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Performance Analysis of Inverter Fed Mathematical Modeling of Five Phase Induction Motor

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ABSTRACT: Three phase induction motor is invariably used in industrial, residential commercial and utility applications due to its advantages like low cost, most reliable, low maintenance. Multiphase motor drives with phase numbers greater than three leads to improvement in medium to high power applications. The multiphase induction motor finds application in the special and critical area where high reliability is required for the operation such as ship propulsion, electric/hybrid electric vehicle, aerospace, and electric locomotive application. This paper represents the mathematical modeling of a five-phase induction motor in MATLAB/Simulink. Reference theory is used for the simulation of the five-phase induction motor. The dynamic model is employed for a better understanding of steady state and transient state response of the five-phase induction motor.

KEYWORDS: Five phase induction motor, Dynamic model, MATLAB/Simulink.

I.INTRODUCTION

Three phase induction motor is the most widely used motor in industrial applications, because of its some advantages like simple and robust construction, reliability, ruggedness, low maintenance and low cost. The speed control of three phase induction motor is more complex as compared to other motors, by using moderate power electronics devices the speed control of three-phase induction flexible and easier than before[1]. The applications of induction motors are in pumps, fans, compressors, rolling mills, cement mills, mine hoists, etc. Induction has some special applications like ship propulsion, traction drives, hybrid vehicles, high power pumps, and aerospace[2].

Kiran S. Aher, A. G. Thosar[1], have presented modeling of five-phase induction motor using reference frame theory. Multiphase motor drives with phase number greater than three phase leads to an improvement in the medium to high power drives application. The multiphase induction motor find application in special and critical area where high reliability is demanded such as Electric vehicles/Hybrid Electric vehicles, aerospace application, ship propulsion and locomotive traction and in high power application. The mathematical equations define the dynamic behavior of a five-phase induction motor. For the simplicity, the five-phase is converted into two phase are d-q and they are quadrature to each other. The study state model of the induction motor is used to study the steady-state analysis of induction motor.
G. Renuka Devi[3], paper analyzes the experimental investigation of indirect field oriented control of Field Programmable Gate Array (FPGA) based five-phase induction motor drive. Recently, multiphase machines have made a great impact on research. Some of the advantages of these machines are lower torque pulsation, reduction in harmonic currents, reduced stator current per phase without increasing the phase voltage. When it is compared to three phase machine, it has greater reliability, fault tolerant feature and increased power in the same frame. These features can

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justify the higher complexity of the multiphase drive in special custom applications, such as electrical ship propulsion, traction drives, electric/hybrid vehicles, high power pumps and aerospace. G. K. Singh[4], due to the potential benefits resulting from the use of a phase order higher than three in transmission, some interest has also grown in the area of multi-phase machine. For machine drive applications, multi-phase system could potentially meet the demand for high power electric drive systems, which are both rugged and energy-efficient. High phase number drives possess several advantages over conventional three-phase drives such as: reducing the amplitude and increasing the frequency of torque pulsation, reducing the rotor harmonic currents, reducing the current per phase without increasing the voltage per phase, lowering the dc link current harmonics, higher reliability and increased power in the same frame. N. Bianchi, S. Bolagnani S., M. Dai Pre, E. Fornasiero[8], this paper compares the post–fault current control strategies of a five–phase permanent magnet motor adopting a half–bridge and a full–bridge converter. The analysis covers both the open circuit of one and two phases. Five–phase permanent magnet (PM) motor can be suitably designed to operate in applications requiring high fault–tolerance degree, for instance, in applications as automotive, aeronautic, aerospace and many others. In multi–phase motor drive, the electric power is divided into more inverter legs reducing the current of each switch. In addition, in the event of failure of one or more phases, the remaining healthy phases continue to operate.

This paper presents mathematical modelling of inverter fed five phase induction motor. The structure of this paper is organized as section-II deals with introduction of five phase induction motor. Section- III describes mathematical modelling of five phase induction motor using reference frame theory. Section- IV describes MATLAB/SIMULINK implementation of inverter fed five phase induction motor. Section –V deals with results. Section –VI deals with conclusion and future scope.

II.FIVE PHASE INDUCTION MOTOR

Construction of Five-Phase Induction Motor is similar to the Conventional Three Phase Induction Motor. It works on the faradays law and the Lorentz force on a conductor. The phase shift between in each phase is 72° while in the case of Three-Phase Induction Motor it will be 120°. The stator of the Five Phase Induction Motor is fed by the five-leg inverter, which can produce the Five Phase supply whose phases are 72 °s displaced[1]. There are two kinds of inverters are available one is half bridge inverter and another one is full bridge inverter. But the advantage of the full bridge is whose phase current is independent and there is no electrical interaction among the phases. For the n-phase inverter for producing its n-phase supply, its firing angle is $\alpha=2\pi/n$, for five phase inverter firing angle $\alpha=2\pi/5$[2].
In fig. 1 and fig. 2 shows the inverter fed five phase induction motor and five phase induction motor.

