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Open Loop V/F Control of Six Phase Induction Motor

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Abstract – *Induction motor have its own importance in automotive industries. Induction motor have high speed range, high reliability, low cost, rigidity in hostile environment. Multiphase Induction Motors have inherent advantages compared to the three phase system. Use of Multiphase induction motor can be possible with the help of power electronic devices with high power ratings. If motor is supplied through DC link inverter then we can use induction motor with any number of phases. This motor can be controlled by various methods, open loop V/F control technique is one of them. The main objective of this paper is to control six phase induction motor which is fed by six phase voltage source inverter. The simulation results of proposed control system are verified with the help of MATLAB.*

Key Words: Six Phase Induction Motor, V/F control.

1. INTRODUCTION.

Induction motor is having high importance in automobile sector as production of electrical vehicle is going on. Induction motor have number of advantages such as High speed range, High reliability, Low cost, Rigidity etc. Induction motor drive we can use with increased number of phases, which can increase drives performance. Multiphase Induction motors have number of advantages [8].

1. The amplitude of per phase stator current is reduced without increasing the per phase voltage.
2. Efficiency of six-phase induction motor is higher than three-phase induction motor.
3. It can produce higher torque density per ampere current, as space harmonic fields also contributes to produce torque.
4. Harmonic distortion is less in stator current.
5. Reduction in torque pulsation.
6. Speed variation from no-load to full-load is less compare to three-phase induction motor.
7. Less copper loss per phase in stator winding.

In this paper we have discussed open loop V/f control which is used to control speed of six phase Induction motor [3].

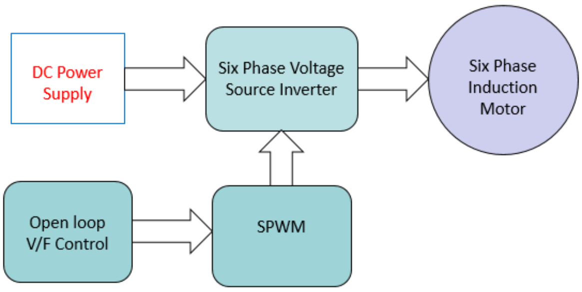


Fig -1: Block diagram of proposed system.

Block diagram of proposed system is shown in figure 1. Six phase voltage source inverter is fed by DC power supply. Six phase induction motor is fed by six phase voltage source inverter. Six phase inverter is controlled by sinusoidal PWM technique, V/F control technique is used for controlling the speed of three phase induction motor.

1.1 Six Phase Induction Motor model.

An induction motor is one of the most often used electric machines in high performance drive applications. Squirrel cage induction motor is popularly known as the workhorse of the modern industry. It is due to its simplicity in design, robust construction, reliability, tremendous self-starting capability and high-efficiency. Induction motor model is built in Matlab Simulink with the help of its mathematical equations [3].

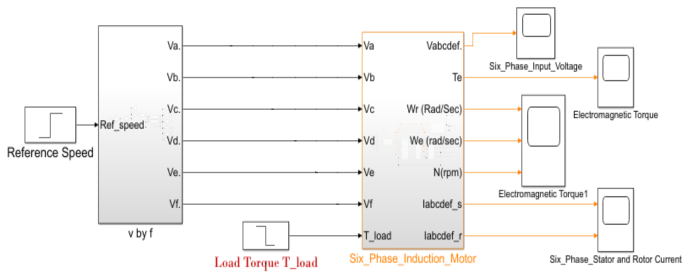


Fig -2: Matlab Block for Six phase Induction Motor.

The six-phase's induction motor stator and rotor windings are showing in space as in Fig.3. With a view to remove the Time-change inductances in the voltage equations, the machine was represented in the q-d-axis reference frame. The q - d axis reference frame is fixed in the rotor, which rotates at ωr [3, 4]. The sinusoidal voltages of six phase induction motor are expressed as:

$$V_{as} = V_m \sin(\omega t)$$
$$V_{bs} = V_m \sin\left(\omega t - \frac{\pi}{3}\right)$$
$$V_{cs} = V_m \sin\left(\omega t - \frac{2\pi}{3}\right)$$
$$V_{ds} = V_m \sin\left(\omega t - \frac{3\pi}{3}\right)$$
$$V_{es} = V_m \sin\left(\omega t - \frac{4\pi}{3}\right)$$
$$V_{fs} = V_m \sin\left(\omega t - \frac{5\pi}{3}\right)$$

