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Improved Flux Estimation Technique For Direct Torque control of Induction Motor Drives

Patel Tejas I[1], Pritesh Mankad R[2], Aboti Ashish N [3],

[1]Electrical Engineering Department, HJD-ITER Kera-Kutch
[2] Electrical Engineering Department, HJD-ITER Kera-Kutch
[3] Electrical Engineering Department, HJD-ITER Kera-Kutch

Abstract —*Induction motors are the starting point to design an electrical drive system which is widely used in many industrial applications. In recently various speed control technique are used. But the direct torque control (DTC) scheme being one of the most recent steps in this direction. This scheme provides excellent properties of regulation without rotational speed feedback. In this control scheme the electromagnetic torque and stator flux magnitude are estimated with only stator voltages and currents and this estimation does not depend on motor parameters except for the stator resistance. Literature review has been done to study the recent improvements in DTC scheme especially in low speed range operation to improved flux estimation and reduce the torque ripple problem.*
The conventional direct torque controlled scheme used voltage model for flux estimation but this model estimate inaccurate flux at lower speed. So due to inaccurate flux estimation DTC drive give poor performance by distortion of stator current and torque ripple. So here I have present another model for flux estimation which gives best DTC drive performance at lower speed.

Keywords*- Introduction, Direct torque control, Stator flux estimation, Simulation Results*

I. INTRODUCTION

In the mid-1980s, an advanced scalar control technique, Known as direct torque and flux control (DTFC or DTC), was introduced by ISAO TAKAHASHI, AND TOSHIHIKO NOGUCHI, for voltage-fed PWM inverter drives [1], [2]. This technique was claimed to have nearly comparable performance with vector controlled drives. Recently, this scheme was introduced in commercial products by a major company and therefore created wide interest. The scheme, as the name indicates, is the direct control of the torque and stator flux of a drive by inverter voltage space vector selection through a lookup table.

In DTC drive stator flux is controllable variable so accurate flux estimation in a high-performance induction motor drive, is important to ensure proper drive operation and stability. Most of the flux estimation techniques proposed are based on the voltage model.

The voltage model, on the other hand, is generally used at a high speed region, since at low speed, voltage model suffer from severe problems. Most severe problem is at low speed because of at low speed supply voltage magnitude directly affected by stator resistive voltage drop. So due to small measurement errors in the resistance value can introduce large errors in flux estimation [11]. Another problems are during Practical implementation, due to the DC component (off set errors) in the input signal applied to integrator, integrator output produce ramp signal (signal which increase with time), no matter how small it is, can drive the pure integrator into saturation. The DC component (off set errors) produces due to the use of continuous (analog) parts in sensor (CT&PT) and amplifier circuit for the measurement of stator voltage and current e [8]. To prevent saturation of integrator due to the DC component, a pure integrator replaced by low-pass filter (LPF). However, if excitation frequency is lower (lower speed) than then the cutoff frequency of LPF, than in estimation of stator flux using low passes filter (LPF) produce errors in magnitude and phase angle in estimated stator flux [10]. To A improve the estimated stator flux based on an LP filter used an adaptive control system which was based on the fact that the back EMF is orthogonal to the stator flux. The compensator is adapted for this condition. However, to implement the proposed system requires large processor resources and longer execution time for a slower processor. The implementation of adaptive Control will significantly increase the complexity of the control system. Due to problem in voltage model at low speed discussed above, here I will present another model for better stator fluxes estimation at low speed (low frequency).

II. DIRECT TORQUE CONTROL STRATEGIES

DTC based on stator flux control, in the stator fixed reference frame using direct control of the inverter switching. Direct torque control (DTC) has become an alternative to the well known Vector Control of induction machine. DTC of induction machine has increasingly become the best alternative to field orientation methods or vector control. A block diagram of a DTC system for an induction machine is shown in Fig1.

