Comparison of FOC And DTC Method To Improve Torque Response of Induction Motor Drive Using Matlab

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Abstract- *This paper presents a contribution for detailed comparison between two sensors less control techniques for high performance induction motor drives: Field-oriented control (FOC) and direct torque control (DTC). The main characteristics of field-oriented control (FOC) and direct torque control (DTC) schemes are studied by comparing these on Matlab using Simulink. The performances of the two control schemes are evaluated in terms of torque and current ripples, and transient responses to load toque variation. We can nevertheless say that the two control schemes provide in their basic configuration, comparable performances of parameter such as torque control and parameter sensitivity. We can note a slight advance of DTC scheme compared to FOC scheme regarding the dynamic flux control performance and the implementation complexity. The choice of one or the other scheme will depend mainly on specific requirements of the application.*

Keywords- Direct torque control (DTC), Field Oriented Control(FOC), Induction Motor, Voltage Source Converter (VSC), Space Vector Modulation, Multilevel Inverter, Total Harmonic Distortion.

I. INTRODUCTION

Control of AC motor drives has improved dramatically during the last two decades[7]. Though traditionally, variable speed electric machines were based on DC motors, variable speed or adjustable torque control of electrical motor drives are now crucial components in almost all modern industrial manufacturing processes. For low performance applications, open loop voltage/frequency control strategies are employed. But in the last three decades, important advances in the power semiconductor and control technology areas have led to new concepts for adjustable speed-drives for AC motors (AC motor mathematical models are much more complex than those of the DC motor and thus require more complex control schemes and more expensive power converters to achieve speed and torque control). Field Oriented Control (FOC) and Direct Torque Control (DTC) allow torque and flux to be decoupled and controlled independently to achieve a dynamic performance at least equivalent to that of a commutator and DC motor.

II. LITERATURESURVEY

Field-Oriented Control: 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.[5]

“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.”

Direct Torque Control (DTC):- DTC is simpler as it deals with flux linkage and torque directly rather than dealing with current as it is the case of FOC. DTC does not require coordinate transformation and it is not necessary to determine the exact position of the flux linkage space vector. Because of these advantages, DTC has become popular with three-phase induction motor drive for various applications. But one of the major drawback of DTC drive is the pulsation in its torque. The pulsation in its torque is due to overshoot and undershoot in magnitude and position of the flux linkage space phasor. There are only six non-zero voltage vectors available in two-level voltage source inverter (VSI) out of which two vectors have to be chosen to nullify the flux and torque errors obtained from the DTC algorithm.[1]

Various Components which are used in DTC and FOC method:-

Three Phase Induction motor:- An electric motor converts electrical energy into a mechanical energy which is then supplied to different types of loads. AC motors operate on an ac supply, and they are classified into synchronous, single phase and 3 phase induction motor, and special purpose motors. Out of all types, 3 phase induction motors are most widely used for industrial applications mainly because they do not require a starting device.[1]

Three Phase Diode Rectifier:- In three phase full wave rectifier six diodes are used. It is also called 6-diode half wave rectifier. In this each diode conducts for 1/6th part of the AC cycle. The output DC voltage fluctuations are less in 3 phase full wave rectifiers. The output voltage fluctuates between maximum value of peak voltage i.e (Vs) max and 86.6% of the maximum voltage.[6]

Braking Chopper:- It controls the DC-link voltage by connecting the brake resistor across it and thus dissipates the energy. The braking chopper in the frequency converter is rated for continuous drive rated power. External brake resistor for energy dissipation together with an internal, factory mounted brake chopper. The extra energy from the load is turned into heat in the brake resistor.[8]

Speed Controller:- The Speed Controller (AC) block represents a PI speed regulator model for AC machines used in vector-controlled drives. It has two operating instances: the first with both torque and flux references outputs and the second with torque reference output only.

Bridge Firing Circuit:- The Bridge Firing Unit (DC) block generates gate signals for a standard two-leg or three-leg thyristor bridge. It features two operating modes: detailed and average. In detailed mode, the block outputs synchronized pulses for each thyristor. In average mode, it outputs the firing angle for the Thyristor Bridge.

DC Voltage Controller:- The Voltage Controller (DC Bus) block represents a PI DC bus voltage regulator model for a thyristor bridge rectifier. The controller outputs the thyristor bridge firing angle (Alpha). This firing angle is typically used by a thyristor bridge firing unit to generate the gate signals needed to reach the desired DC bus voltage.

