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Direct Torque Control Based Induction Machines

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ABSTRACT
In industry most of the electric motor load is Induction Motor (IM). IM has high performability with good degree of reliability as well as low maintenance which make it popular electric motor choice. However, it suffers from complex dynamic control architecture. IM has complex sets of non-linear equations with multivariable functionality. Also, its control has direct as well as indirect proportionality which make it difficult to design. In this paper the speed-torque characteristic of IM is designed using one very popular direct control method i.e., Direct Torque Control Method (DTCM). The simulation results are presented to study the behavior of speed under variable torque which is the result of variable loading condition. The control is so designed so as to keep the speed constant even under varying torque and vice-versa.

Keywords— Induction Motor (IM), Direct Torque Control Method (DTCM), Field Oriented control (FOC), DC-Drive control, Sliding Mode Control (SMC).

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I. INTRODUCTION

Aggregate of the overall industrial electricity demand has been consumed by electric motors particularly Induction Motor (I-M), since it has good degree of reliability as well as low maintenance [1]. Some IM applications requires precise and instant dynamic response, hence versatile control approach has been available in literature [2-5]. While designing control for IM, it must be noteworthy that the modelling of multivariable functions is strongly coupled with the series of non-linear equations. These constraints need fast computational algorithm to control stator flux and torque.

Firstly, scalar control is designed using voltage-frequency (V-F) characteristics for keeping flux constant [6]. V-F is the simplest type of control, but on reversal of directions oscillations generated in stator flux are difficult to damped out. For control of torque in transient state Field Oriented Control (FOC) was developed [7]. FOC has fast dynamic response high efficiency for variable load changing and high range of speed control. But its control is complex. The advancement in control is continued and in 1980's Direct Torque Control Method (DTCM) was developed having significant dynamic torque response and simple control with adequate parametric variation response [8,9]. The comparison of the above mentioned methods is elaborated in table 1. With the advent in the development of computational technologies, various soft computing techniques are also developed by researchers [10, 11]. These techniques requires high computational software with high degree of sensitivity and accuracy. The most common techniques are artificial intelligence, genetic algorithm, fuzzy control, neural network, etc.

Among all the available control architecture DTC is the most popular due to its compatible efficiency with ease of control. This paper presents the performance analysis of DTC based IM for speed torque control.

TABLE I. COMPARISON OF CONTROL STRATEGIES OF I-M

Control Type	Torque Control	Flux Control	Response
DC Drive	Direct	Direct	High
Scalar frequency control	None	None	Low
Field Oriented Control	Indirect	Direct	High
Direct Torque Control	Direct	Direct	High

II. SPPED-TORQUE CHARACTERISTICS OF I-M

The analysis of I-M is carried out considering stator as frame of reference. Analysis is presented for speed-torque relation of an asynchronous three-phase squirrel cage (ATPSC-IM). The efficiency and power factor of standard IM shows that torque, the speed for pull-out torque are functions of the loading condition. The design parameter for ATPSC-IM is presented in table 2. The classic speed torque characteristics is designed using MATLAB model of conventional IM as shown in figure 1 and 2. Respectively.

TABLE II. PARAMETER OF I-M

S.No.	**Parameter**	**Value**
1.	RMS Voltage	460V
2	Frequency	60 Hz
3	Power rating	200HP
4	Stator resistence	0.018Ω
5	Stator inductance	0.0019 H
6	Rotor resistence	0.0099Ω
7	Rotor inductance	0.0019H
8	Mutual Inductance	0.0094H

