other providing the control of torque.

An induction motor is said to be in vector control mode, if the decoupled components of the stator current space vector and the reference decoupled components defined by the vector controller in the synchronously rotating frame match each other respectively. FOC technique operates the induction motor like a separately excitedly DC motor and vector control further classified into direct vector control and indirect vector control.

C. Direct Torque Control

The name direct torque control is derived by the fact that, on the basis of the errors between the reference and the estimated values of torque and flux, it is possible to directly control the inverter states in order to reduce the torque and flux errors within the prefixed band limits. Unlike FOC, DTC does not require any current regulator, coordinate transformation and PWM signals generator (as a consequence timers are not required). In spite of its simplicity, DTC allows a good torque control in steady-state and transient operating conditions to be obtained.

On the other hand, it is well known that DTC presents some disadvantages like difficulty to control torque and flux at very low speed; high current and torque ripple; variable switching frequency behaviour; high noise level at low speed; lack of direct current control. To solve this problem many solution have been developed such as use of improved switching tables; use of comparators with and without hysteresis, at two or three levels; implementation of DTC schemes for constant switching frequency operation with PWM or SVM techniques; introduction of fuzzy or neuro-fuzzy techniques; use of sophisticated flux estimators to improve the low speed behaviour.

II. LITERATURE SURVEY

In [1] High-efficiency and Quick-response control of an induction motor, which is moderately different from that of the field-oriented control, is projected. The most noticeable differences between the two are in this fashion. The planned area is based on limit cycle control of both flux and torque using optimum PWM output voltage; a switching table is employed for selecting the optimum inverter output voltage vectors so as to attain as fast a torque response, as low an inverter switching frequency, and as squat harmonic losses as possible. And second focuses on the efficiency optimization in the steady-state operation is also considered; it can be achieved by controlling the amplitude of the flux in accordance with the torque command. To verify the feasibility of this method, experimentation, simulation, and comparison with field-oriented control are carried out. The results proved the outstanding characteristics for efficiency as well as for torque response, which confirm the validity of this control scheme. The Results States that in steady state, by selecting the accelerating vector and the zero voltage vectors alternately, the torque can be maintained constant with small switching frequency by the hysteresis comparator of torque. Accordingly, the harmonic losses and the acoustic noise level of the motor can be reduced. And the amplitude of the primary flux is also controlled to attain the maximum efficiency in steady-state operation. The flux level can be automatically adjusted to get the At extremely low frequency operation, the proposed control circuit makes some drift, but can be compensated easily and automatically to minimize the effect of the variation of the machine constants. With these results the proposed scheme is found to be very promising and precious as compared to field-oriented control. Scheme is found as superior in every respect to field oriented control.

In [2] authors had proved the industrial standards of Field-oriented control and direct torque control for induction motors torque control. This research was aimed to give a contribution for a detailed comparison between the two control techniques, emphasizing advantages and disadvantages. The performance of the two control methods is evaluated in terms of torque and current ripple, and transient response to step variations of the torque command. The analysis has been carried out on the basis of the results obtained by numerical simulations, where secondary effects introduced by hardware implementation are not present.

Fair comparison between DFOC and DTC techniques is done to allow the users to identify the more suitable solution for any application that requires torque control. Several numerical simulations have been carried out in steady-state and transient operating conditions. A new DTC scheme had also presented in order to improve the performance of the basic DTC structure. After considering all the parameters it was concluded that DTC might be preferred for high dynamic applications, but, on the other hand, shows higher current and torque ripple and the implementation of DSVM technique requires only a small increase (25%–30%) of the computational time required by basic DTC scheme. Then, using a cycle period of 80 s, as in numerical simulations, a large amount of time is available for parameter adaptation, protection and diagnostic facility.

In [3] newly developed direct torque control for an induction motor using two sets of three-phase inverters had presented. Instantaneous voltage vectors applied by an inverter have redundancy characteristics which provide some flexibility for selecting the inverter switching modes. By using this switching freedom, control is achieved according to the priorities as high-speed torque control, regulation of the primary flux, decreasing the zero phase sequence current and minimization of the inverter switching frequency. Simulations and experiments had carried out to verify the feasibility of this priority control, accompanied by comparisons with another control scheme. Torque frequency-response corner frequencies above 2000 Hz had experimentally measured, and time constants of 4 ms have been achieved for rotor speed step responses from - 500 to 500 r/ min. The peak transient torque during the step change is about 20 times the rated torque. This control scheme is quite different from field oriented control, because it depends on the concept of the instantaneous slip frequency control in spite of the magnetic force. This research especially proposed switching methods for a large-capacity inverter control system using a priority control scheme. Results show that the new control schemes are more suitable for high-speed servo systems than field-oriented control in all respects.