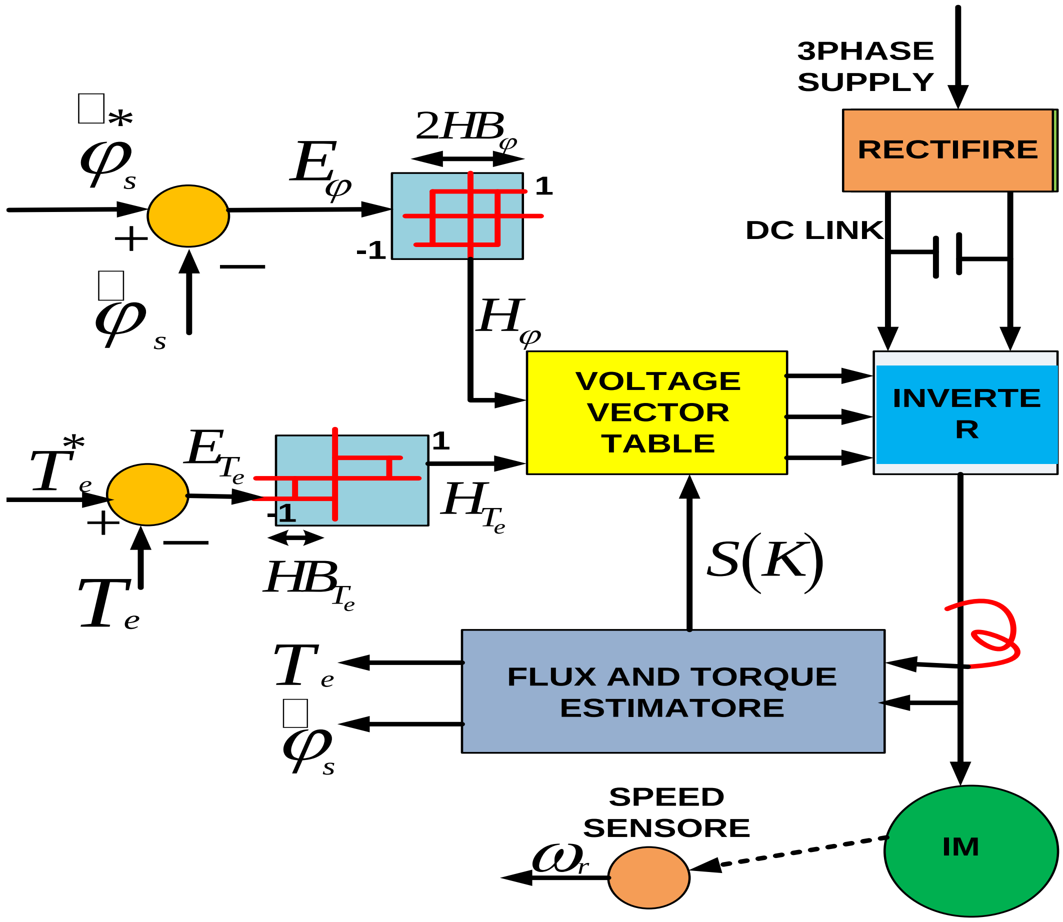

Fig.1: Direct torque control of induction machine

The DTC scheme is very simple; in its basic configuration it consists of hysteresis controllers, torque and flux estimator and a switching table. The configuration is much simpler than the vector control system due to the absence of coordinate transformation between stationary frame and synchronous frame and PI regulators. It also does not need a pulse width modulator and a position encoder, which introduce delays and requires mechanical transducers respectively. DTC based drives are controlled in the manner of a closed loop system without using the current regulation loop. DTC scheme uses a stationary d-q reference frame (fixed to the stator) having its d-axis aligned with the stator q axis. Torque and flux are controlled by the stator voltage space vector defined in this reference frame.
The basic concept of DTC is to control directly both the stator flux linkage (or rotor flux linkage, or magnetizing flux linkage) and electromagnetic torque of machine simultaneously by the selection of optimum inverter switching modes. The use of a switching table for voltage vector selection provides fast torque response, low inverter switching frequency and low harmonic losses without the complex field orientation by restricting the flux and torque errors within respective flux and torque hysteresis bands with the optimum selection being made. The DTC controller consists of two hysteresis comparator (flux and torque) to select the switching voltage vector in order to maintain flux and torque between upper and lower limit.
Salient features of DTC control.
Simple direct control of torque and stator flux by selection of a voltage vector
Somewhat analogous to hysteresis band current control PWM
No vector transformation as in vector control
No feedback current control
No traditional PWM technique
Ripple in current, torque, and flux
Limitation of minimum speed (integration and stator resistance variation problems)
Has been applied to pumps, fans, extruders, etc as improvement of volts/hz control

III. STATOR FLUX ESTIMATION

In the voltage model also referred to as "V-I estimator" used stator voltage and current and fluxes are computed using all quantities referred stationary reference frame equivalent circuit shown in fig 2