The motor d-q equations in synchronously rotating reference frame are expressed as voltage drops and as well as across two sets of stator windings and single common rotor winding voltages referred to stator as this. This stator and rotor voltage equations are given by,

$$V_{qs1} = r_s * i_{qs1} + \frac{d\lambda_{qs1}}{dt} + \omega\lambda_{ds1} \quad 1$$
$$V_{qs2} = r_s * i_{qs2} + \frac{d\lambda_{qs2}}{dt} + \omega\lambda_{ds2} \quad 2$$
$$V_{ds1} = r_s * i_{ds1} + \frac{d\lambda_{ds1}}{dt} - \omega\lambda_{qs1} \quad 3$$
$$V_{ds2} = r_s * i_{ds2} + \frac{d\lambda_{ds2}}{dt} - \omega\lambda_{qs2} \quad 4$$
$$V'_{dr} = r_r * i'_{dr} + \frac{d\lambda_{dr}}{dt} - (\omega - \omega_r)\lambda'_{qr} \quad 5$$
$$V'_{qr} = r_r * i'_{qr} + \frac{d\lambda'_{qr}}{dt} - (\omega - \omega_r)\lambda'_{dr} \quad 6$$

Flux equations for direct and quadrature axis are given by,

$$\lambda_{qs1} = (L_{ls} + L_{lm} + L_m)i_{qs1} + (L_{lm} + L_m)i_{qs2} + L_m i'_{qr}$$
...........7

$$\lambda_{qs2} = (L_{ls} + L_{lm} + L_m)i_{qs2} + (L_{lm} + L_m)i_{qs1} + L_m i'_{qr}$$
.............8

$$\lambda_{ds1} = (L_{ls} + L_{lm} + L_m)i_{ds1} + (L_{lm} + L_m)i_{ds2} + L_m i'_{dr}$$
...........9

$$\lambda_{ds2} = (L_{ls} + L_{lm} + L_m)i_{ds2} + (L_{lm} + L_m)i_{ds1} + L_m i'_{dr}$$
..........10

$$\lambda'_{dr} = (L'_{lr} + L_m)i'_{dr} + L_m(i_{ds1} + i_{ds2})$$
..........11

$$\lambda'_{qr} = (L'_{lr} + L_m)i'_{qr} + L_m(i_{qs1} + i_{qs2})$$
..........12

Where,

$\lambda_{qs1}, \lambda_{qs2}$ = are stator q axis flux linkage components.

$\lambda_{ds1}, \lambda_{ds2}$ = are stator d axis flux linkage components.

$\lambda'_{dr}, \lambda'_{qr}$ = are rotor d and q axis flux linkage components.

L_{ls} = stator leakage inductance;

L_m= air gap inductance.

L_{lm}= mutual stator leakage inductance.

i_{ds1}, i_{ds2} = stator d axis current components.

i_{qs1}, i_{qs2} = stator q axis current components.

i'_{dr}, i'_{qr} = correspondingly rotor current q and d axis components.

ω_r = is rotational speed of motor.

Electromagnetic torque calculated according to formula:

$$T_e = \frac{3}{2} * \frac{P}{2} * \left(\frac{L_m}{L'_{lr}}\right) * \left[\lambda'_{dr}(i_{qs1} + i_{qs2}) - \lambda'_{qr}(i_{ds1} + i_{ds2})\right]$$
..........13

$$\frac{d\omega}{dt} = \frac{1}{J_r}(T_e - T_L)$$
..........14

Where,

ω = Motor rotational speed.

J_r = Rotor inertia.

T_e = Electromagnetic torque.

T_L = Load Torque.

Relationship between abs and arbitrary dq0 is shown in figure 4[5].

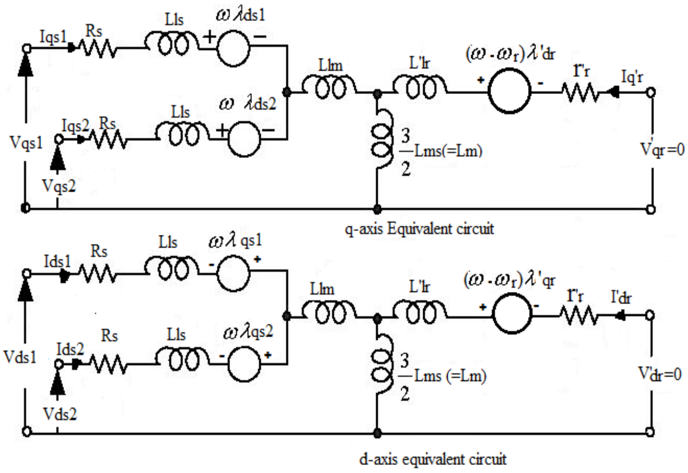


Fig -3: d-q equivalent circuit diagram for six phase induction motor.