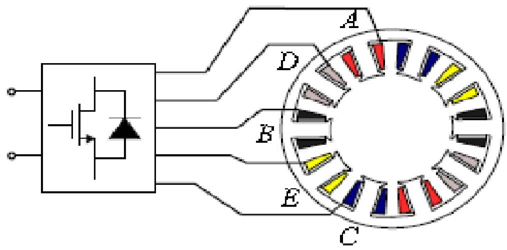

Figure 1: Inverter Fed Five Phase Induction Motor

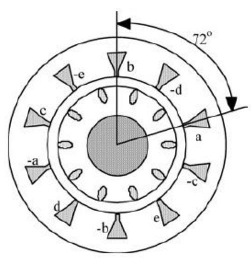

Figure 2: Five Phase Induction Motor

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The mathematical equations define the dynamic behavior of a five-phase induction motor. For the simplicity, the five-phase is converted into two phase are d-q and they are quadrature to each other. The study state model of the induction motor is used to study the steady-state analysis of induction motor[1]. The theory of reference frame has been used to analyze the performance of five phase induction machine. In this paper Simulink implementation of induction machine using dqxy0 axis transformation is used[2]. A detailed d-q modeling and Space Vector Pulse Width Modulation (SVPWM) technique of 5-phase drive is elaborated in this paper[3]. A high number of phase drives have some advantages over the conventional three-phase drive, like reducing amplitude and increasing frequency of torque pulsation, decrease dc link current harmonics, high reliability and increased power in the same frame[4]. Using the concept of vector space decomposition, the proposed technique is established on the basis of the asymmetrical winding structure directly, and thus provides a precise, physically insightful tool to the modeling and control of induction machines with structural unbalance[5]. The performance of multiphase concentrated winding induction machines specifically designed for operation with static power converters is investigated. The winding distributions are intentionally rectangular to better accommodate the rectangular wave forms of solid state inverters[6].

III. MATHEMATICAL MODEL OF INDUCTION MOTOR

Equations of induction motor like voltage, torque which describes the dynamic behavior of induction motor time varying in nature. But that equation increases the complexity while solving the differential equation, because of relative motion between the electrical circuits. To minimize the complexity of the equations, the time-variant equations can be converted into the time-invariant equations. The multiphase winding can be converted into the two-phase winding (d-q) which are in quadrature to each other. It means the stator and rotor variables are transferred to the arbitrary reference frame.
Five phase stator voltage of induction motor at balanced condition is

$$V_a = \sqrt{2}V_{rms}\sin(wt) \tag{1}$$

$$V_b = \sqrt{2}V_{rms}\sin\left(wt - \frac{2\pi}{5}\right) \tag{2}$$

$$V_c = \sqrt{2}V_{rms}\sin\left(wt - \frac{4\pi}{5}\right) \tag{3}$$

$$V_d = \sqrt{2}V_{rms}\sin\left(wt + \frac{4\pi}{5}\right) \tag{4}$$

$$V_e = \sqrt{2}V_{rms}\sin\left(wt + \frac{2\pi}{5}\right) \tag{5}$$

The machine model in original form is transformed by using a decoupling transformation matrix,

$$\begin{bmatrix} V_q \\ V_d \\ V_x \\ V_y \\ V_0 \end{bmatrix} = \frac{2}{5}\begin{bmatrix} 1 & \cos\alpha & \cos2\alpha & \cos3\alpha & \cos4\alpha \\ 0 & -\sin\alpha & -\sin2\alpha & -\sin3\alpha & -\sin4\alpha \\ 1 & \cos3\alpha & \cos6\alpha & \cos9\alpha & \cos12\alpha \\ 0 & -\sin3\alpha & -\sin6\alpha & -\sin9\alpha & -\sin12\alpha \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} \tag{6}$$

Where $\alpha = 2\pi/n$
The five-phase voltage which is simulated in MATLAB and after transformation of five phase supply into two-phase (d-q axis) stator voltage is shown in fig.3 and fig. 4.