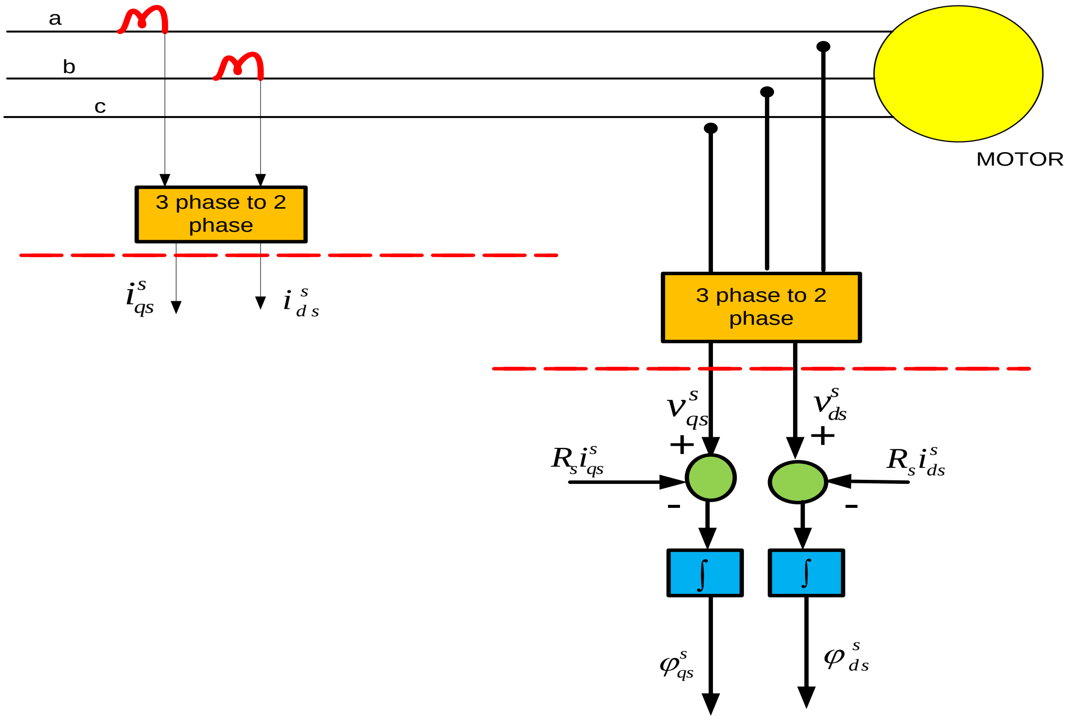

Figure 2 voltage model

And equations of voltage model are

$$\varphi_{ds}^{s} = \int \left(v_{ds}^{s} - R_s i_{ds}^{s} \right) dt \quad 1$$

$$\varphi_{qs}^{s} = \int \left(v_{qs}^{s} - R_s i_{qs}^{s} \right) dt \quad 2$$

$$\varphi_s = \sqrt{{\varphi_{ds}^{s}}^2 + {\varphi_{qs}^{s}}^2} \quad 3$$

$$\overline{\varphi}_s = \int \left(\overline{v}_s - R_s \overline{i}_s \right) dt \quad 4$$

The stator flux under sinusoidal steady-state condition (that means its rotates with constant synchronous speed ω rad/sec and constant magnitude), this reduces to

$$\overline{\varphi_s} = \left| \overline{\varphi}_s \right| e^{j\omega t} \quad 5$$

$$\frac{d}{dt} \overline{\varphi}_s = \frac{d}{dt} \left| \overline{\varphi}_s \right| e^{j\omega t} = \left| \overline{\varphi}_s \right| e^{j\omega t} \omega t = \overline{v}_s - R_s \overline{i}_s \quad 6$$

Put $\overline{\varphi_s} = \left| \overline{\varphi}_s \right| e^{j\omega t}$

$$\overline{\varphi}_s \omega t = \overline{v}_s - R_s \overline{i}_s \quad 7$$

$$\bar{v}_s = \overline{\varphi_s \omega t} + R_s \bar{i}_s \tag{8}$$

From above equation show that at lower speed neglect the term $\overline{\varphi_s \omega t}$

So $$\bar{v}_s = R_s \bar{i}_s \tag{9}$$

So from equation 9 show that at low speed supply voltage magnitude directly affected by stator voltage drop due to the resistance. So due to small measurement errors in the resistance value can introduce large errors in flux estimation. And it clear from equation 9 that at low speed, since there is no feedback mechanism and input of integrator is small signal so runaway problems can occur, and the precision of the integration process is severely compromised.

The problem associated with voltage model at low low-speed region, can be solved easily by determine the position of rotor flux. Since these method use motor stator current and speed. So this model for the stator flux estimation is called "current model". It is also referred as I-ω estimators. Block diagram of current model is shown in figure 3.