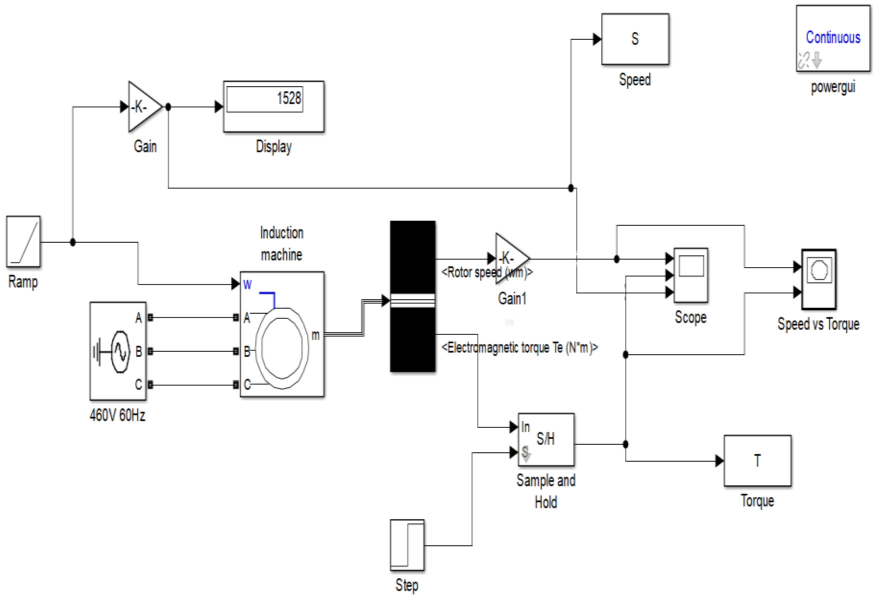

Figure 1 Simulation model of IM

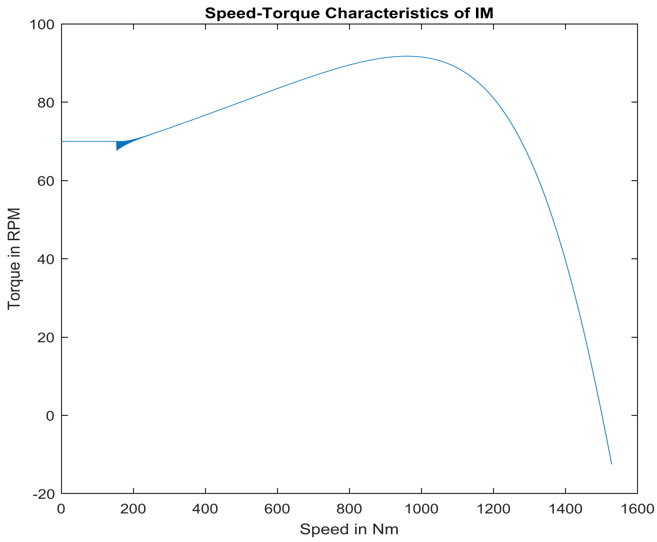

Figure 2. Speed-torque characteristics of IM

The IM is an AC machine which either perform for speed greater than synchronous speed that is motoring mode or less than synchronous speed that is generating mode. The speed-torque characteristics of IM shows the motoring mode, where even at zero speed initial torque is present. Since IM sustains with starting torque. The linear portion of the curve presents the range of operation of IM with good efficiency.

III. DIRECT TORQUE CONTROL

IM has multivariable characteristics and the variation in one parameter effects the other which make it non-linear. Hence under dynamic operating condition a robust control to track the speed torque characteristics within linear range is required. Among all the available control techniques DTC is most popular since its control is independent of parametric variations, which is the most desirable aspect of IM control.

DTC has accurate torque characteristics with fast response and high accuracy. The DTC is designed using conventional voltage converter whose switching sequences are controlled by direct triggering to the switches [12]. The choice of the sequence of switches is designed using switching table and two hysteresis regulators. DTC design architecture comprises of two Hysteresis Controllers (HC); one for stator flux control and another for speed estimation as demonstrated in figure 3.

The relative motion of flux and winding generates the electro-magnetic torque whose control is governed by three-level HC. In DTC, the accuracy of stator flux and speed estimation is very important to ensure satisfactory performance [13]. Hence, several parameters are need to be calculated to determine switching states of voltage variables (Sa, Sb and Sc) produced by the switching table [14].