Papers Studied:

The following papers were studied and analyzed in detail and hence summarized in the table below

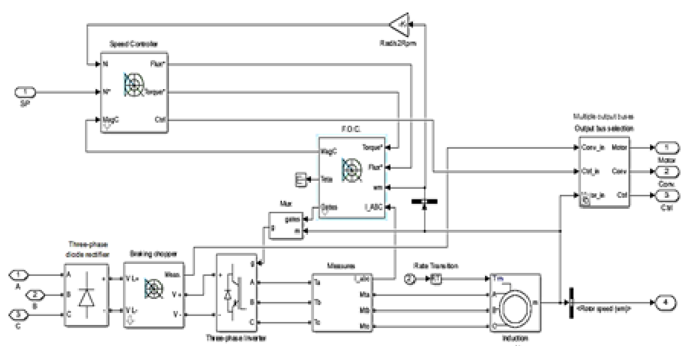
Topic of Paper	**Concept Analyzed**	Tools Used
Overview of Advanced Control Strategies for Electric Machines.[7]	Analysis of control strategies of electric machines.	Hardware Implementation
FOC and DTC: Two Viable Schemes for Induction Motors Torque Control.[1]	Analysis of torque response in three phase induction motor	MATLAB
An approach to flux control of induction motors operated with variable-frequency power supply.[5]	Concept of flux control of three phase induction motor.	Hardware Implementation
Electric Motor Drives: Modeling Analysis and Control.[13]	Analysis of electric motor drives.	MATLAB

III. MATLAB SIMULATION MODELING AND ITS IMPLEMENTATION

We use the Simulink schematics of FOC and DTC on Matlab and compare the graph of various parameters such as stator current, rotor speed and electromagnetic torque.

3.1 Field Oriented Control (FOC).

3.1.1 Simulink schematics:



Figure(3.1) Simulink schematics of Field Oriented Control (FOC).

3.2 Direct Torque Control (DTC)

3.2.1 Simulink Diagram of Direct Torque Control DTC:

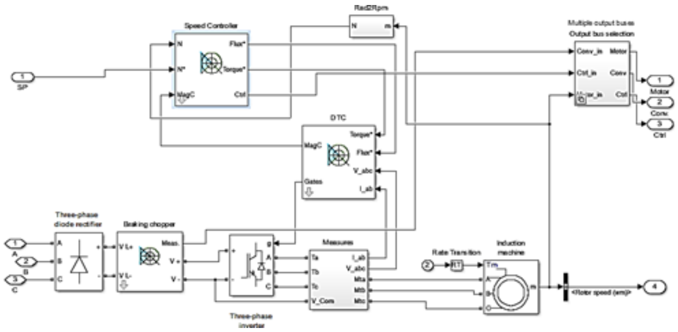


Figure (3.4) Simulink Model of DTC.

3.3 Model Specifications:

The model specification of the FOC and DTC is given in the following table (3.1).

Table (3.1): - Specification of used Model

S.NO	PARAMETER	VALUE
1	Supply Voltage	460V
2	Frequency	60Hz
3	Power	200HP
4	Speed	1785 RPM
5	Input Voltage	460V
6	Stator Resistance	0.01485 Ohm
7	Rotor Resistance	0.00929 Ohm
8	No of Pole Pair	2
9	Inertia	3.1 Kgm^2
10	Braking Resistor	10000 Ohm
11	Activation Voltage	700V
12	Shutdown Voltage	660V

IV. RESULTS

4.1 Simulation result of FOC.

Outputs of the different variables of FOC at different time and load as the following table (4.1)

Table (4.1): - Different Load at different Time

Time (Sec.)	Load A (Nm	Load B (Nm)
0	0	0
0.5	500	750
1.5	-500	-750
3	0	0

4.1.1 Stator current.

Stator current given in Figure (4.1a) at load torque 500 Nm and in figure (4.1b) at 750 Nm.

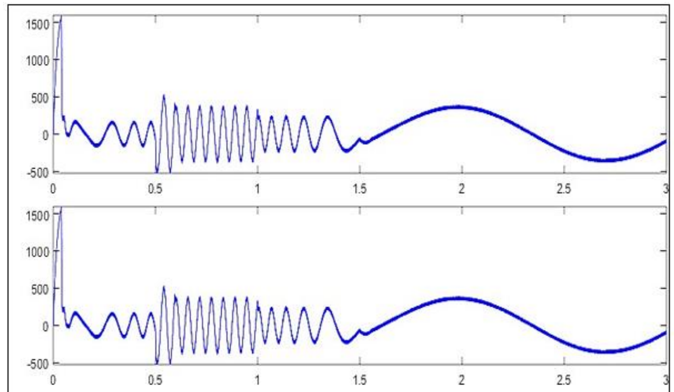


Figure (4.1a)and (4.1b) Stator Current Vs Time.

4.1.2 Rotor speed.

Rotor Speed given in figure (4.2a) at load torque 500 Nm and in figure (4.2b) at 750 Nm.