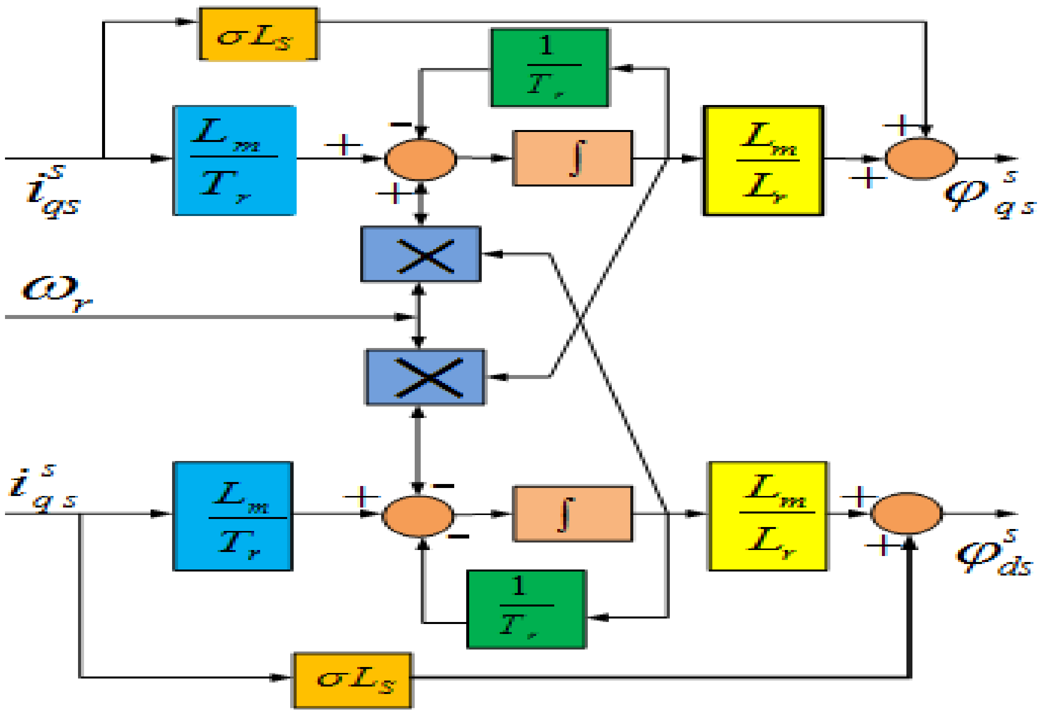

Figure 3 current model

And equations of current model are

$$\varphi^s_{dr} = \int \left(\frac{L_m}{T_r} i^s_{ds} - \omega_r \varphi^s_{qr} - \frac{1}{T_r} \varphi^s_{dr} \right) dt \tag{10}$$

$$\varphi^s_{qr} = \int \left(\frac{L_m}{T_r} i^s_{qs} + \omega_r \varphi^s_{dr} - \frac{1}{T_r} \varphi^s_{qr} \right) dt \tag{11}$$

And stator flux is finding from rotor flux using the following relationship

$$\varphi_{ds}^{s} = \frac{L_m}{L_r}\varphi_{dr}^{s} + \sigma L_s i_{ds}^{s} \qquad 12$$

$$\varphi_{qs}^{s} = \frac{L_m}{L_r}\varphi_{qr}^{s} + \sigma L_s i_{qs}^{s} \qquad 13$$

Where $\sigma = 1 - \frac{L_m^2}{L_r L_s}$, $T_r = \frac{L_r}{R_r}$

IV. SIMULATION RESULTS

(a) Simulation result of voltage model flux estimation

From the simulation studies speed below the 15rad/sec is consider as a lower speed because of below this speed DTC drive give a poor performance (large torque ripple and more distortion in stator current). And distortion in stator current describe by THD (total harmonics distortion) factor shown in table 1

Sr.no	SPEED (RAD /SECONDS)	THD FACTOR FOR STATOR CURRET
1	150	5.4%
2	100	7.33%
3	75	9.55%
4	50	9.52%
5	35	18.41%
	25	23.41%
6	15	76.48%

Table 1 effect of speed on THD of stator current

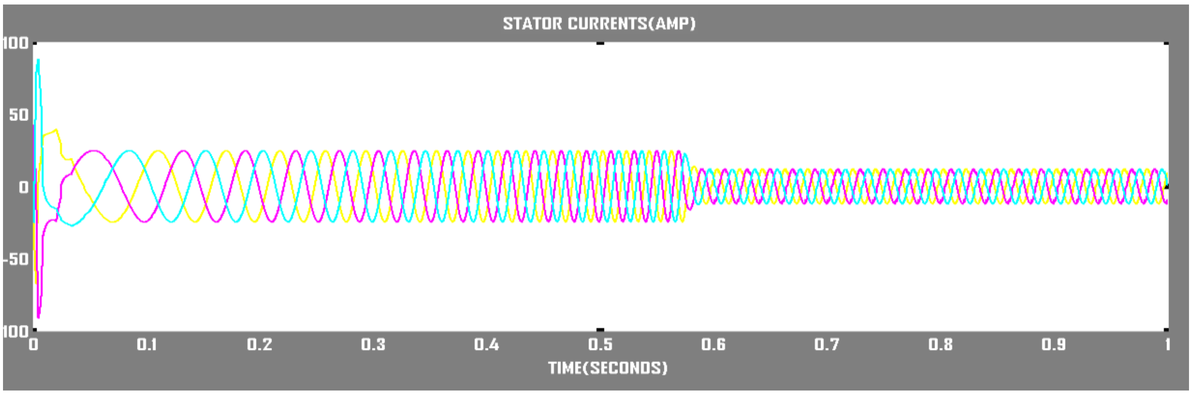

Figure 4 simulation result of stator current using voltage model flux estimator in DTC at Rated speed =150rad/ sec

