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A New Direct Torque Control Strategy for Induction Motor Adjustable Speed Drives

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ABSTRACT- *An new approach to Direct Torque Control (DTC) method is proposed in this paper for Induction Motor drives. In traditional DTC approach, two primary reference parameters are used as: flux and torque. In this paper, the new approach has been proposed to improve the Induction Motor dynamic performance. A primary difference from the conventional approach of it changed into that only one reference parameter (velocity) became used to Control the Induction motor and the second control parameter (flux) turned into received from speed errors through the proposed control set of rules. Thus, the DTC performance has been mainly stepped forward on structures which need variable speed and torque at some stage in operation, like electric motors. The dynamic models of the Induction Motor and the DTC approach have been created on Matlab/Simulink. The proposed technique has been showed and tested by means of the dynamic simulations on distinct operating situations.*

KEY WORDS
Induction Motor Direct Torque Control, Vector Control, Torque 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 DCmachine 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 was introduced: The Direct Torque Control (DTC) method is characterised 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, which is based on an independent hysteresis control of flux and torque. The main advantages of DTC are absence of coordinate transformation and current regulator absence of separate voltage modulation block. Common disadvantages of conventional DTC are a sluggish response (slow response) in both starts up and changes in either flux or torque, large and small errors in flux and torque are not distinguished. In other words, the same vectors are used during start up and step changes and during steady state. In order to overcome the mentioned drawbacks, there are different solutions, which can be classified as follows modification of the switching table, so modified DTC (M_DTC) and twelve sectors DTC (12_DTC). In this paper a comparison of various direct torque control methodologies (Conventional TC, M-DTC, and 12_DTC) have been presented with evaluation of the influence on the transient performances of induction motor.

Those are such as the field weakening control method, overlapping method, PWM chopping method. Usually, these applications are characterized by relatively high torque ripples. In this study, closed-loop speed control of Induction motor fed by six step inverter for desktop CNC machine investigated. Motor has 3 phases, 0.0089 kg/m2 /0.00091 kg/m2 changes inertia moment, 0.005 viscous damping, 3000 rpm reference speed, 4 poles and trapezoidals back EMF wave form. Inverter has 3 bridge arms with IGBTs, snubber resistance 5000 ohms and snubber capacitance 1 microF.

Direct Torque Control (DTC) method proposed in has been utilized to drive the Induction motors. DTC which is also known as conventional DTC has features such as fast torque response, simple and robust design. These features have made it popular in industrial applications. This control method operates in a two phase conduction mode which is simplified to just a torque controlled drive by intentionally keeping the stator flux linkage amplitude almost constant by eliminating the flux control in the constant torque region.

In literature, many kind of Induction motor drive methods can be found. In, artificial neural networks based method was used in modeling of Induction motor to get the maximum power consumption. Very simple and effective three-level neutral point clamped inverter was proposed to drive axial flux Induction motors, in. Field Programmable Gate Array (FPGA) based induction motor driver with using digital pulse-width modulation (PWM) is presented in .

In addition, several different methods, which based of the DTC, were studied in BLDC drivers. Reference [10] proposes the DTC method for matrix converter fed induction motor. The DTC of induction motor method using with four-switch inverter in constant torque region was proposed in. In this paper, a new approach to the DTC method has been proposed for small sized electric vehicles that work in variable speed and torque conditions, naturally. In the proposed method, optimum stator flux reference value was obtained by PI controller with usage of the speed error. The dynamic model of the proposed method was developed with Matlab/Simulink. The dynamic simulations were performed and results were presented to illustrate the validity of the proposed method.

DIRECT TORQUE CONTROL OF INDUCTION MOTOR

The Induction motor has three phase stator windings with permanent magnet rotor and electrical model of the motor that connected with PWM inverter, is given in Fig.1. Voltage equations of the motor can be obtained by the following equation;

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

The mechanical moment equation of the motor given by the following equation;

When V_a, V_b, V_c are phase voltages R is resistance, L is inductance, i_a, i_b, i_c are phase currents and e_a, e_b, e_c are back EMFs.