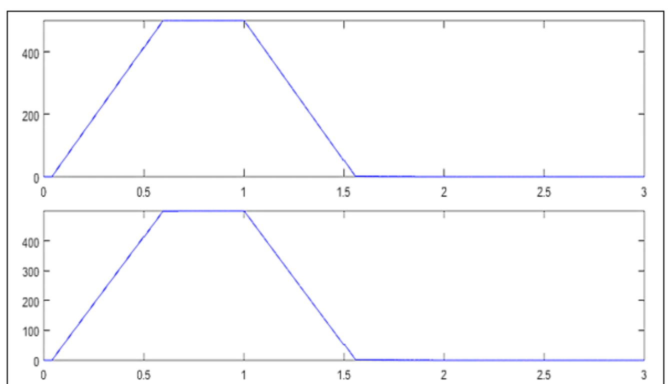


Figure (4.2a) and (4.2b) Rotor speed vs Time

4.1.3 Electromagnetic Torque.

Electromagnetic Torque given in figure (4.3a) at load torque 500 Nm and in figure (4.3b) at 750 Nm.

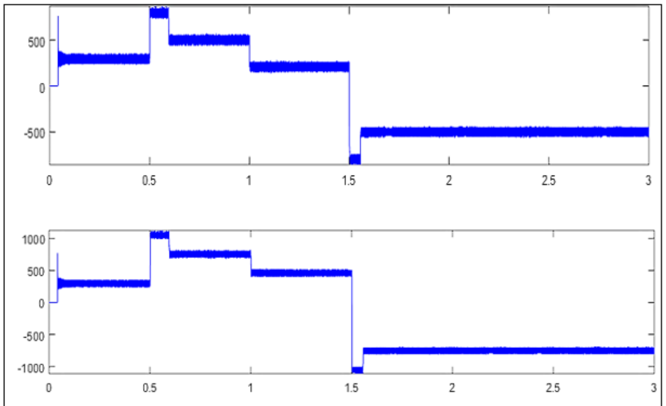


Figure (4.3a) and (4.3b) Electromagnetic Torque Vs Time

4.1.4 DC Bus Voltage.

DC Bus Voltage given in figure (4.4a) at load torque 500 Nm and in figure (4.4b) at 750 Nm.

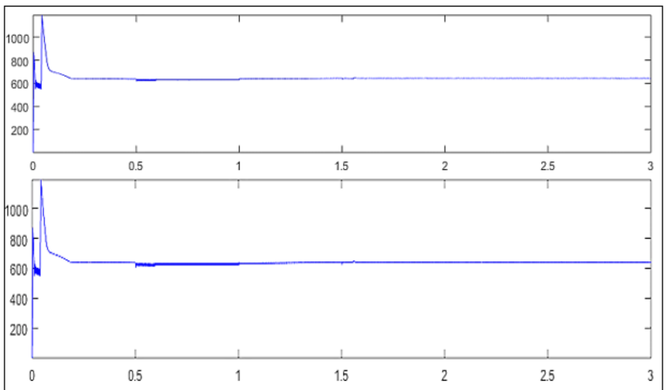


Figure (4.4a) and (4.4b) DC Bus Voltage Vs Time.

4.2 Simulation result of DTC.

Outputs of the different variables of DTC at different time and load as the following table (4.2)

Table (4.2): - Different Load at different Time.

S. No.	Time (Sec.)	Load A (Nm)	Load B (Nm)
1	0	0	0
2	0.5	500	750
3	1.5	-500	-750
4	3	0	0

4.2.1 Stator current.

Stator current given in Figure (4.5a) at load torque 500 Nm and in figure (4.5b) at 750Nm.

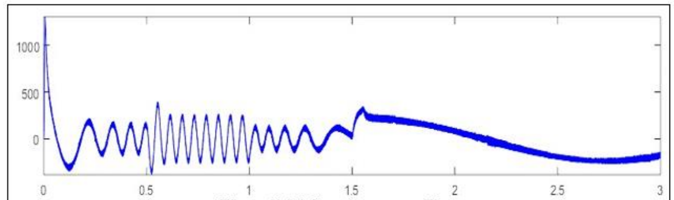


Figure (4.5a) Stator current vs Time

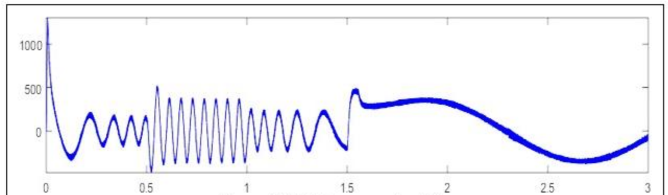


Figure (4.5b) Stator current vs Time.