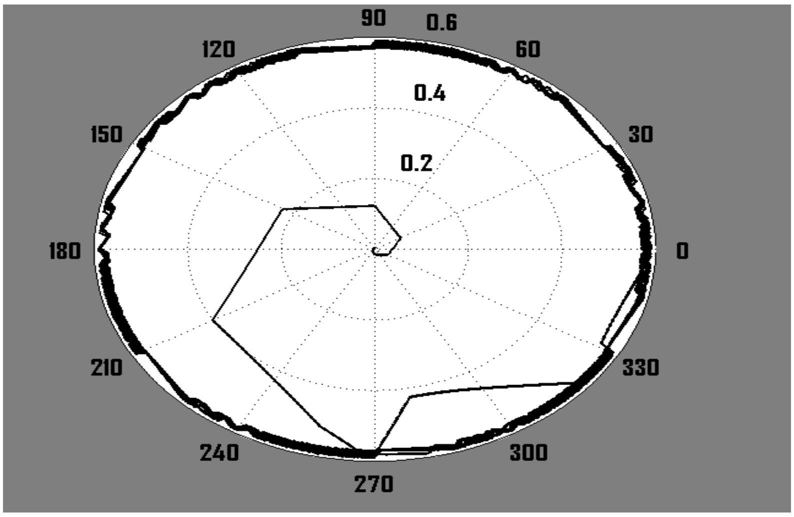

Figure 5 simulation result of stator flux magnitude (0.58 wb) in polar form using voltage model flux estimator in DTC At Rated speed =150rad/ sec

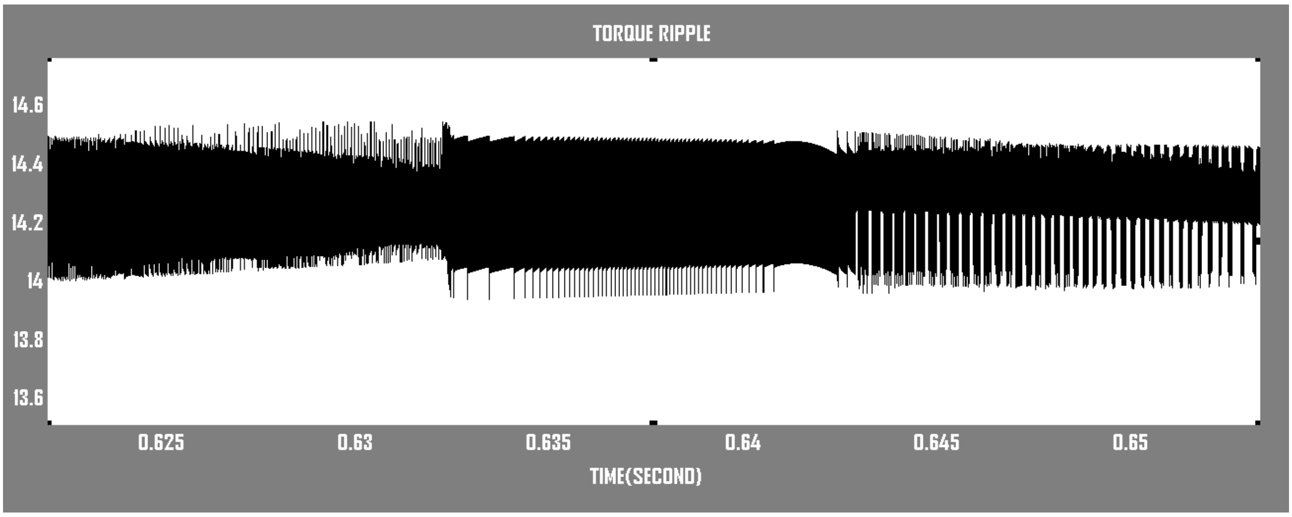

Figure 6 simulation result of motor torque ripple using voltage model flux estimator in DTC at Rated speed =150rad/ sec

