A Project Report on

"Phase variable model & dq model of Induction Motor "

"Open loop V/F speed Control Technique with Voltage fed Inverter"

"Direct Rotor field FOC using SPWM technique"

"DIRECT TORQUE CONTROL OF INDUCTION MOTOR"

Submitted in partial fulfillment of the requirement for the Second Semester of

Master of Technology

In

"Power Engineering"

Of

Indian Institute of Technology, Ropar

Submitted by

[GROUP-4]

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Aim- Phase variable model & dq model of IM (synchronous reference frame)

Q1: Compare the torque, speed and stator currents of both the models (Report in the docx file)
Q2: Find the slip of the motor under full load condition from both the models.
Q3: In the dq model find the magnitude of the Vqds, Iqds, Iqdr, lambda_qds, lambda_qdr'' when 2/3 constant . is used for abc to qd0 transformation and compare it with Vabs, Iabcs, Iabcr',lambda_abcs, lambda_abcr' . Do similar exercise when sqrt (2/3) constant is used for the transformation

Q.4 using three phase inverter which is operated using Sine PWM technique at 0.9 modulation index. (use the dc link voltage judicially). Operate the inverter in such a way that the torque ripple is less than 5% of the nominal. Use open loop v/f control technique to operate the motor in both the direction of speed and two different speed reference.

Q.5 implement direct Rotor field FOC using SPWM technique.

Q.6 Direct Torque control of induction motor

Ratings and Parameters

Rated Voltage [V]	V	460
Rated Frequency [Hz]	f	60
Rated Speed [rpm]	ω_m	1760
Stator Resistance [Ω]	R_s	0.09961
Rotor Resistance [Ω]	R_r	0.05837
Mutual Inductance [H]	L_m	0.03039
Stator Leakage Inductance [H]	L_{ls}	0.000867
Rotor Leakage Inductance [H]	L_{lr}	0.000867
Motor Inertia [kg.m^2]	J	0.4
Damping Coefficient [Nms/rad]	B	0.00005

Theory: -

1)PHASE VARIABLE MODEL

The modelling of the electromagnetic part which contains stator and rotor was done in the a-b-c three-phase stationary frame.

Electromagnetic Part

The three-phase stator voltages Vas, Vbs, Vcs with respect to the motor neutral point can be given as:

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = R_s \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + \frac{d}{dt}\begin{bmatrix} \psi_{as} \\ \psi_{bs} \\ \psi_{cs} \end{bmatrix} \qquad \begin{bmatrix} \psi_{as} \\ \psi_{bs} \\ \psi_{cs} \end{bmatrix} = [L_s]\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + [L_{sr}]\begin{bmatrix} i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix}$$

where Rs is the stator resistance Ias, Ibs, Ics are the stator phase currents, ψas ψbs ψcs as bs cs are the three-phase stator flux linkages, Iar Ibr Icr iii are the rotor phase currents, [Ls]and {Lsr} can be written as

$$[L_s] = \begin{bmatrix} L_{ls}+L_{ms} & -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & L_{ls}+L_{ms} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} & L_{ls}+L_{ms} \end{bmatrix} \qquad [L_{sr}] = L_{sr}\begin{bmatrix} \cos\theta_r & \cos(\theta_r+\frac{2\pi}{3}) & \cos(\theta_r-\frac{2\pi}{3}) \\ \cos(\theta_r-\frac{2\pi}{3}) & \cos\theta_r & \cos(\theta_r+\frac{2\pi}{3}) \\ \cos(\theta_r+\frac{2\pi}{3}) & \cos(\theta_r-\frac{2\pi}{3}) & \cos\theta_r \end{bmatrix}$$

On the rotor part, the rotor windings for a squirrel-cage type induction motor are short circuit. Then, the three-phase rotor voltage equation can be written as

$$\begin{bmatrix}\psi_{ar}\\ \psi_{br}\\ \psi_{cr}\end{bmatrix} = [L_{sr}]^T \begin{bmatrix} i_{as}\\ i_{bs}\\ i_{cs}\end{bmatrix} + [L_r]\begin{bmatrix} i_{ar}\\ i_{br}\\ i_{cr}\end{bmatrix} \qquad [L_r] = \begin{bmatrix} L_{lr}+L_{mr} & -\frac{L_{mr}}{2} & -\frac{L_{mr}}{2}\\ -\frac{L_{mr}}{2} & L_{lr}+L_{mr} & -\frac{L_{mr}}{2}\\ -\frac{L_{mr}}{2} & -\frac{L_{mr}}{2} & L_{lr}+L_{mr}\end{bmatrix}$$

where Llr and Lmr are, respectively, the leakage and magnetizing inductance of the rotor winding. Assuming the three-phase stator current are balanced, that is Ias + Ibs+ Ics =0

motor developed electromagnetic torque

$$T_e = \frac{P}{2}\frac{dE_c}{d\theta_r} = \frac{P}{2}[i_{as} \quad i_{bs} \quad i_{cs}]\frac{d[L_{sr}]}{d\theta_r}\begin{bmatrix} i_{ar}\\ i_{br}\\ i_{cr}\end{bmatrix}$$

2.Modelling of Induction Motor [dq Model in Synchronous reference frame]

The dynamic model of the induction motor is derived in terms of direct and quadrature axes components . This method is required to obtain the conceptual simplicity with the two sets of the windings, one is on the stator and the other is on the rotor.

The (*as-bs-cs*) components resolved into voltages v_{ds}^s and v_{qs}^s and can be represented in matrix form as:

$$\begin{bmatrix} v_{qs}^s\\ v_{ds}^s\\ v_{os}^s\end{bmatrix} = \begin{bmatrix}\cos\theta & \cos(\theta-120) & \cos(\theta+120)\\ \sin\theta & \sin(\theta-120) & \sin(\theta+120)\\ 0.5 & 0.5 & 0.5\end{bmatrix}\begin{bmatrix} v_{as}\\ v_{bs}\\ v_{cs}\end{bmatrix}$$

where v_{os}^s is added as the zero-sequence component, which may or may not be present.