The versatile and robust control characteristics of DTC has attracted researcher to design the IM for high precision and sensitive applications. By modify the design for switching sequence of the inverter or for stator and flux estimation, the saturation in hysteresis controller or high ripples in flux as well as unavoidable noises can also be reduced to a large value. In literature many such techniques employing artificial intelligence or tuning techniques are sited. There is a wide range of DTC methods with conventional and modified versions are available which is tabulated in figure 4.

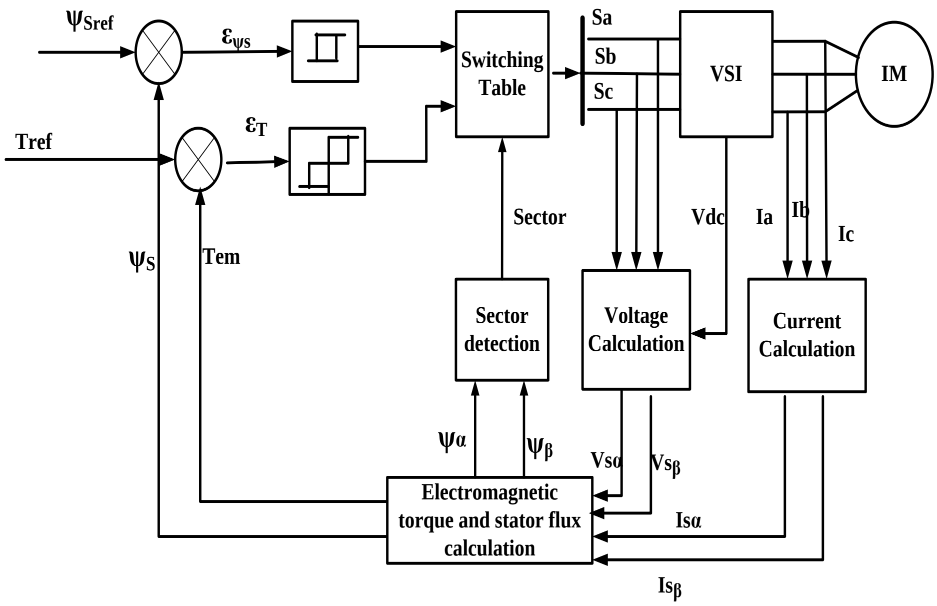

Figure 3 Schematic of DTC method

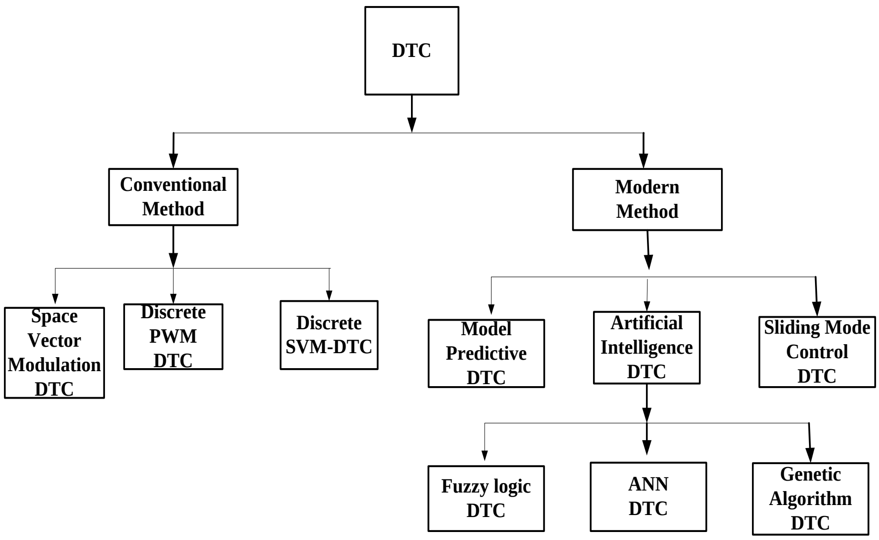

Figure 4 Classification of DTC

IV. SIMULATION RESULTS

In this work performance analysis of induction motor under the condition varying load torque is presented without controller and with DTCM. The IM must provide fast dynamic response under varying loading condition. With the change in load, Electro Magnetic Torque (EMT) and speed varies. Hence accuracy is judged on the basis of its quick response under varying operating condition. To improve the performance of the classic three phase induction motor, in this work DTC control is used. The simulation model for the DTC-IM is presented in figure 5. Figure 6 shows the look-up table for sector selection of voltage vector.