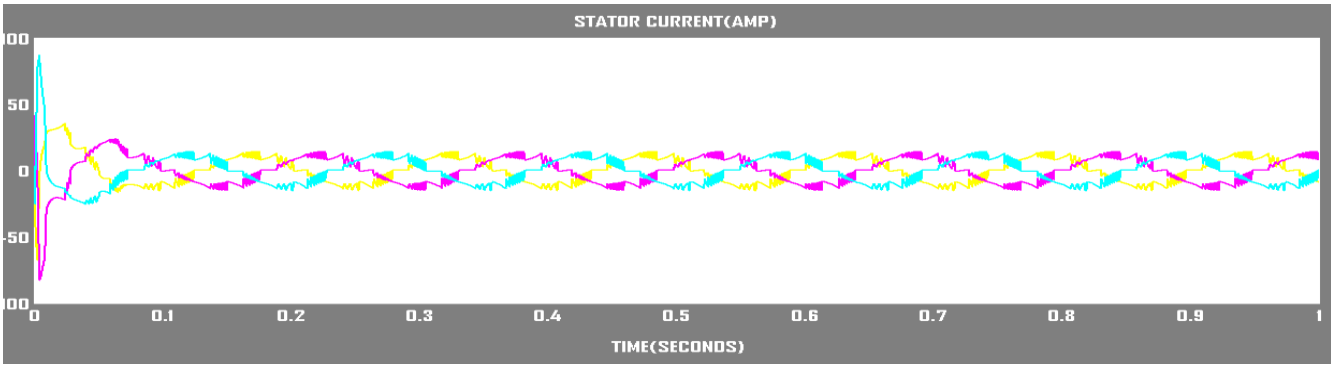

Figure 7 simulation result of stator current using voltage model flux estimator in DTC at Lower speed =15rad/ sec

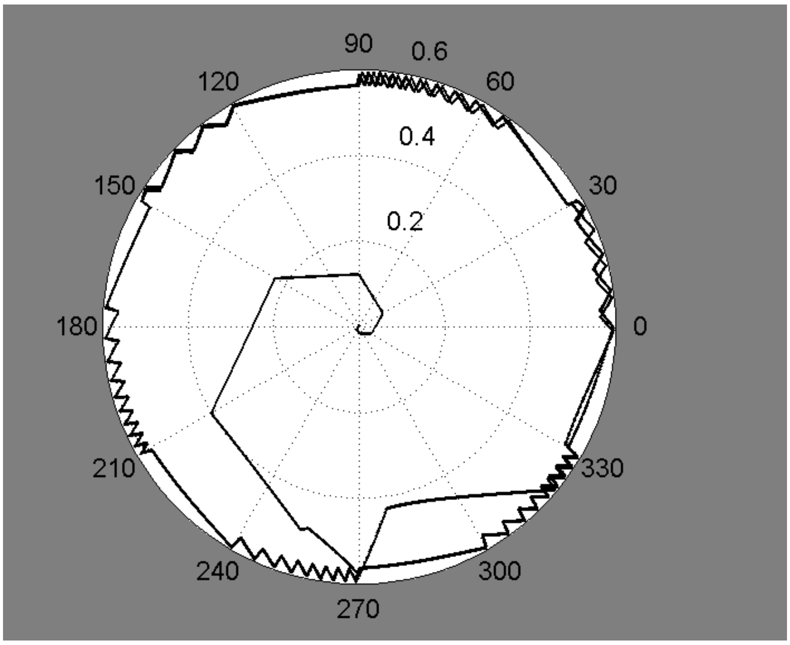

Figure 8 simulation result of stator flux in polar form using voltage model flux estimator In DTC at lower Speed=15rad/sec