In [4] recently used direct torque and flux control (DTC) techniques for voltage inverter-fed induction and permanent-magnet synchronous motors had reviewed. A variety of techniques, different in concept, are described as switching-table-based hysteresis DTC, direct self control, constant- switching-frequency DTC with space-vector modulation (DTC-SVM). Also, the emerging trends in the DTC-SVM techniques based on neuro-fuzzy logic controllers are presented. Also author had reviewed DTC strategies for PWM inverter- fed ac motor drives. DTC represents a viable alternative to FOC; it requires an accurate estimation of the rotor flux vector. However, when an accurate estimation of the motor flux is available, there is no need to set up a current control loop and DTC is the natural solution. It has observed that DTC has a simple and robust control structure; however, the performance of DTC strongly depends on the quality of the estimation of the actual stator flux and torque. Starting from the IM drives, the DTC strategies have been divided into three groups: hysteresis-based ST DTC, hysteresis based DSC, and constant-switching-frequency DTC schemes operating in association with space-vector modulators (DTCSVM). The basic principles and the latest progress of these strategies have been systematically presented. Their advantages and limitations have been briefly examined and the application fields had indicated. DSC is preferred for high-power low-switching-frequency drives and is very effective in the square-wave operation region where fast flux weakening and torque control are achieved. Therefore, it is well suited for traction and vehicle drives. DTC-SVM is an excellent alternative solution for general-purpose IM and PMSM drives in a very wide power range.

In [5] a new approach based on Direct Torque Control strategy is presented. The newly designed controller was used to control an induction motor fed with a three-level inverter. The new control scheme avoids the use of the classical hysteresis block and the look-up table. As an alternative, the Torque and Stator flux errors are used together with the motor speed to generate a reference voltage that can be synthesized using different techniques. Experimental results show some improvement regarding the reduction of torque ripple, stationary mean torque error, THD in stator currents and switching frequency when compared to the Classical DTC scheme. Controller based on the DTC principle is easily applied to three-level inverters. One of the aims during the design is to keep the system simplicity as close as possible to the Classical DTC system. The new controller incorporates the motor speed in order to improve the performance at different operating points. Using the speed it is possible to eliminate the steady-state error of the mean torque at high speeds.
The novel controller equations exclude the utilization of motor parameters providing high robustness. It was also demonstrated that the novel structure also provides the possibility of easily incorporate modulation techniques due the output of the controller, which is a reference voltage vector. Initially a very simple technique choosing the nearest vector to the reference voltage vector is applied. Results of newly developed DTC scheme shows a reduction in torque and flux ripple, harmonic distortion in stator currents and switching frequency, when compared to classical DTC with a two-level inverter. Additionally, the elimination of the steady-state error in the mean torque is achieved.

In [6] investigation of Deadbeat current control and Direct Torque-Flux Control method was done with space vector modulation (SVM) for induction motor fed by three level NPC power converters. In this research, the induction motor models had explicitly given. DBC and DTFC control methods are applied to such system.
Control performances of DTFC & DBC for outer (speed) as well as inner (current/torque) loops during both high and low (zero) speed ranges had compared experimentally by maintaining same test bench with same conditions. Good control performances both at transient and steady states were observed induction machine

control with a 3L-NPC power converter when applying such strategies. Nevertheless, due to the parameters sensitivity of DBC method, DTC scheme may outperform the DBC method in terms of the (inner) loop steady status tracking performances. While DBC greatly reduces the required tuning efforts during the controller design process.

In [7] Direct self-control is explained briefly and various parameters related to it studied briefly and it was found that this method of simple signal processing which gives three-phase machines fed by VSI an excellent performance even at the low switching frequencies usual in weighty power applications. Torque Control of an induction motor, processing of the measured signals of the stator currents and the total flux linkages is sufficient. Optimal performance of drive systems was obtained by combination of several two-limit controls which was accomplished in steady state as well as in transient conditions. In earlier cases of DSC the power semiconductors of a three-phase VSI are directly switched on and off via three Schmitt triggers, comparing the time integrals of line-to-line voltages to a reference value of desired flux, if the torque has not yet reached an upper limit value of a two-limit torque control. It was found that just after the upper limit value is reached, zero voltages are switched on to the machine, as long as the lower limit value of torque is not yet under passed. The track curve of a space vector of stator fluxes forms a hexagonal nature. Dynamic properties of induction machines with DSC can be represented by response to step change of tracking speed of the flux space vector keeping the track curve constant and vice versa. Digitally computer simulations and experimental measurements are done which confirmed the validity of these theoretical investigations.

In [12] Investigation of the influence of the amplitude of flux and torque hysteresis bands on torque and flux ripple, current distortion, switching frequency, and drive losses is done. By using simple signal processing method high dynamic performance of direct torque control can be obtained but this control technique doesn't require current regulators so reducing the hardware requirements. The benefits of a careful choice of hysteresis band amplitudes are emphasised. Verification of numerical results was achieved by experimental tests carried out on a DSP based processing System. Analysis of control scheme for direct torque control of induction machine had done to emphasise the effects of flux and torque hysteresis band amplitudes on drive performance. For the comparative analysis some performance evaluation criteria such as torque dispersion, harmonic distortion factor, average switching Frequency and drive losses had utilised. The obtained results show that the flux hysteresis band mainly affects the motor current distortion in terms of low order harmonics. In scrupulous, high values of the flux hysteresis band determine high harmonic copper losses. The switching frequency and then the switching losses are mainly affected by the torque hysteresis band. It has been shown that a minimum for the sum of the harmonic copper losses and switching losses may be determined. When the torque hysteresis band amplitude is established by load requirements, the drive losses are function of $\Delta\emptyset$ only. For the drive system considered in this paper, the drive losses assume the lover values for $\Delta\emptyset = 0$. However, considering different semiconductor devices or motors, the lower values of the drive losses may occur for $\Delta\emptyset$ values greater than zero.