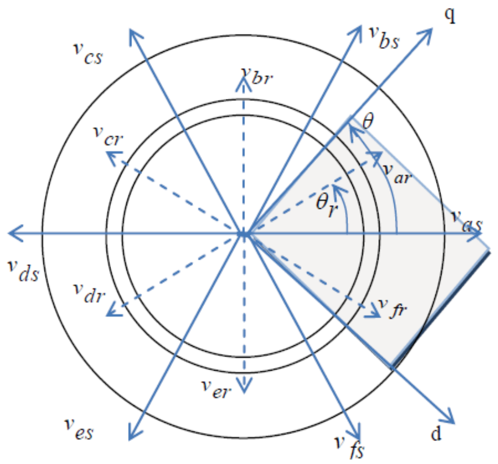


Fig -4: Relationship between abs and arbitrary dq0.

1.2 V by F Control.

In v by f control technique speed of induction motor is controlled by adjusting magnitude of stator voltage and frequency. For any change in frequency V/F ratio must be maintained constant so as to maintain flux constant. In this case torque becomes independent on the supply frequency. As speed increases stator voltage must be increased proportionally so as to maintain constant V/F ratio. Open loop speed control can be used when accuracy in speed response is not concern. We provide reference speed that speed is converted in to corresponding frequency. This frequency is again converted in to angle theta. From this we generate unit vectors Va, Vb, Vc ,Vd,Ve,Vf [3].Relation for induced voltage, stator flux and supply frequency is given by,

$$E = -\frac{d\lambda}{dt} \quad \text{........15}$$

$$E = K_w * f_s * \Phi_m \quad \text{...... 16}$$

$$\Phi_m = \frac{E}{f_s} \quad \text{.......17}$$

Matlab Simulink block for v by f control is shown in figure3.

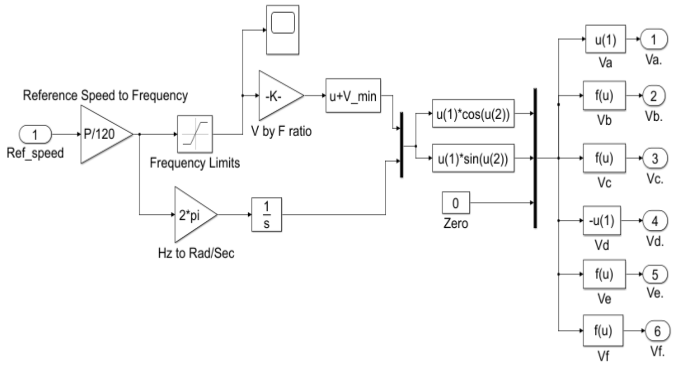


Fig -3: Matlab block for V/F control.

Extended Clarks transformation equations can be used for transforming voltages from six phase reference to alpha beta and vice versa with the help of inverse extended Clarks transformation [7].

Stationary alpha beta orthogonal coordinate to 6-phase stationary coordinate system is given by,

$$abcdef = \frac{1}{3}\begin{bmatrix} 1 & 0 \\ \cos\left(\frac{\pi}{3}\right) & -\sin\left(\frac{\pi}{3}\right) \\ \cos\left(\frac{2\pi}{3}\right) & -\sin\left(\frac{2\pi}{3}\right) \\ \cos(\pi) & \sin(\pi) \\ \cos\left(\frac{4\pi}{3}\right) & -\sin\left(\frac{4\pi}{3}\right) \\ \cos\left(\frac{5\pi}{3}\right) & -\sin\left(\frac{5\pi}{3}\right) \end{bmatrix} * \begin{bmatrix} alpha \\ beta \end{bmatrix} \quad \text{.......17}$$

$$abcdef = \frac{1}{3}\begin{bmatrix} 1 & 0 \\ \frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} * \begin{bmatrix} alpha \\ beta \end{bmatrix} \quad \text{......18}$$