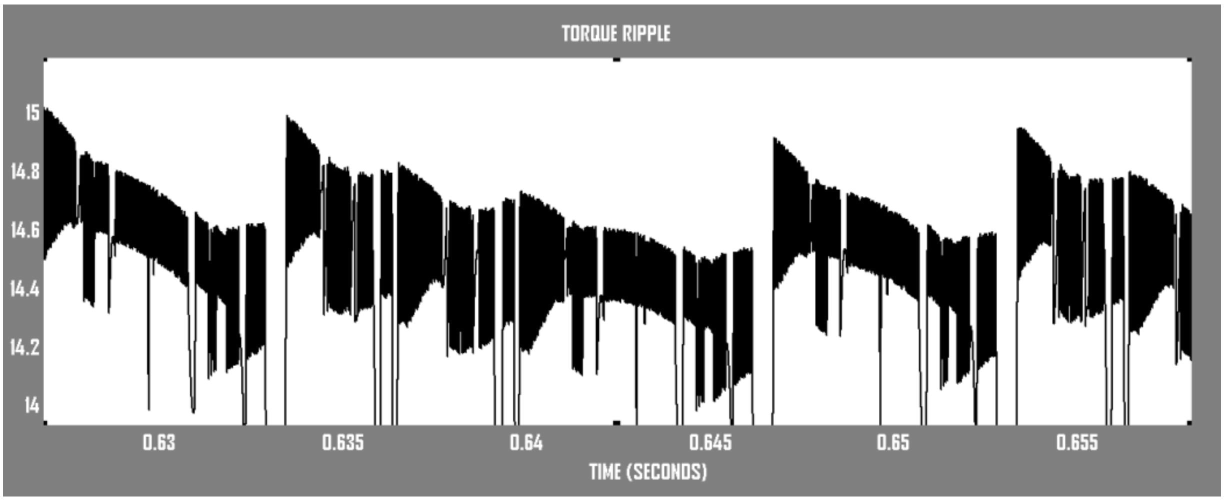

Figure 9 simulation result of motor torque ripple using voltage model flux estimator in DTC at Rated speed =15rad/ sec

From above simulation result we can see that at higher speed (150rad/sec) voltage model Estimate accurate stator flux that means low distortion in estimated flux so DTC drive produce low ripple in torque and also less distortion in stator current. But at lower speed (15rad/ sec) voltage model estimate inaccurate stator flux so DTC drive produce large ripple and also more distortion in stator current. So I will present another model which give best performance at lower speed.

(b) Simulation result of current model at lower speed

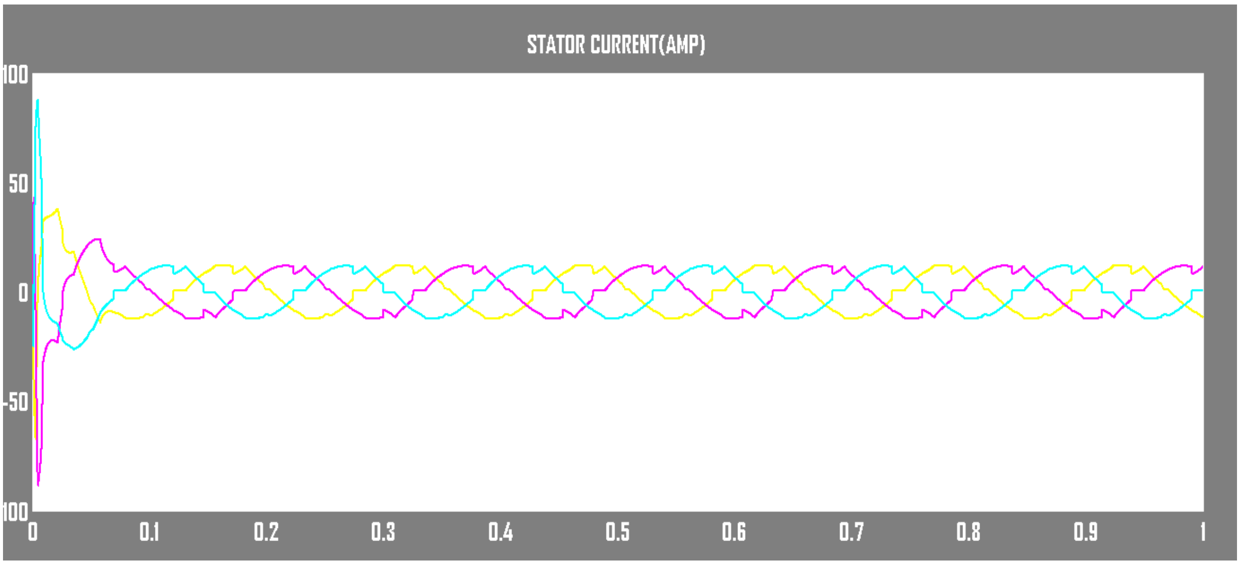

Figure 10 simulation result of motor stator current using current model flux estimator in DTC at Lower speed =15rad/ sec