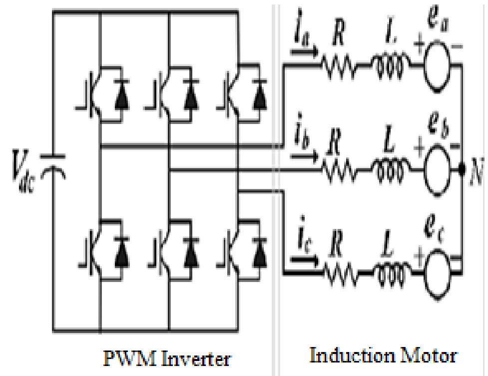

Figure 1. Electrical model of the motor that connected with PWM inverter

$$T_e = T_L + Bw_m + i\frac{dw_m}{dt}_e \tag{2}$$

T_e and T_L describes generated electromagnetic torque and load torque, respectively.

B is the friction coefficient, j is the inertia and ω is the angular velocity of rotor.

The DTC method needs to transformation of the three phase motor parameters to two Phase. In this transformation, electrical parameters of the motor (voltages, currents, back emf) should to be transformed to stationary reference frame and it can also be named as α − β transformation or Clarke transformation in many sources.

The Clarke transformation matrix is given (3).

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \tag{3}$$

Where, fα, fβ are α − β components of motor parameters, and f_a , f_b , f_c are the abc frame components .

With the transforming of the three phase parameters of the motor, α − β components of the phase voltages can be written as:

$$V_{s\alpha} = R_s i_{s\alpha} + L_s \frac{di_{s\alpha}}{dt} + e_{i_{s\alpha}} \tag{4}$$

$$V_{s\beta} = R_s i_{s\beta} + L_s \frac{di_{s\beta}}{dt} + e_{i_{s\beta}} \tag{5}$$

Where vsα, vsβ are the stator voltages, isα, isβ are the stator currents and eα, eβ are back emf in the α − β referance frame.

In the DTC scheme, stator flux components are obtained from α − β components of the measured stator voltages and currents as given below:

$$\lambda_{s\alpha} = \int (V_{s\alpha} - R_s i_{s\alpha}) dt \tag{6}$$

$$\lambda_{s\beta} = \int (V_{s\beta} - R_s i_{s\beta}) dt \tag{7}$$

The magnitude of the flux can be calculated with;

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$$\lambda = \sqrt{\lambda_{s\alpha}^2 + \lambda_{s\beta}^2} \quad (8)$$

and position of the stator flux vector can be calculated with;

$$\theta = arctan\frac{\lambda_{s\alpha}}{\lambda_{s\beta}} \quad (9)$$

In the conventional DTC (C-DTC) method, control algorithms works with two separate reference values as torque (or speed) and flux references. Because, in idea of the DTC, stator flux vector has two components (α − β components) and they can be controlled independently from each other. One of them controls flux, while the other one controls torque. In generally, flux reference is kept constant and the speed control of the motor can be achieved by setting up the torque reference value. This approach is very appropriate for constant torque-variable speed applications. The conventional DTC block diagram is given in Fig. 2.