$$v_{qs}^s = \frac{2}{3}v_{as} - \frac{1}{3}v_{bs} - \frac{1}{3}v_{cs} = v_{as}$$

$$v_{ds}^s = -\frac{1}{\sqrt{3}}v_{bs} + \frac{1}{\sqrt{3}}v_{cs}$$

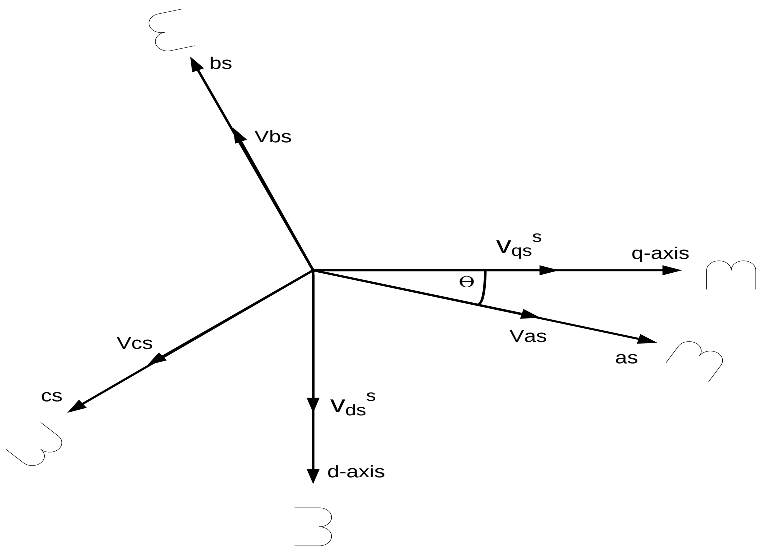


Figure 2.1 Stationary frame *a-b-c* to *ds-qs* axes transformation

In d^e-q^e frame these equations can be written as:

$$v_{qs} = R_s i_{qs} + \frac{d}{dt}\psi_{qs} + \omega_e \psi_{ds}$$

$$v_{ds} = R_s i_{ds} + \frac{d}{dt}\psi_{ds} - \omega_e \psi_{qs}$$

where ψ_{qs}^{s} and ψ_{ds}^{s} are q-axis and d-axis stator flux linkages, respectively.

Since the rotor is rotating at a speed ω_r , then in d^e-q^e frame, the rotor equations should be modified as

$$v_{qr} = R_r i_{qr} + \frac{d}{dt}\psi_{qr} + (\omega_e - \omega_r)\psi_{dr}$$

$$v_{dr} = R_r i_{dr} + \frac{d}{dt}\psi_{dr} - (\omega_e - \omega_r)\psi_{qr}$$

where ψ_{qr} and ψ_{dr} are q-axis and d-axis rotor flux linkages respectively.

The state-space equations are given as

$$\frac{dF_{qs}}{dt} = \omega_b \left[v_{qs} - \frac{\omega_e}{\omega_b} F_{ds} - \frac{R_s}{X_{ls}} (F_{qs} - F_{qm}) \right]$$

$$\frac{dF_{ds}}{dt} = \omega_b \left[v_{ds} + \frac{\omega_e}{\omega_b} F_{qs} - \frac{R_s}{X_{ls}} (F_{ds} - F_{dm}) \right]$$

$$\frac{dF_{qr}}{dt} = -\omega_b \left[\frac{(\omega_e - \omega_r)}{\omega_b} F_{dr} + \frac{R_r}{X_{lr}} (F_{qr} - F_{qm}) \right]$$

$$\frac{dF_{dr}}{dt} = -\omega_b \left[-\frac{(\omega_e - \omega_r)}{\omega_b} F_{qr} + \frac{R_r}{X_{lr}} (F_{dr} - F_{dm}) \right]$$

where ω_b=base frequency of the machine and F_{qs} F_{ds} F_{qr} F_{dr} are the flux linkage variables and

$$F_{qm} = X_{ml} \left[\frac{F_{qs}}{X_{ls}} + \frac{F_{qr}}{X_{lr}} \right]$$

$$F_{dm} = X_{ml} \left[\frac{F_{ds}}{X_{ls}} - \frac{F_{dr}}{X_{lr}} \right]$$

$$X_{ml} = \frac{1}{\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}}$$

The currents in d-q reference frame are given as

$$I_{qs} = \frac{1}{X_{ls}} \left[F_{qs} - F_{qm} \right]$$

$$I_{ds} = \frac{1}{X_{ls}} \left[F_{ds} - F_{dm} \right]$$

$$I_{qr} = \frac{1}{X_{lr}} \left[F_{qr} - F_{qm} \right]$$

$$I_{dr} = \frac{1}{X_{lr}} \left[F_{dr} - F_{dm} \right]$$

Torque expression is given as follows:

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{1}{\omega_b}\left(F_{ds}i_{qs} - F_{qs}i_{ds}\right)$$

Magnitude and angle of the stator flux are calculated as:

$$F_s = \sqrt{{F_{qs}}^2 + {F_{ds}}^2}$$

$$\theta_s = \tan^{-1}\frac{F_{qs}}{F_{ds}}$$

The sector is selected on the basis of θ_s.

Open loop V/F speed Control Technique with Voltage fed Inverter to Operate Induction motor

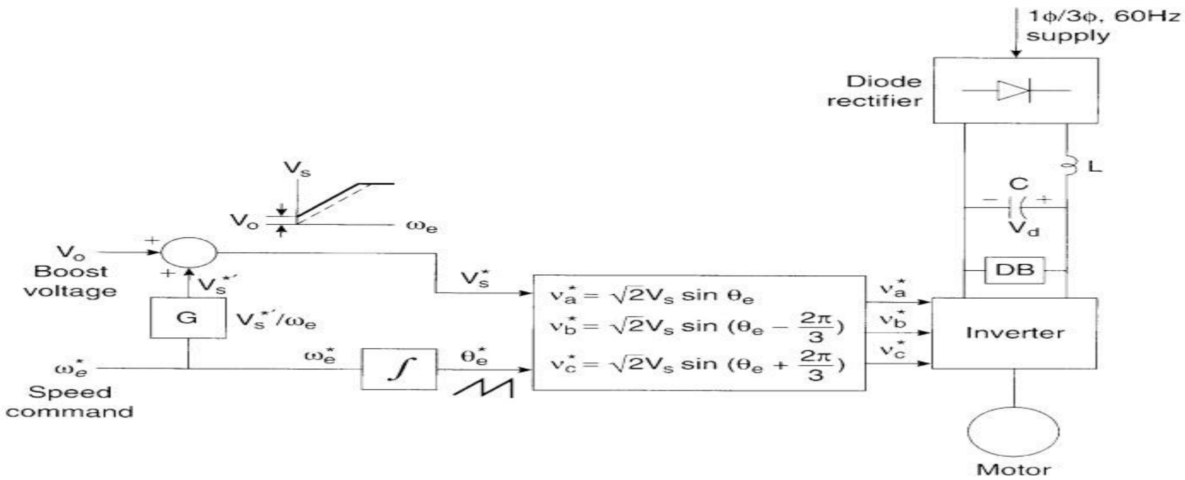
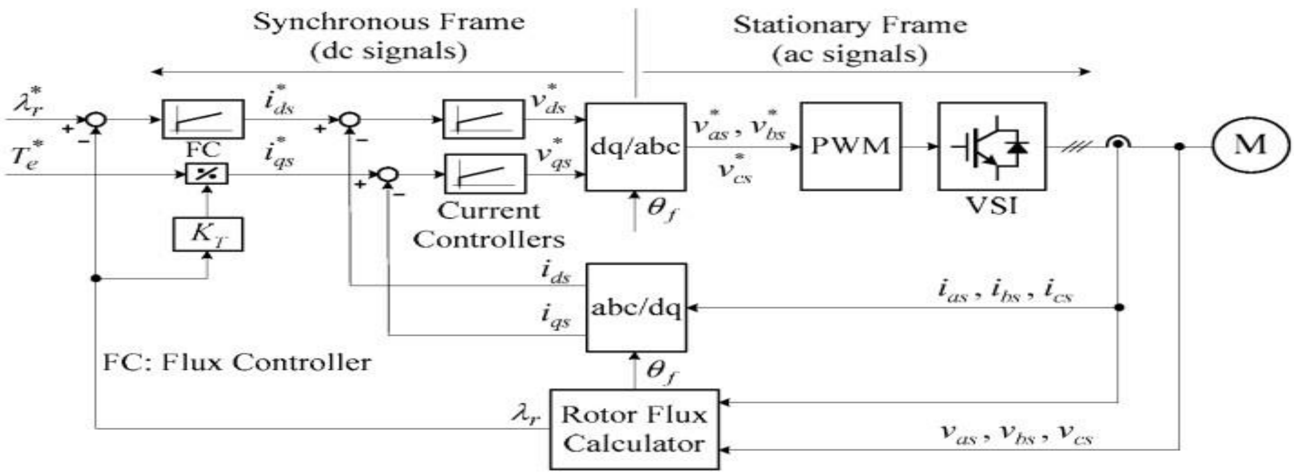