6-phase stationary coordinate system to the stationary alpha beta orthogonal coordinate system is given by,

$$alpha, beta = \frac{1}{3}\begin{bmatrix} 1 & \cos\left(\frac{\pi}{3}\right) & \cos\left(\frac{2\pi}{3}\right) & \cos(\pi) & \cos\left(\frac{4\pi}{3}\right) & \cos\left(\frac{5\pi}{3}\right) \\ 0 & -\sin\left(\frac{\pi}{3}\right) & -\sin\left(\frac{2\pi}{3}\right) & -\sin(\pi) & -\sin\left(\frac{4\pi}{3}\right) & -\sin\left(\frac{5\pi}{3}\right) \end{bmatrix} abcdef$$

......19

$$alpha, beta = \frac{1}{3}\begin{bmatrix} 1 & \frac{1}{2} & -\frac{1}{2} & -1 & -\frac{1}{2} & \frac{1}{1} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} & 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} * abcdef$$

......20

1.3 Proposed Control Strategy:

In Proposed control strategy simple open loop v by f control is used together with six phase Clarks transformation. Theses reference waveforms we can directly use to drive six phase induction motor or we can use these signals as reference signals and can be used to produce gate pulses six phase voltage source inverter can be used to generate voltages, which can drive our motor. Figure 4. shows the six phase inverter driving six phase induction motor. Figure 5 show the matlab Simulink connections for six phase induction motor and its control from V/F control strategy with extended Clark's transformation method [8].

Six phase VSI with Six phase Induction Motor:

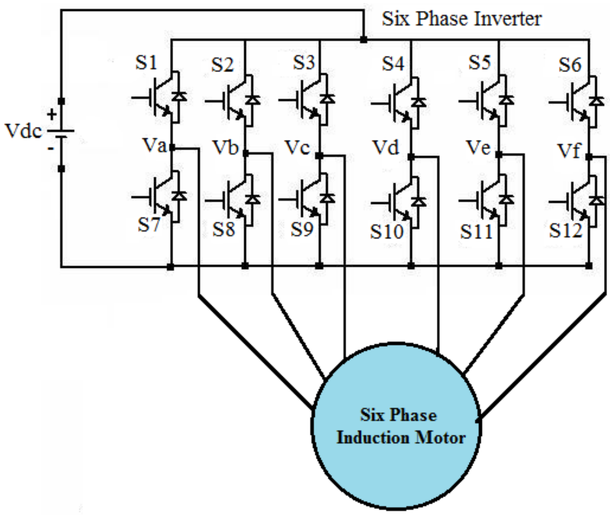


Fig -4: Six phase VSI with Six Phase Induction motor.

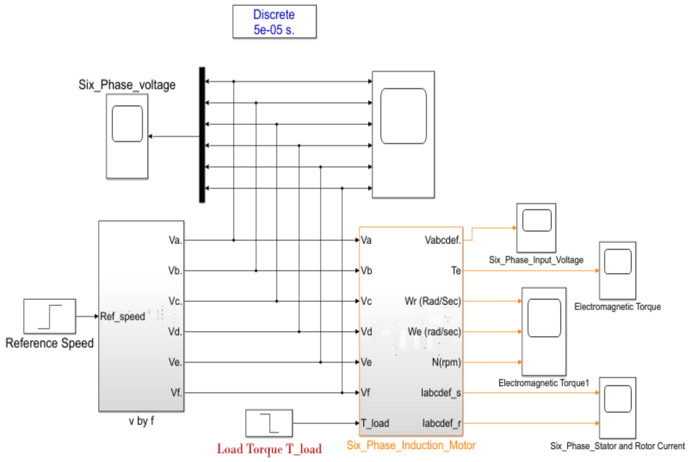
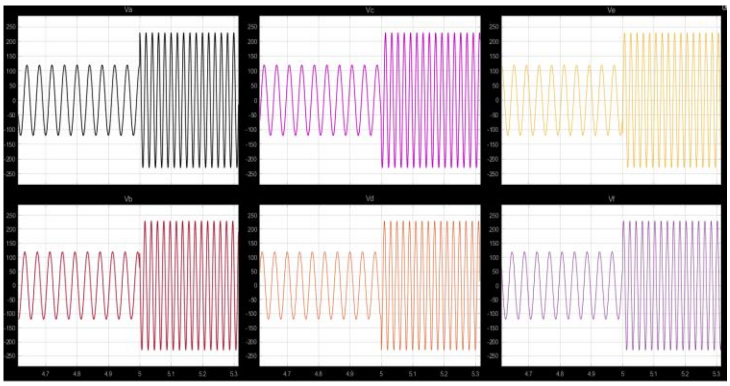


Fig -5: Proposed control strategy in matlab Simulink.