4.2.2 Rotor speed.

Rotor Speed given in Figure (4.6a) at load torque 500 Nm and in figure (4.6b) at 750 Nm.

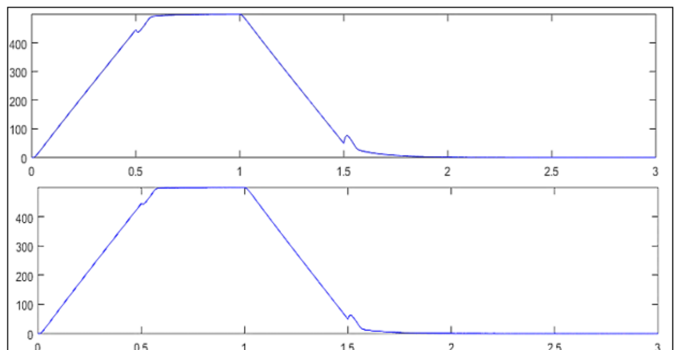


Figure (4.6a) and (4.6b) Rotor Speed Vs Time.

4.2.3 Electromagnetic Torque.

Electromagnetic Torque given in Figure (4.7a) at load torque 500 Nm and in figure (4.7b) at 750 Nm.

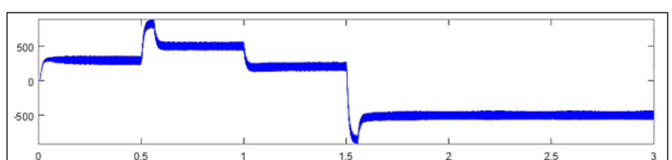


Figure (4.7a) Electromagnetic Torque Vs Time

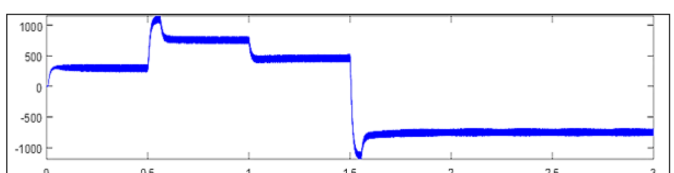


Figure (4.7b) Electromagnetic Torque Vs Time.

4.2.4 DC Bus Voltage.

DC Bus voltage given in Figure (4.8a) at load torque 500 N-m and in figure (4.8b) at 750 Nm.

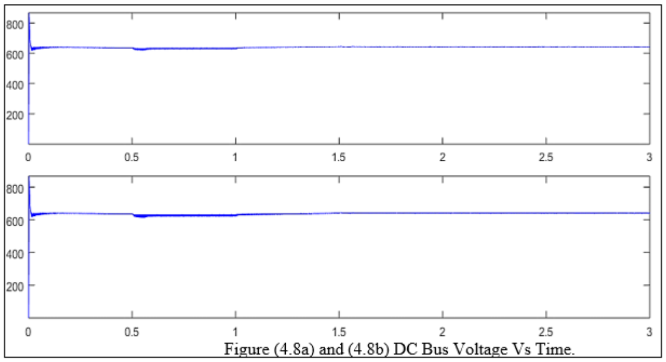


Figure (4.8a) and (4.8b) DC Bus Voltage Vs Time.

V. CONCLUSION

This work presents a comparison between two control methods of induction motor drive: field- oriented control and direct torque control. Both methods provide a decoupled control of torque and flux during transients and steady-state. With DTC scheme the motor attains steady state much faster but have oscillations in the torque whereas with FOC the oscillations in the torque are much smaller but takes more time to attain steady state. So, depending upon the needs of a particular application one method can be use according to requirement.

In a separately excited DC Motor torque is proportional to the product of flux and armature current. Without vector control method, torque of induction motor is square of either voltage and current. But the with use of vector control method to achieve the torque is proportional to the product of flux and armature current. Therefore, vector control gives control like separately DC Motor.

Table of Comparison Between FOC and DTC

S. No.	Parameter	Field Oriented Control (FOC)	Direct Torque Control (DTC)
1	Dynamic response to torque	Fast	Very fast
2	Behavior of steady-state torque, flux and current	Less ripple and distortion	More ripple and distortion
3	Controlled variables	Direct and Quadrature axis current	Torque
4	Complexity of Implementation	High Complexity	Average Complexity
5	Park transformation	Need No	need
6	Current control	Need	No need
7	PWM modulator	Need	No need
8	Regulator Used	PI regulator	Hysteresis bands
9	Switching losses	Low	Lower (requires high quality current sensors)
10	Coordinate transformations	Required	Not required
11	Switching frequency	Constant	Varies widely around average frequency
12	Rotor position measurement	Required (either sensor or estimation)	Not required