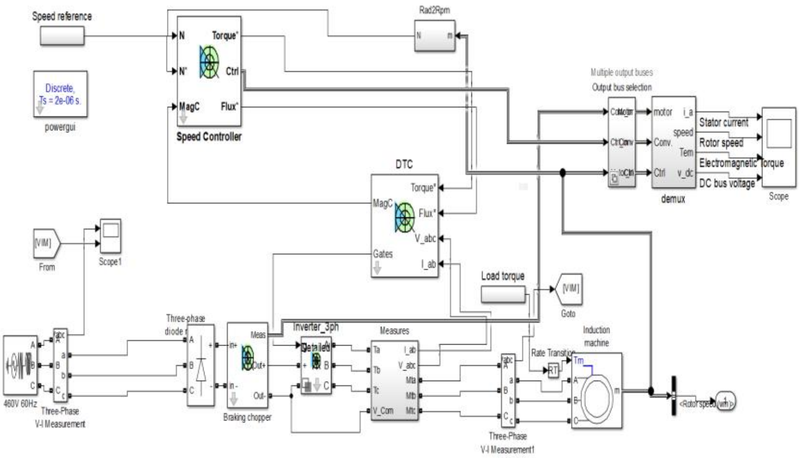

Figure 5 Simulation model of DTC-IM

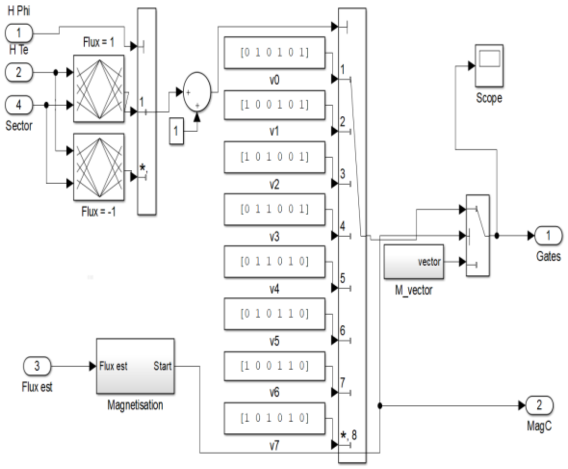

Figure 6 Voltage vector selection for switching state of DTC

For torque HC bandwidth is 10 Nm, for flux HC bandwidth is 0.02wb. The DC bus capacitance at inverter side is 7500µF with switching frequency 20KHz. The classic IM and DTC-IM is simulated for torque variation of 0 to 800 to -800 Nm for t= 0-0.5-1.5 sec. As shown in figure 7 For this condition the speed and torque output of classic IM are presented in figure 8. Figure 9 presents the speed and torque output of DTC-IM.