2. SIMULATION RESULTS:-

2.1 Six Phase input voltage Waveform:



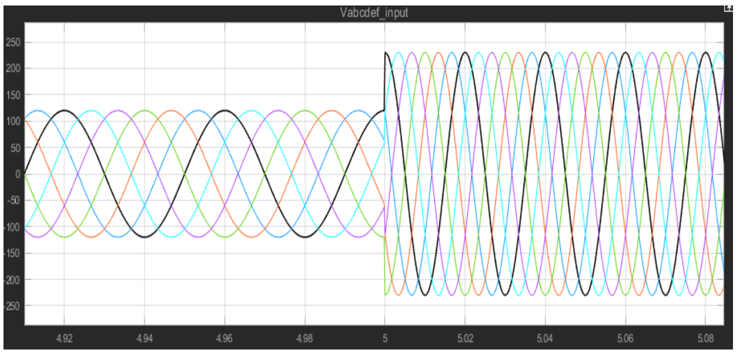


Fig -6.1): Six Phase input voltage to Induction Motor.

2.2 Six phase output voltage waveforms:

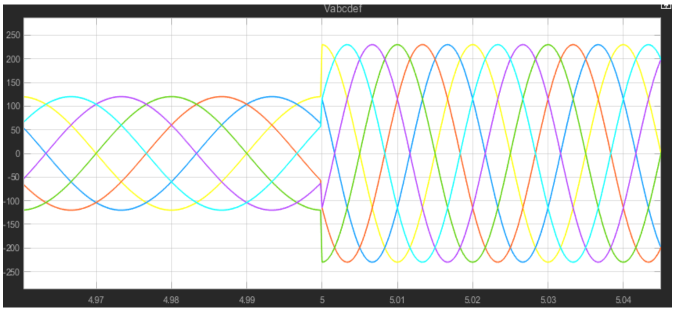


Fig -6.2): Six Phase Output voltage of Induction Motor.

2.3 Output current waveforms for six phase Induction motor:

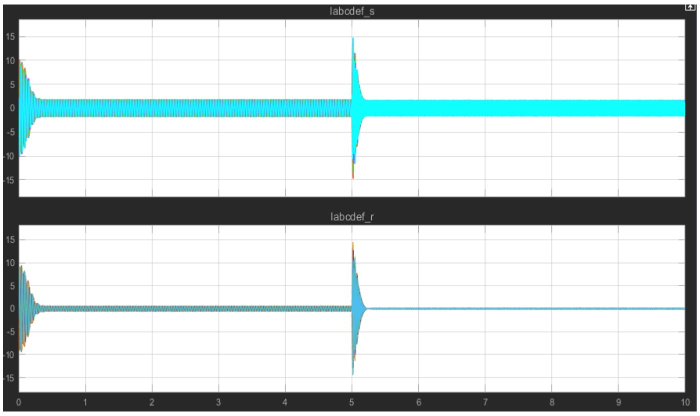


Fig -6.3): Stator and Rotor current waveforms.

2.3 Mechanical Speed output waveforms (rpm, rad/sec):

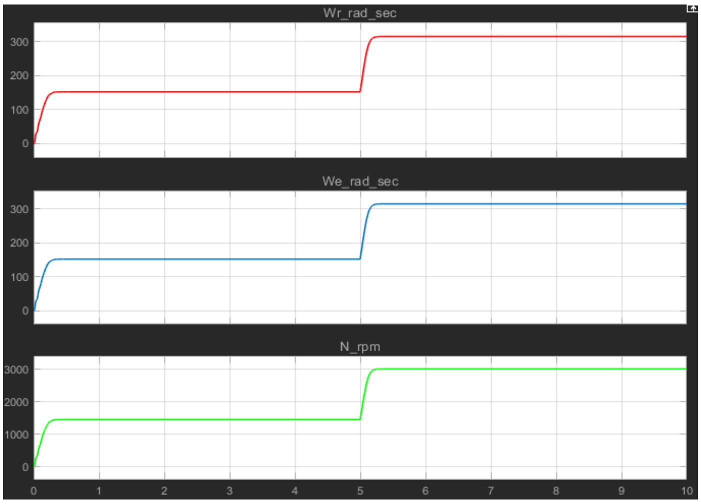


Fig -6.4): Mechanical speed output (for t<5 sec= 1500 rpm and for t>5 sec = 3000 rpm).