In [13] Author completely reviewed the basic operation of an IM and of a PWM inverter using the space vector theory. The field-oriented (FO) control is also reviewed. Then the concept of DTC is illustrated and three DTC-based strategies (i.e. switching table (ST), direct self control (DSC), space vector modulation (SVM)) are described. The ST strategy is dealt with in depth, illustrating by means of experimental data the flux and torque responses generated with different choices of the switching table and the influence of the amplitude of the hysteresis bands of the flux and torque controllers on the drive performance. Moreover, an improved stator flux estimator is presented which allows the system under to be kept under control even at standstill. Finally the sensitivity of the control system to parameter variations is presented as direct torque control (DTC) is an emerging technique for controlling the PWM inverter-fed induction motor (IM) drives. It allows the precise and quick control of the IM flux and torque without calling for complex control algorithms and, DTC requires only the knowledge of the stator resistance. It is observed that there is no need of current loops and variable transformation also any need of a speed sensor for implementing the IM flux and torque control. IM parameters, apart from the stator resistance are also eliminated in DTC. The performance of DTC in the low speed range and at standstill can be enhanced using an improved flux estimator. A reduction in the sensitivity of the control scheme to parameter variations is also achieved by the use of this flux estimator.

III. OBJECTIVES

1. The primary aim of this work is to develop a controlling method to achieve fast torque response as well as superior dynamic response.
2. Another aim is to analyse the most sophisticated IM control method i.e. DTC and investigate its performance characteristics.

IV. PROBLEM IDENTIFICATION

Vector control of the induction motor is classified as Field Oriented Control and Direct Torque Control of the Induction Motor. The Field Oriented Control has some drawback such as:

1. Easiness of the implementation is complicated because of the Parks and Clarks transformations.
2. During interruptions, speed of the drive deviates gradually and current increases gradually.
3. Torque response is faster but spiky.
4. Speed sensor is necessary.
5. The operation of FOC is affected by variation in parameters.
6. Current controller is required.
7. PWM modulator is necessary.

To overcome this drawback, Direct Torque Control (DTC) is used. This method provides a good performance with a simpler structure and control diagram. In DTC it is possible to control directly the stator flux and the torque by selecting the appropriate inverter state**.**

V. FEATURES OF DTC

1. Direct control of flux and torque.
2. DTC needs stator flux and torque estimation. It is therefore insensitive to rotor parameters.
3. Indirect control of stator currents and voltages.
4. Approximately sinusoidal stator fluxes and stator currents.
5. Absence of separate voltage modulation block, usually required in vector drives.
6. High dynamic performance even at locked rotor.
7. DTC operates with closed torque and flux loops, but without using current controllers.
8. Inherently sensor less control since speed information is not required at all in the torque mode of operation.
9. In its basic form DTC scheme is sensitive to only variation in stator resistance.
10. Inverter switching frequency depends on width of flux and torque hysteresis.
11. DTC has simple and robust control structure.

VI. ADVANTAGES AND DISADVANTAGES OF DTC

A. Advantages

1. The structure is independent on rotor parameters.
2. Simple implementation of Sensorless operation.
3. No coordinate transformation.
4. No current control loops.
5. Absence of voltage modulator block, as well as other controllers such as PID for flux and torque.
6. Minimal torque response time, even better than the vector controllers.
7. Direct controlling of flux and torque is possible.
8. Control structure of DTC is simpler and robust.
9. Indirect control of stator currents and voltages are possible in this controlling method.

B. Disadvantages

1. Variable switching frequency.
2. High switching losses.
3. Difficulty to control torque and flux at very low speed.
4. High current and torque ripple.
5. High noise level at low speed.

VII. CONCLUSION

In Electrical industries Induction motor plays a vital role in various applications, So it's necessary to study controlling Methods of induction Motor to achieve better performance through it along with this the speed control of induction motor at a low cost with fewer sensor, more effective solutions are required. They are v/f, field oriented control and direct torque control of induction motor. Detailed study of all this methods covers various parameters related to it and their comparison is also done with those parameters to prove effectiveness in various applications. After Comparison of different parameters and on the basis of overall working of DTC that it is concluded that DTC is beneficial over other methods because of no coordinated transformation, absence of the PI regulator, minimal torque response time, etc.

Literature Survey also shows that DTC is beneficial in many ways in comparison with remaining controlling methods. So taking these things into considerations a mathematical model is developed and certain parameters are focused for generation of MATLAB model.

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