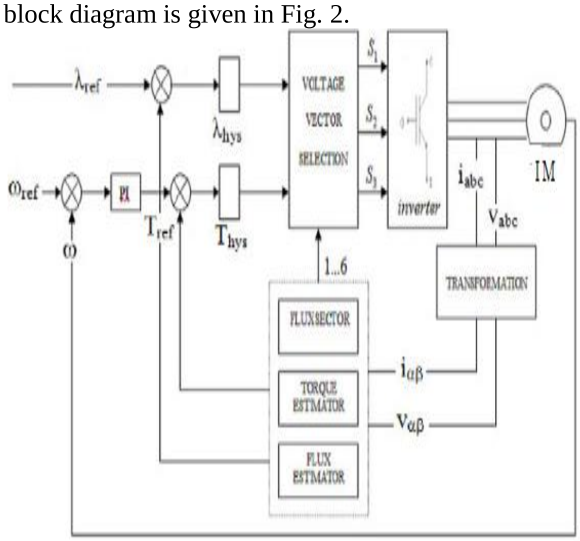

Figure 2. The conventional DTC block diagram

ADAPTIVE FLUX BASED METHOD

A main difference from the conventional method of it was that only one reference parameter (speed) was used to control the induction motor and the second control parameter (flux) was obtained from speed error through the proposed control algorithm. Thus, the DTC performance has been especially improved on systems which need variable speed and torque during operation, like electric vehicles. The dynamic models of the induction and the DTC method have been created on Matlab/Simulink. The proposed DTC method Simulink block diagram is given in Fig. 3.

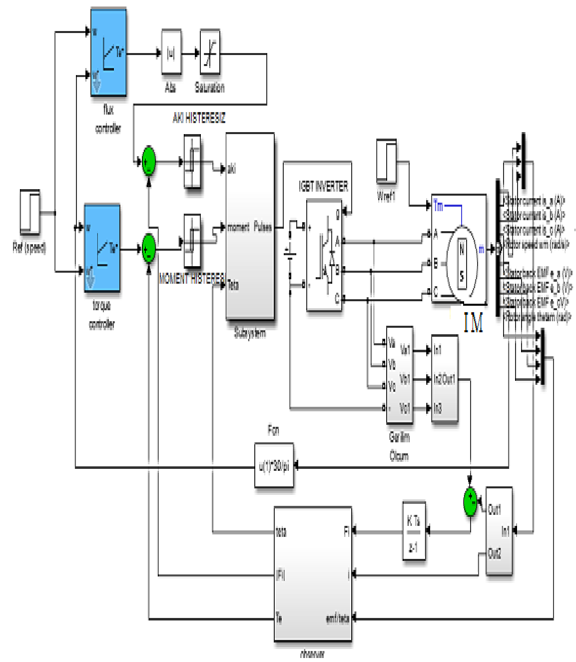

Figure.3. The Proposed DTC Simulink Block Diagram

INDUCTION MOTOR

An induction motor (IM) is a type of asynchronous AC motor where power is supplied to the rotating device by means of electromagnetic induction. Other commonly used name is squirrel cage motor due to the fact that the rotor bars with short circuit rings resemble a squirrel cage (hamster wheel).An electric motor converts electrical power to mechanical power in its rotor.

The Induction motor is a three phase AC motor and is the most widely used machine. Its characteristic features are-

- Simple and rugged construction
- Low cost and minimum maintenance
- High reliability and sufficiently high efficiency
- Needs no extra starting motor and need not be synchronized
- An Induction motor has basically two parts – Stator and Rotor

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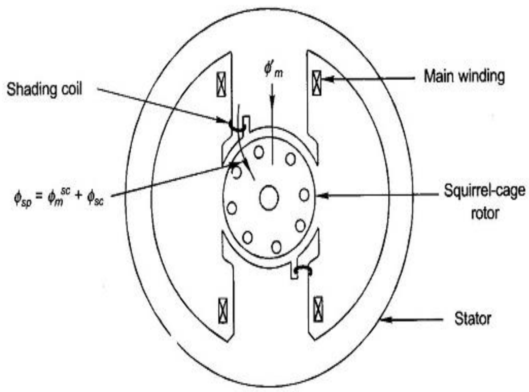

Figure.4. diagram of induction motor

Principle of operation

When a three-phase supply is connected to the stator windings, a rotating magnetic field is produced. As the magnetic flux cuts a bar on the rotor, an e.m.f. is induced in it and since it is joined, via the end conducting rings, to another bar one pole pitch away, current flows in the bars.

SYNCHRONOUS SPEED:

The speed of the rotating magnetic field is referred to as synchronous speed (NS). Synchronous speed is equal to 120 times the frequency (F), divided by the number of poles (P).

$$N_s = 120\frac{F}{P} \qquad (10)$$

STEADY-STATE REPRESENTATION

The traditional methods of variable-speed drives are based on the equivalent circuit representation of the motor shown below.