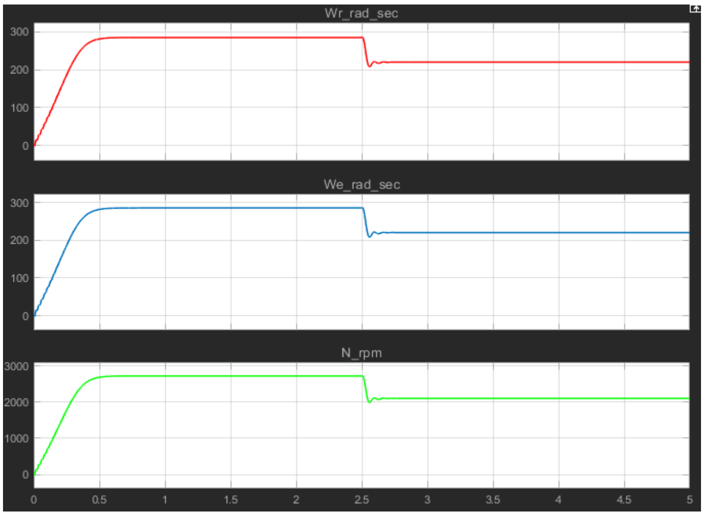


Fig -6.5): Mechanical speed output (for t<2.5 sec= 2800 rpm and for t>5 sec = 2000 rpm).

2.4 Torque output waveforms (N-m):

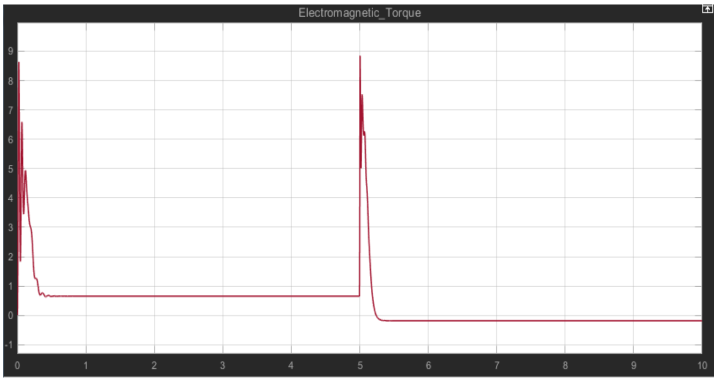


Fig -6.6): Torque output (for t<5 sec= 0.5N-m and for t>5 sec = -0.5N-m).

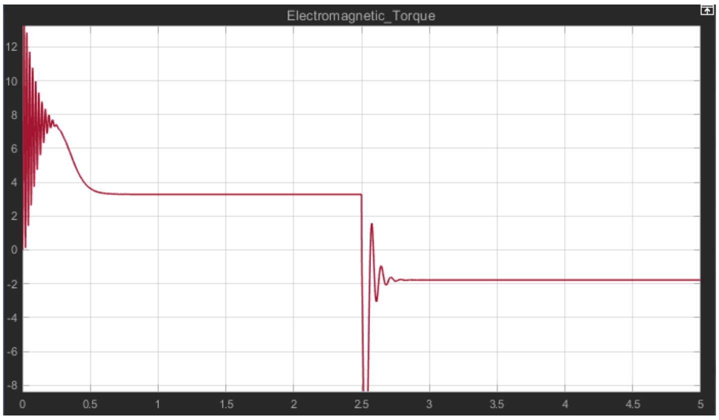


Fig -6.6): Torque output (for t<2.5 sec= 3N-m and for t>2.5 sec = -2 N-m).

3. CONCLUSION.

This paper discusses Six phase Induction motor controlled by open loop v by f control. A brief review of the operating principle is provided. The main focus of this paper is to model six phase induction motor in matlab Simulink and to implement open loop v by f control strategy for the same in Simulink. After successful modeling, we have analyzed different load changing conditions at different speed. It is observed that drive response is good as compared to the conventional three phase induction motor drive. It is also seen that, extended Clark's transformation can be useful for transforming alpha beta to six phase voltages.

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BIOGRAPHIES

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