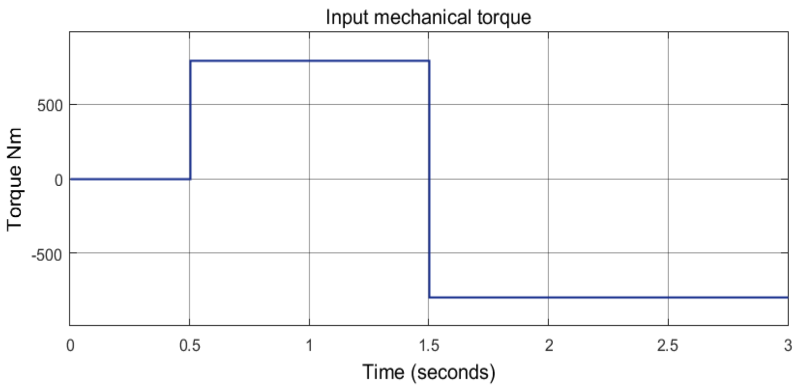

Figure 7 Mechanical Input torque for IM control

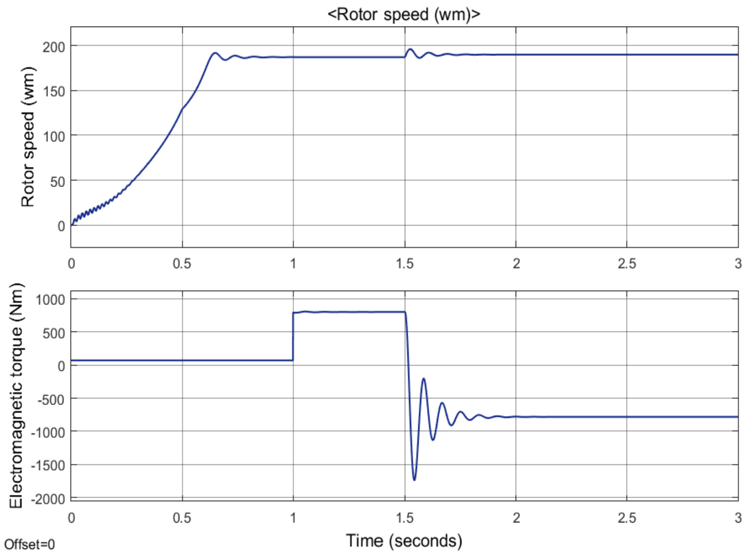

Figure 8 speed-torque output of classic IM for varying load torque input

From the figure 8 it can be observed that IM without control has very delayed response. The IM is controlled in stationary frame with mechanical input as torque as given in figure 7. Initially mechanical input torque is zero, at t=0.5 sec the it is increased to 800 Nm and at t=1.5 sec it is reduced to -800 Nm. In response to this, the rotor speed of classic IM has parabolic graph from t=0-0.7 sec and then holds a constant value throughout. On the other hand, the EMT has an initial value of 70 Nm from t=0-1 sec and oscillates for 6-7 cycles before settling to -800 Nm value that to after 0.5 sec. hence it has a delayed response of 0.5 sec which is very slow. Contrary with DTCM, the response of EMT is very quick and accurate. The rotor speed has linear graph for t= 0-0.5 sec and then constant throughout. Figure 10 shows the stator current-phase ‘a’ for classic IM which has very vulnerable characteristics. On the other hand, the stator current for DTC-IM has a very stable and constant value as shown in figure 11. The stator current governed by the response of EMT, hence stator current for classic IM is very fluctuating in nature while DTC-IM has very settled response. The three phase source voltage for classic-IM as well as for DTC-IM is constant and is not affected by the variable load torque as shown in figure 12. From the figure it can be seen that the source voltage is sinusoidal with negligible harmonics having THD 0.1% as shown in figure 13.