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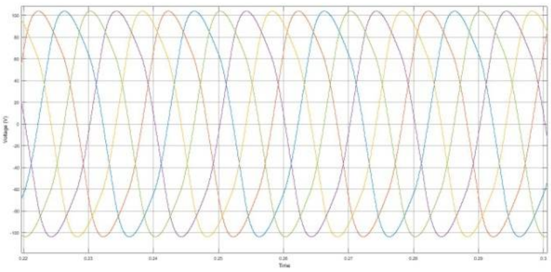

Figure 3: Five phase supply voltage

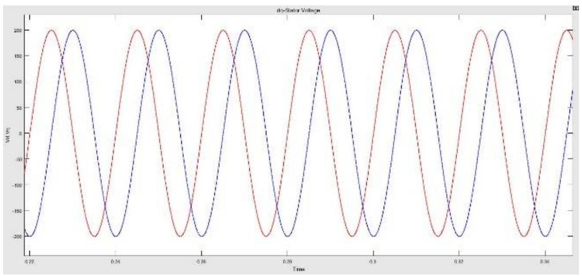

Figure 4: d-axis and q-axis stator voltage

Stator to rotor coupling can take place in d-q equations. Rotational transformation is applied only these pairs of equations. These equations are identical to that of the three-phase induction machine. Assume that the machine equation is transformed into the arbitrary frame of reference that is rotating at an angular speed of w_a. Model of an induction machine with stator side uses the equation in the d-q reference frame are as follows[4].

$$V_{ds} = R_s i_{ds} - w_a \Psi_{qs} + \rho \Psi_{ds} \quad (7)$$

$$V_{qs} = R_s i_{qs} + w_a \Psi_{ds} + \rho \Psi_{qs} \quad (8)$$

$$V_{xs} = R_s i_{xs} + \rho \Psi_{xs} \quad (9)$$

$$V_{ys} = R_s i_{ys} + \rho \Psi_{ys} \quad (10)$$

$$V_{0s} = R_s i_{0s} + \rho \Psi_{0s} \quad (11)$$

Rotor side voltage equations in d-q reference frame is,

$$V_{ds} = R_r i_{dr} - (w_a - w)\Psi_{qr} + \rho \Psi_{dr} \quad (12)$$

$$V_{qr} = R_r i_{qr} + (w_a - w)\Psi_{dr} + \rho \Psi_{qr} \quad (13)$$

$$V_{xr} = R_r i_{xr} + \rho \Psi_{xr} \quad (14)$$

$$V_{yr} = R_r i_{yr} + \rho \Psi_{yr} \quad (15)$$

$$V_{0r} = R_r i_{0r} + \rho \Psi_{0r} \quad (16)$$

Flux equation of stator side is given as,

$$\Psi_{ds} = (L_{ls} + L_m) i_{ds} + L_m i_{dr} \quad (17)$$

$$\Psi_{qs} = (L_{ls} + L_m) i_{qs} + L_m i_{qr} \quad (18)$$

$$\Psi_{xs} = L_{ls} i_{xs} \quad (19)$$

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Vol. 7, Issue 10, October 2018

$$\Psi_{ys} = L_{ls} i_{ys} \tag{20}$$

$$\Psi_{0s} = L_{ls} i_{0s} \tag{21}$$

Flux equation of rotor side is given as,

$$\Psi_{dr} = (L_{lr} + L_m) i_{dr} + L_m i_{ds} \tag{22}$$

$$\Psi_{qr} = (L_{lr} + L_m) i_{qr} + L_m i_{qs} \tag{23}$$

$$\Psi_{xr} = L_{lr} i_{xr} \tag{24}$$

$$\Psi_{yr} = L_{lr} i_{yr} \tag{25}$$

$$\Psi_{0r} = L_{lr} i_{0r} \tag{26}$$

Where L_m = (n/2)M and M is the maximum value of the stator to rotor mutual inductances in the phase variables model. Symbols R and L stand for resistance and inductance, V, I and ψ denote voltage, current and flux linkage while indices s, r identifies stator, rotor variables/parameters. Index indentifies leakage inductances. From the above equations, torque and rotor speed can be determined as,

$$T_e = \frac{5}{2}\left(\frac{p}{2}\right)\frac{5}{w_b}\left(\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}\right) \tag{27}$$

$$w_r = \int \frac{p}{2J}\left(T_e - T_L\right) \tag{28}$$

where P is the number of poles, J is a moment of inertia, T_L is load torque, T_e is electromagnetic torque, w_r is rotor speed.