Figure 8.4 Open loop volts/Hz speed control with voltage-fed inverter

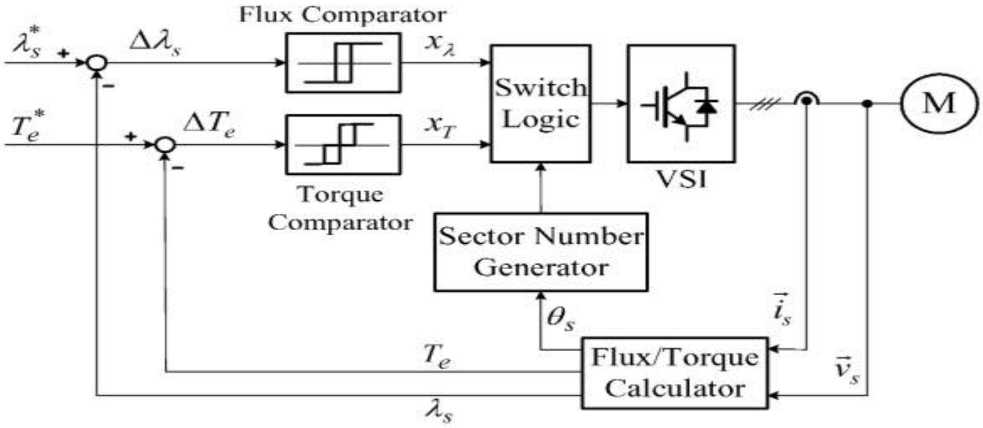
Direct Rotor field FOC using SPWM technique



Direct field-oriented control with rotor flux orientation.

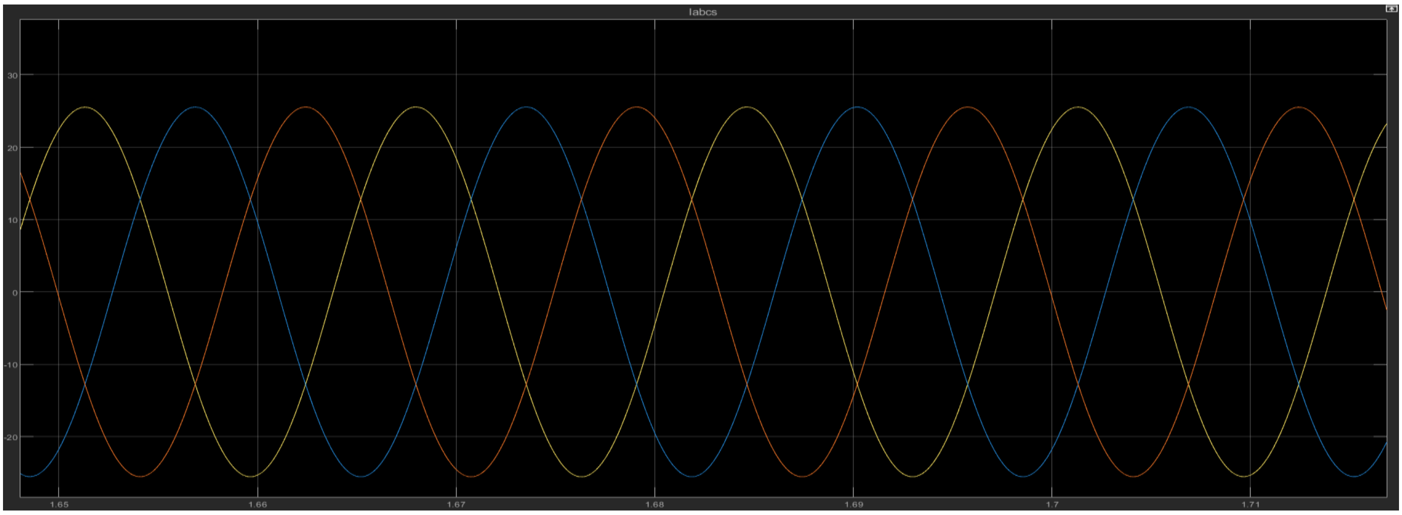
“DIRECT TORQUE CONTROL OF INDUCTION MOTOR”

The main variable to be controlled in the DTC scheme is the stator flux vector(lamda_ss)