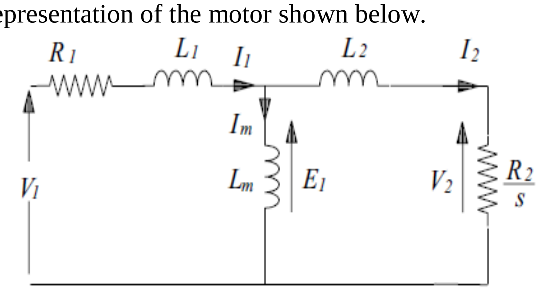

Figure.5.Steady-state equivalent circuit of an induction motor

Power in the rotor circuit,

$$p_2 = 3I_2^2\frac{R_2}{s} = 3V_2I_2 = \frac{3sR_2E_1^2}{R_2^2+(s\omega_1L_2)^2} \qquad (11)$$

The output power

$$P_o = P_2 - 3I_2^2R_2$$
$$= (1-S)P_2 = \omega_0 T$$
$$= \frac{(1-s)\omega_1}{P}T \qquad (12)$$

Advantages

The advantages of induction motors are:

1. They are robust and sturdy.
2. They can operate in a wide range of industrial conditions.
3. Induction motors are cheaper in cost. The construction is simple.
4. Induction motors do not have accessories such as brushes, slip rings or commentators
5. Low Maintenance.
6. Very little maintenance is required for induction motors.
7. It does not require any complex circuit for starting.
8. The three phase motor is self starting while the single phase motor can be made self-starting simply by connecting a capacitor in the auxiliary winding.

SIMULATION RESULTS

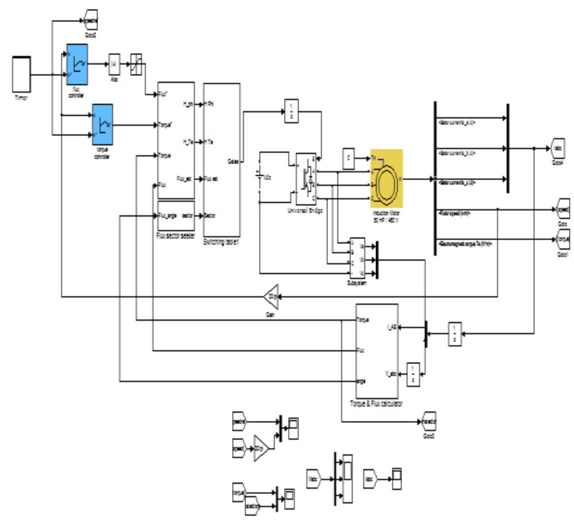

Figure.6.Block Diagram Of Simulation

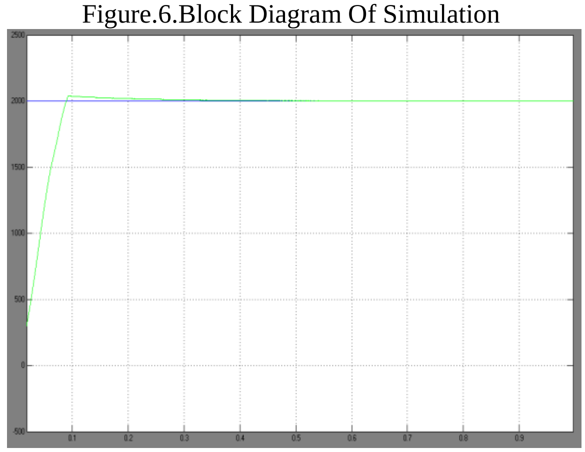

Figure 7. Speed responses of the induction motor in variable speed-constant load

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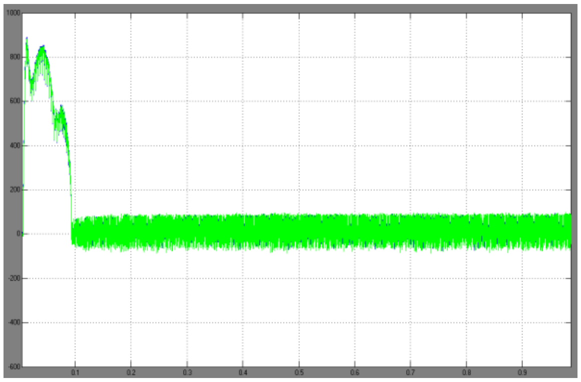