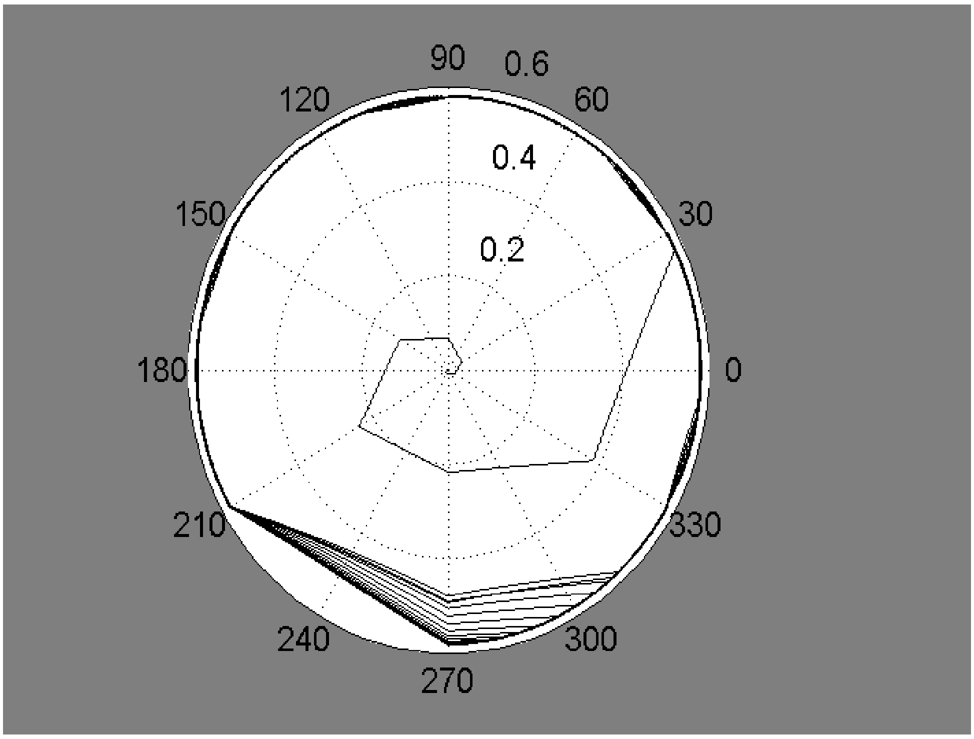

Figure 11 simulation result of polar form of stator flux magnitude (0.58 wb) using current Model flux estimator In DTC At Lower speed =15rad/ sec

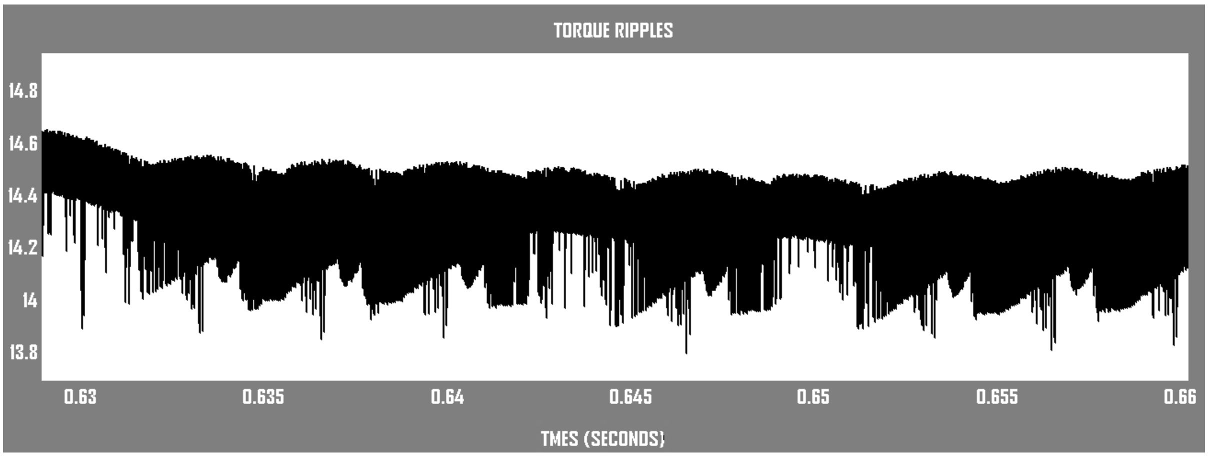

Figure12 Simulation result of motor torque ripples using current model flux estimation in DTC at Lower Speed=15rad/ sec

V. CONCLUSION

In the present report a new method for improved stator flux estimation and torque ripple reduction at lower speed based on the new model (current model) for flux estimation is discussed. Here induction motor drive is simulated for conventional DTC which used voltage model for flux estimation with modified DTC which used current model for flux estimation at lower speed and compared. Form result of simulation see that voltage model give poor performance at lower speed. Which give inaccurate flux estimation and produce stator current distortion and torque ripples So here I have present another model for flux estimation at low speed which gives best performance at lower speed and measure accurate flux estimation at lower speed and reduction in stator current distortion and torque ripples.

VI. APPENDIX

The parameter of 3 phase induction motor employed for simulation purpose is given below:

Motor Parameter

output Power:	**3 hp**
Voltage(Line to Line):	**220 V**
Frequency:	**50 Hz**
Stator resistance:	**0.435Ω**
Stator Inductance:	**0.002H**
Rotor Resistance:	**0.816Ω**
Rotor Inductance:	**0.002H**
Mutual Inductance	**0.06931H**
Inertia:	**0.089(kg.m^2)**
Friction Factor:	**0 (N.m.s)**
Pole Pairs:	**2**

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