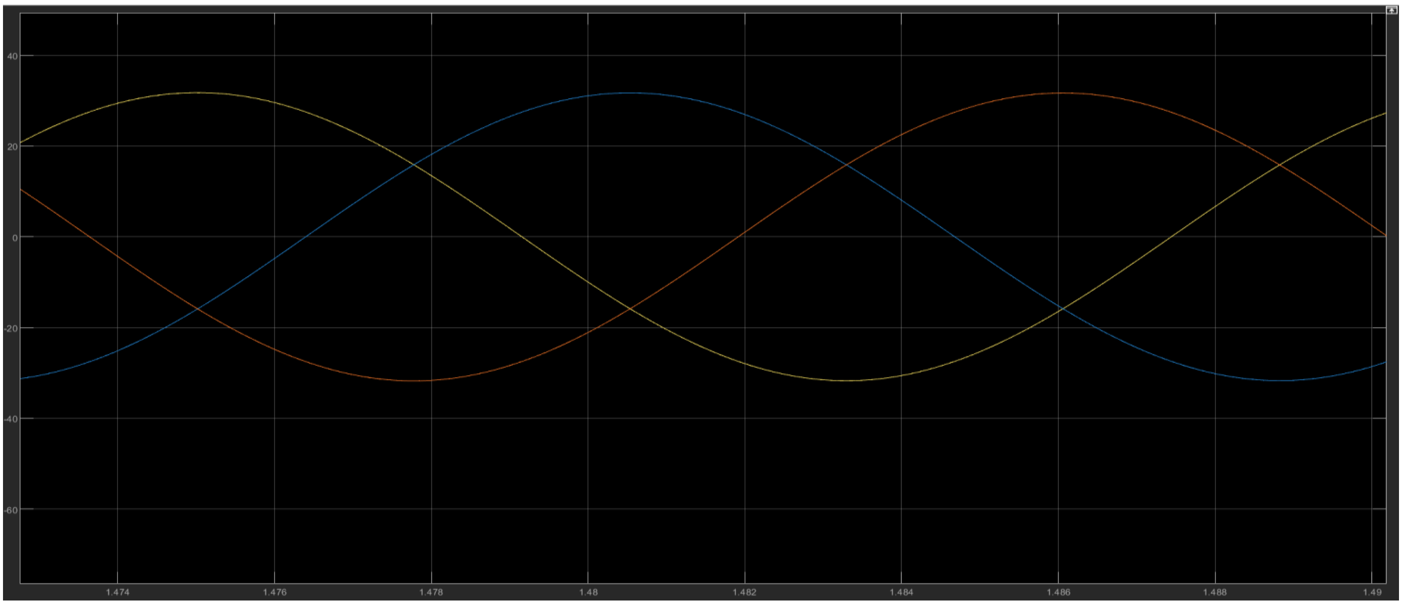


Block diagram of direct torque control scheme

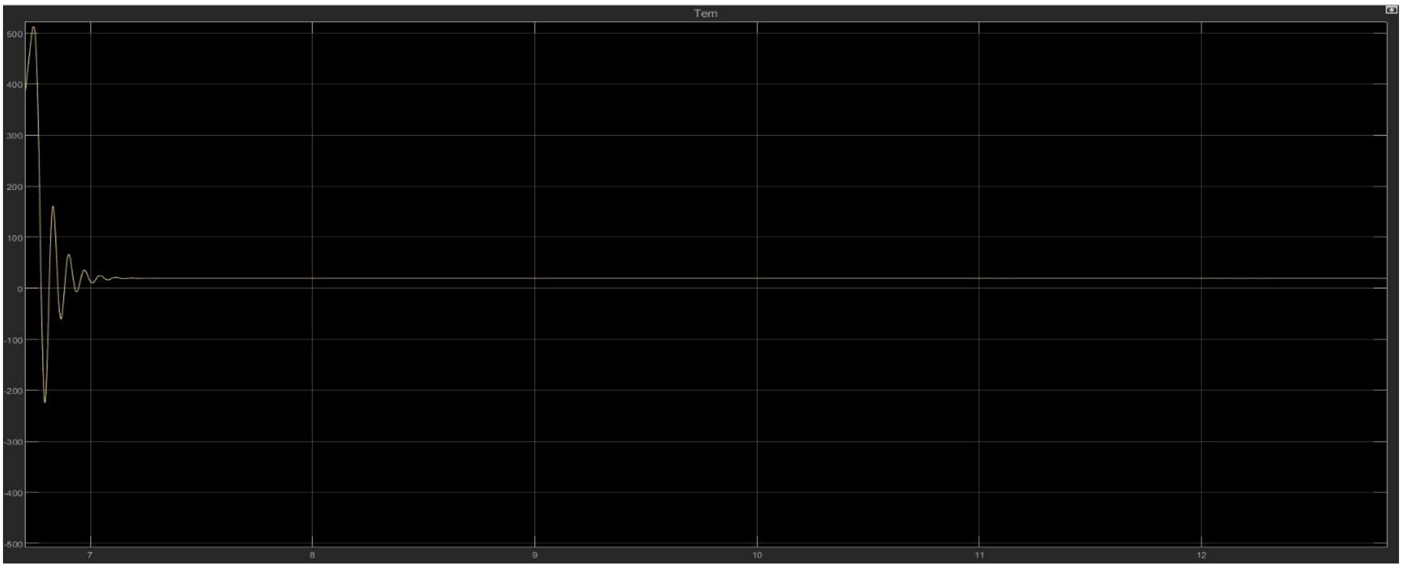
SIMULATION AND RESULTS



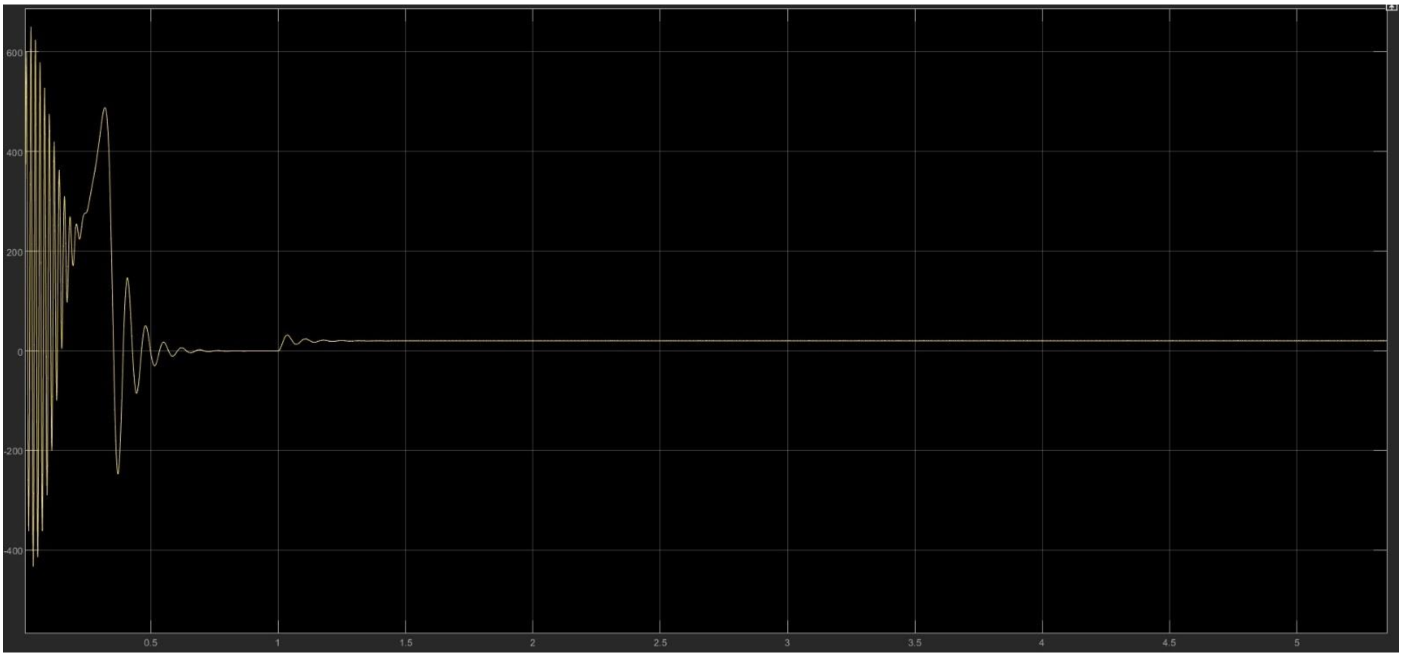
Fig(a) Iabc (stator current)(Phase variable Model (abc model)