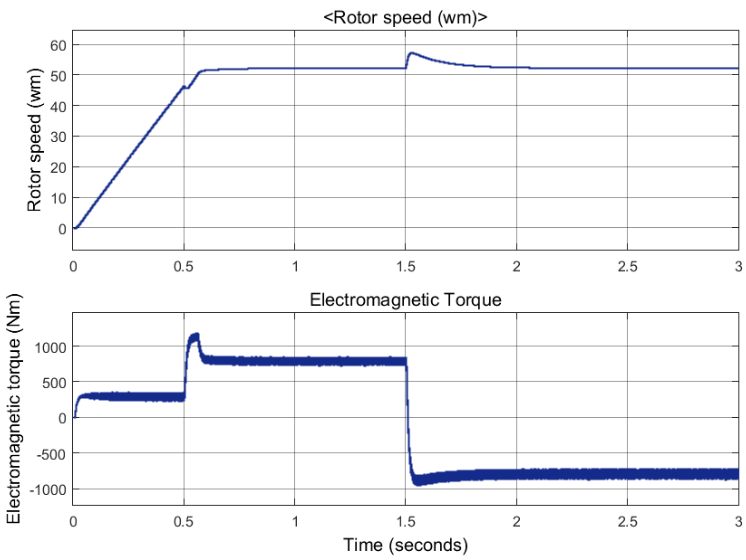

Figure 9 speed-torque output of DTC-IM for varying load torque input

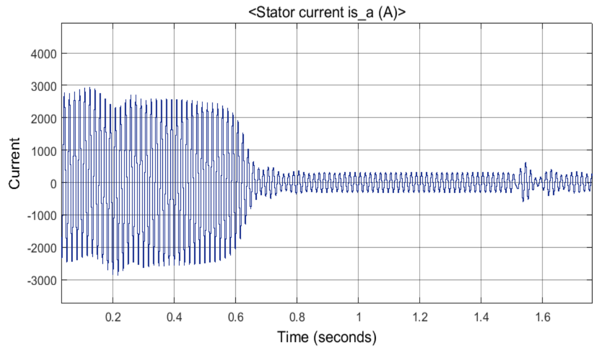

Figure 10 Stator current for phase ‘a’ in case of classic IM

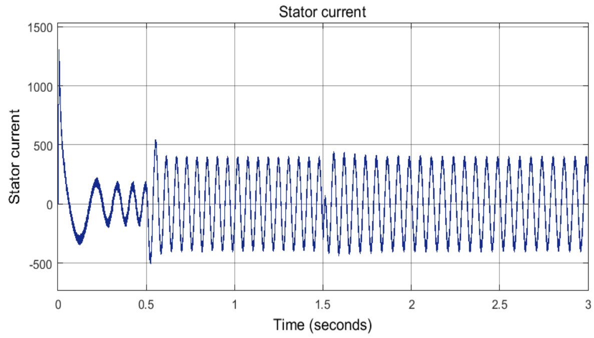

Figure 11 Stator current for phase ‘a’ in case of DTC-IM

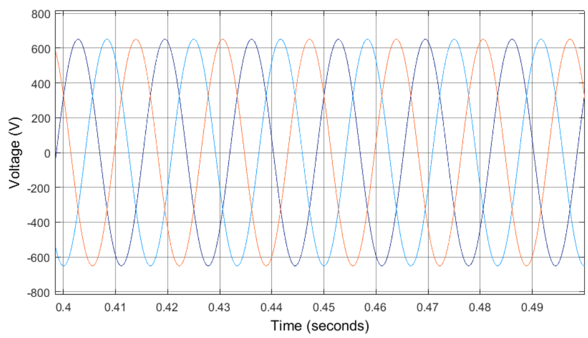

Figure 12 three phase source voltage input to the IM

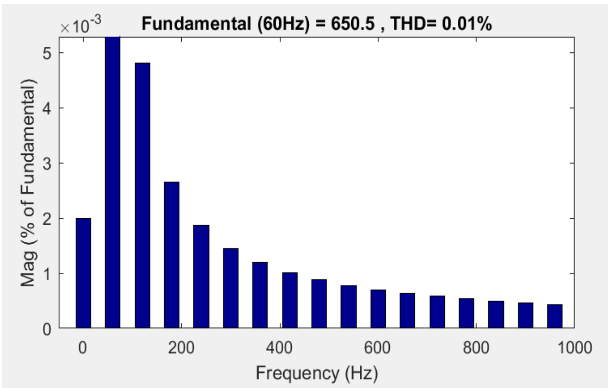

Figure 13 THD of source voltage

V. CONCLUSION

The wide are application of induction motor is always been a research interest for designing precise and robust control for rotor speed and electro-magnetic torque under dynamic condition. The initial current drawn from IM is high since its starting condition. Also rotor speed gradually takes pace which has to be linear, but the classic IM has parabolic function for initial rotor speed which is undesirable. In this work hysteresis controller based DTC-IM is presented which has a quick response to varying loading condition and also its parameters are unaffected by the operating condition of the motor. The DTC-IM also has linear initial speed response which is desirable. The load torque also has good dynamic response has shown by simulation results.

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