Figure.8. Torque responses of the induction motor in variable speed-constant load

In dynamic simulations, the induction motor was performed under two diverse working conditions. The parameters of the squares and the motor that utilized as a part of dynamic simulations were given in index. Add up simulation time was 1 sec. for all conditions. The testing time was 10 µs. The engine stack consistent (5Nm) and the speed reference was changed 2000 rpm to 400 rpm at 0,5. sec. in first working condition.

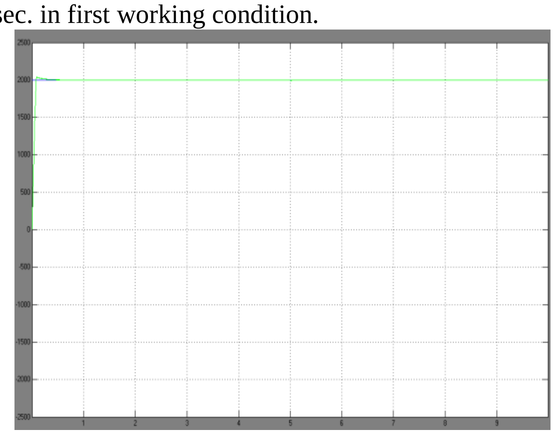

Figure.9. Speed responses of the induction motor in variable torque-constant

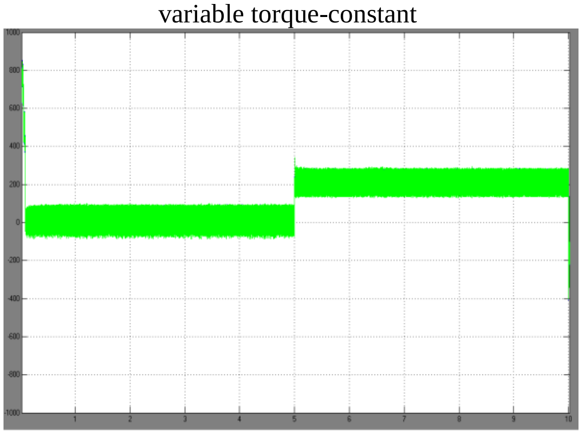

Figure.10. Torque responses of the induction motor in variable torque-constant speed

In the second test, the motor was simulated at consistent speed reference (2000 rpm) and the torque reference was changed to 1 Nm to 5 Nm at 0,5.sec. The speed and the torque reactions of the engine were given in Fig.9 and Fig. It can be seen in from figures (Fig.7– Fig. 10) that, the induction motor speed and torque reactions were enhanced with the P-DTC technique. The torque and speed ripples diminished remarkably with the P DTC technique particularly in speed reference values. In 400 rpm speed referenc dynamic practices were relatively same with the two strategies.

CONCLUSIONS

Over the final decades, the induction motors were used many industrial applications and it has gain great popularity between electric automobiles. On the alternative hand, the DTC is well-known excessive performance control method not best for Induction Motor motors but additionally many other motor types. This paper gives a new perspective to the conventional DTC method. The proposed DTC approach implemented to the Induction vehicles which considered drives small size electric powered cars. These vehicles works in variable speed and torque situations with single referenc DTC method was changed with the adding of second PI controller that produces most desirable flux reference. In order to test the simulations had been been achieved The simulations consequences confirmed that the proposed approach reduced remarkably the speed and the torque ripples whilst in comparison traditional DTC method. The proposed method easy structure to use the conventional DTC and its greater computational load to the control became almost zero.

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