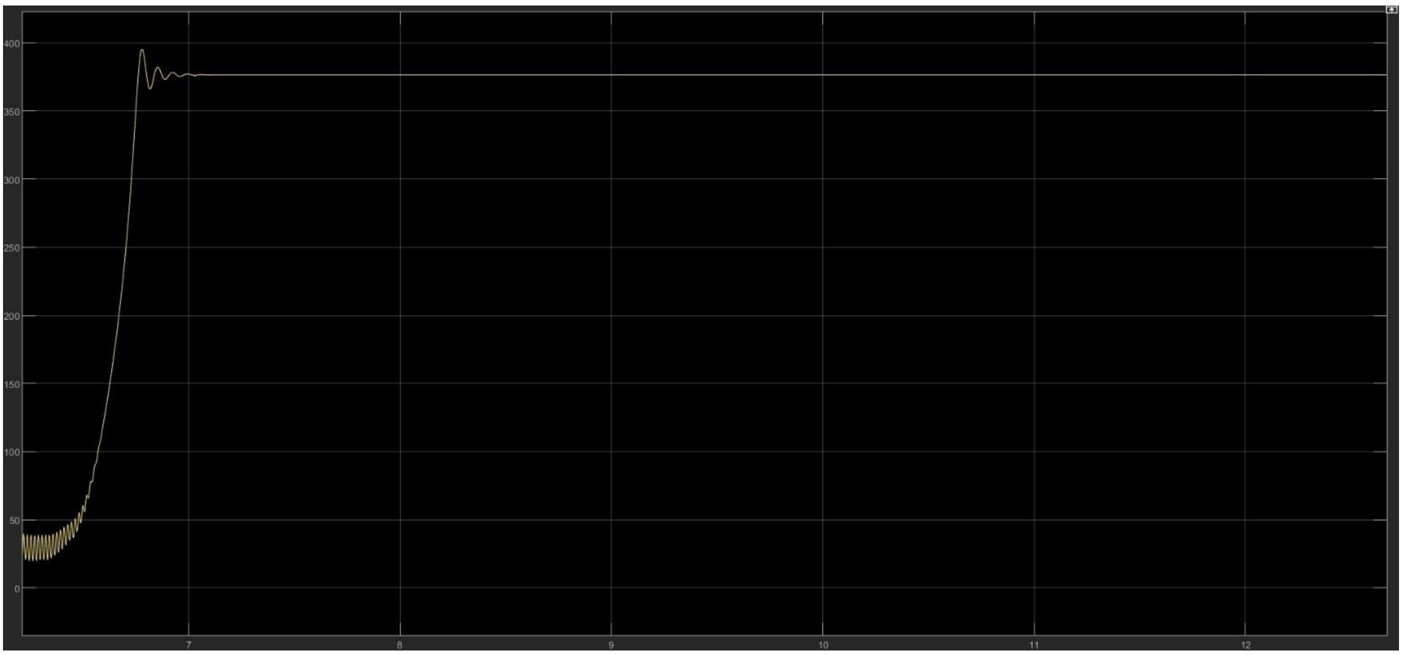
Fig(b) Iabc (stator current)(dqo model(synchronous reference frame)



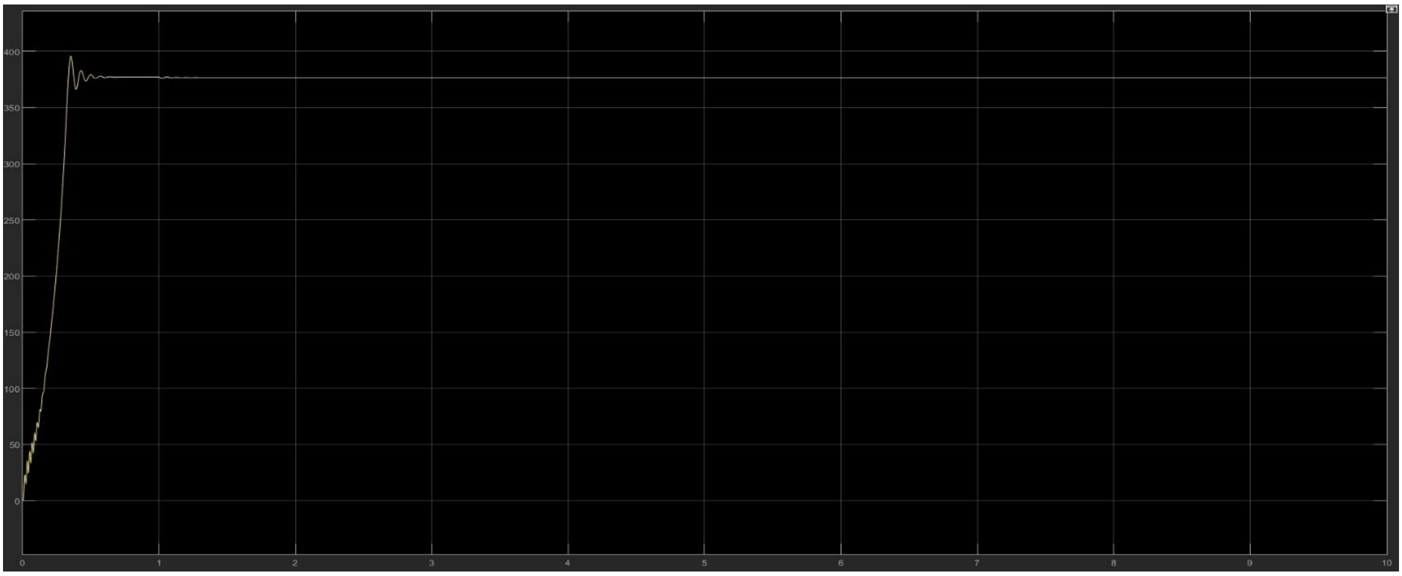
Fig(c) Torque (Phase variable Model (abc model)



Fig(d) Torque(dqo model(synchronous reference frame)



Fig(e) speed wr (Phase variable Model (abc model)



Fig(e) speed (dq model)

<u>2) the slip of the motor under full load condition from both the models.</u>

At Full load

Tload = 200

Slip= (Ns-Nr)/Ns

Ns=120*f/P=1800

Slip= (1800-1757)/1800 =0.023888

3) In the dq model find the magnitude of the Vqds , Iqds, Iqdr, lambda_qds, lambda_qdr'' when 2/3 constant is used for abc to qd0 transformation and compare it with Vabs, Iabcs, Iabcr', lambda_abcs, lambda_abcr' (from the phase variable model). Do similar exercise when sqrt (2/3) constant is used for the transformation.

Vds=375.6

Vqs=0

Iqs=31.84

Ids=6.973

Idr=6.895

Iqr=0

Lamda(ds)= 0.008413

Lambda(qs)= -0.09944

Lambda(dr)=-0.0003611

Lamda(qr)=-0.9688

Vabcs=265.6

Iabcs= 52.56

Iabcr`=68.81

Lambda(abc)= [0.4878 , -0.7838 ,0.4904]

Lambda(abcr`)= [-0.07672 , -0.7838 , 0.4904]

Do similar exercise when sqrt (2/3) constant is used for the transformation

Vds=460

Vqs=0

Iqs=38.99

Ids=5.8

Idr=5.627

Iqr=0

Lamda(ds)= 0.0103

Lambda(qs)= -1.219

Lambda(dr)=-0.0003941

Lamda(qr)=-1.185

AIM-3 (**"Open loop V/F speed Control Technique with Voltage fed Inverter")**

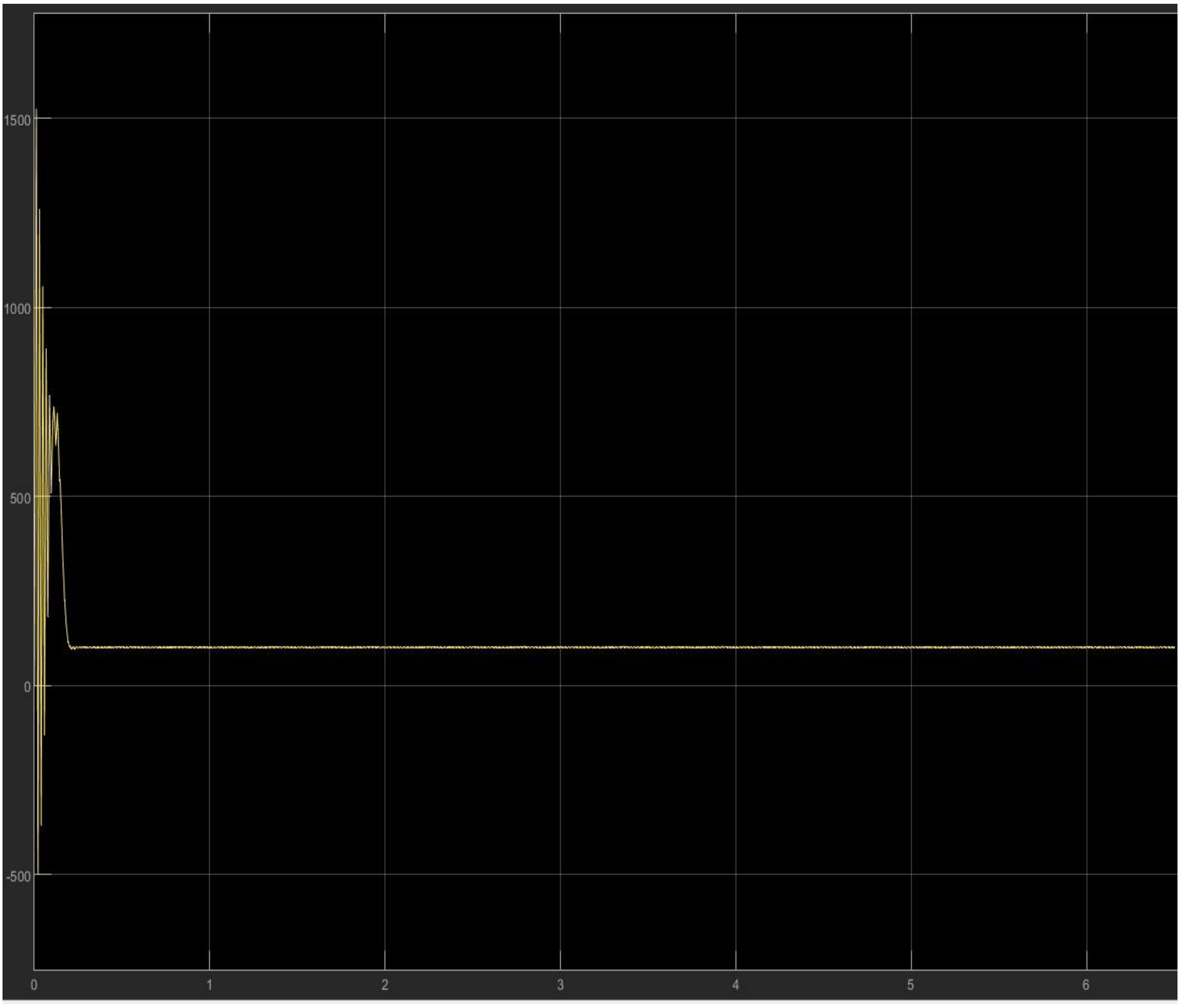


Fig3.a: - **ELECTROMAGNETIC TORQUE**

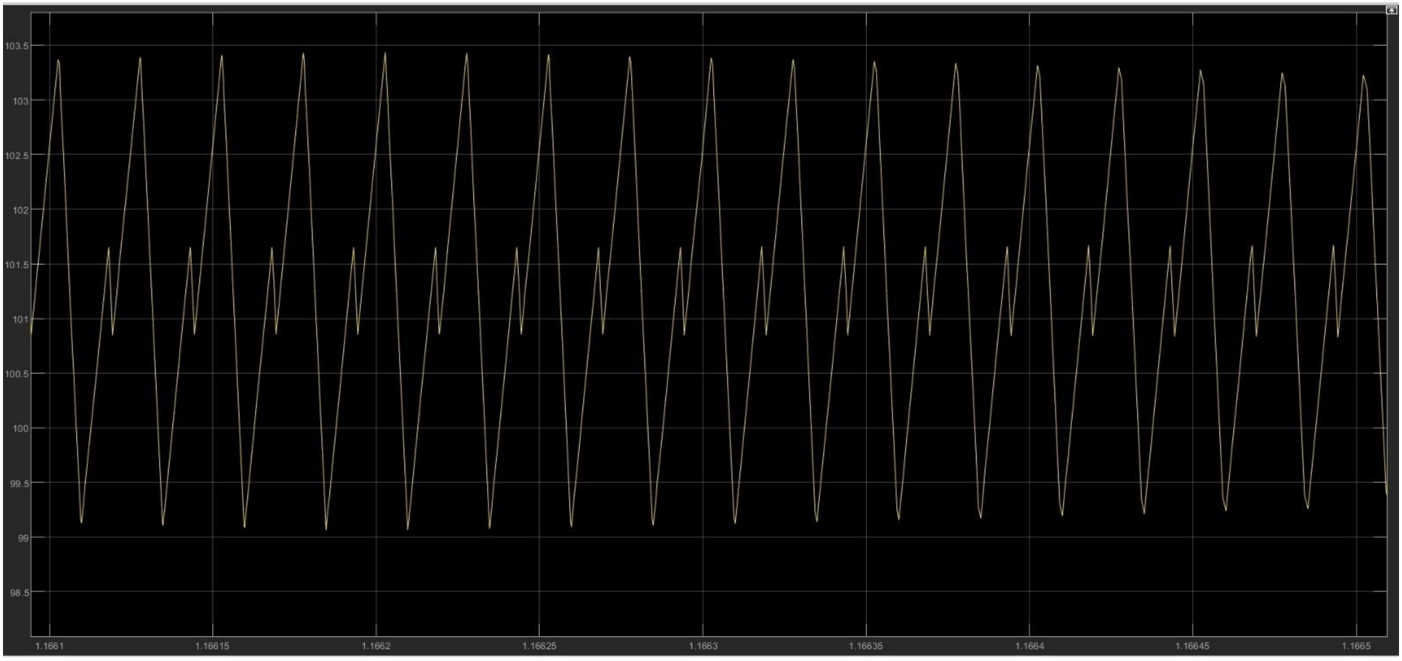


Fig 3.b: - 4% Ripple in Torque

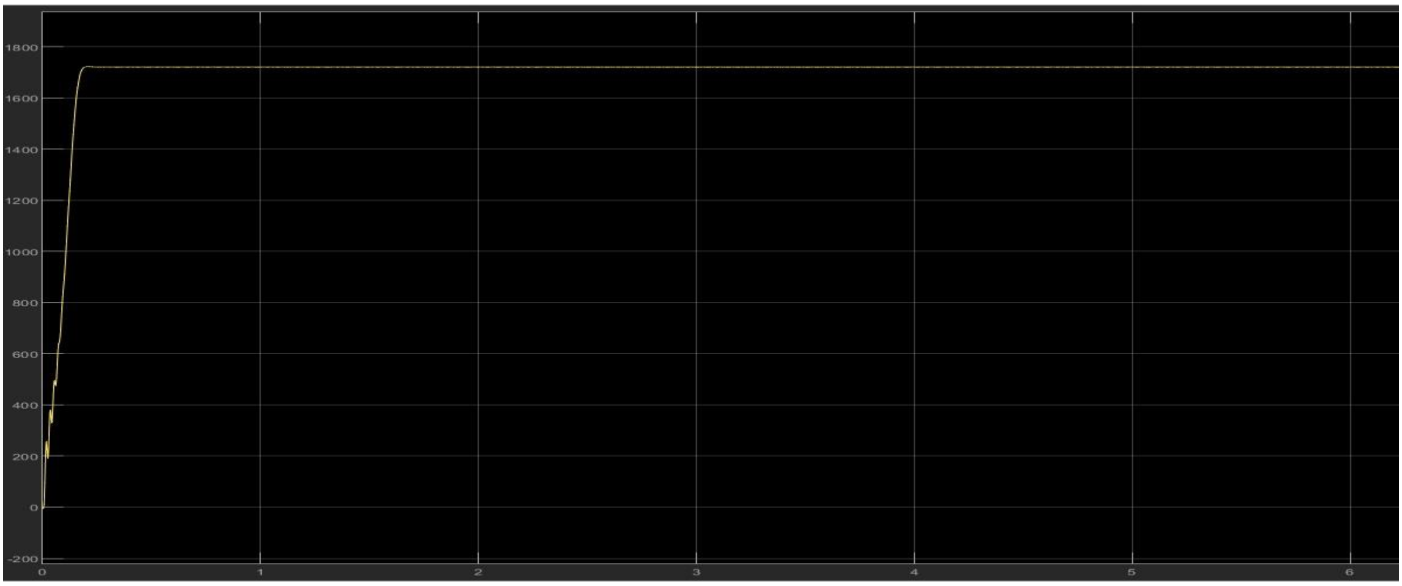
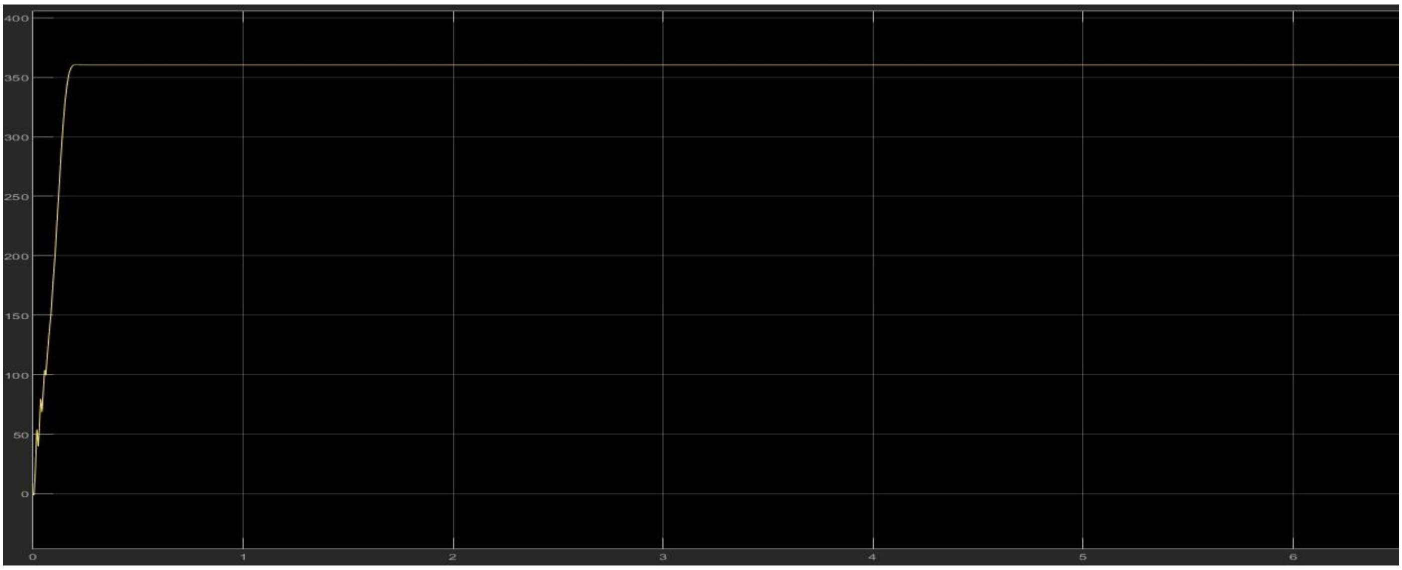
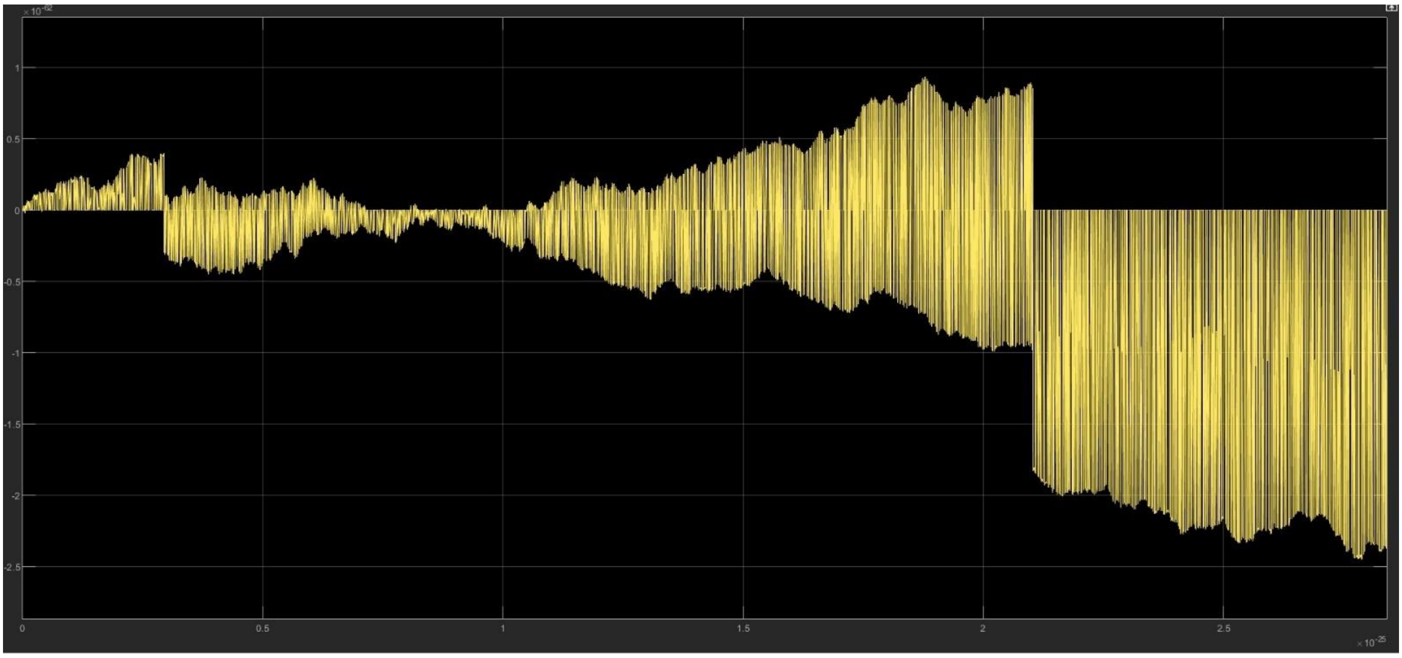


Fig 3.c: - Nr (speed of the rotor get reduced)



Fig©: - Wr also gets reduced

***AIM-4:-* “DIRECT TORQUE CONTROL OF INDUCTION MOTOR”**



ELECTROMAGNETIC TORQUE

AIM-5:- “Direct Rotor field FOC using SPWM technique”

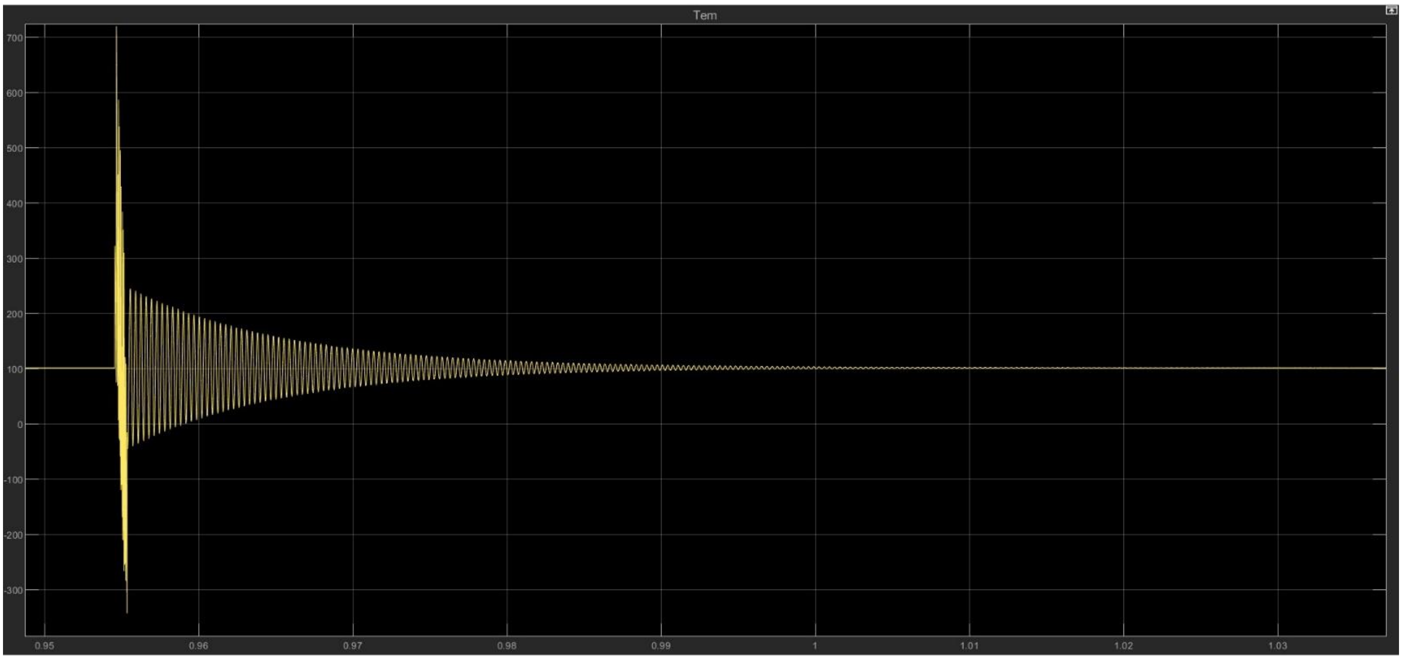


Fig 5.a- Electromagnetic Torque

Spikes is coming at the reference torque

References

[1] Ms. Tripti Rai, Prof. Prashant Debre "*Generalized Modelling Model Of three phase Induction Motor"* 978-1-4673-9925-8/16/$31.00 ©2016 IEEE

2) A New Version of Phase-Variable Modeling of an Induction Motor Using PSIM Ming-Fa Tsai, Chung-Shi Tseng, Yu-Yuan Chen*, and Wen-Yang Peng* Department of Electrical Engineering, Minghsin University of Science and Technology, Hsinchu, Taiwan *Industrial Technology Research Institute of Taiwan, ROC