The mathematical model equation for d-q component and torque equation are identical for a three-phase induction motor. The only difference between a three-phase induction motor and five-phase induction motor is the presence of xy-component in voltage and flux equation. Rotor xy-component are fully decoupled from the d-q component since rotor winding short-circuited because of that it does not appear in rotor winding. Zero sequence component equation for both stator and rotor are not included for further consideration due to the short circuit rotor winding and the star connected stator winding[3]. It means the model of the five-phase induction motor is similar to the model of the three-phase induction motor in the arbitrary reference frame and some of the control schemes are used for the multiphase motor as for three-phase motor. The existence of xy equation means that utilization of voltage source that creates stator voltage xy component will lead to a flow of potentially large stator xy current component since these are by stator leakage impedance.

Once the stator voltage is transformed to the d-q frame then we implement the flux linkage equation, current equation, torque equation and rotor speed equation inn terms of i_{qs}, i_{ds}, i_{qr}, i_{dr} then by using the inverse transformation equation to obtain current in the machine variables from in arbitrary reference frame to current in machine variable to study the nature of current in stator as,

$$\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \\ i_{ds} \\ i_{es} \end{bmatrix} = \sqrt{\frac{2}{5}} \begin{bmatrix} 1 & 0 & 1 & 0 & 1 \\ \cos\alpha & \sin\alpha & \cos 2\alpha & \sin 2\alpha & 1 \\ \cos 2\alpha & \sin 2\alpha & \cos 4\alpha & \sin 4\alpha & 1 \\ \cos 3\alpha & \sin 3\alpha & \cos 6\alpha & \sin 6\alpha & 1 \\ \cos 4\alpha & \sin 4\alpha & \cos 8\alpha & \sin 8\alpha & 1 \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{xs} \\ i_{ys} \\ i_{0s} \end{bmatrix} \tag{29}$$

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Vol. 7, Issue 10, October 2018

IV. MATLAB/SIMULINK IMPLEMENTATION

SIMULINK MODEL

To produce the Five Phase supply here we use the five-leg inverter. The five-leg inverter input is from the DC supply. In five leg inverter, the IGBT's are used for switching operation due to its advantages. For the switching of the IGBT here we used a pulse generator. By varying the pulse width and the period of the wave to get appropriate phase difference of degree in each phase. The output of the five-leg inverter is not purely sinusoidal for that reason to get a pure sine wave here we use the filters. The filter's output is then given to the model of five-phase induction motor. In fig. 5 shows the model of five phase inverter.

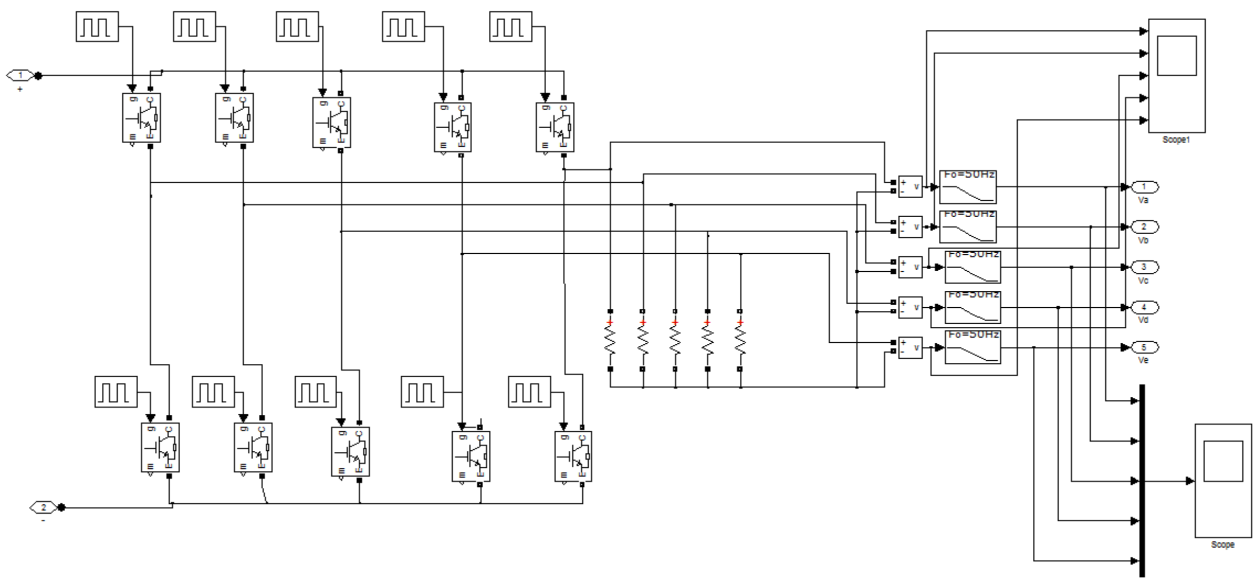

Figure 5: Model of Five Phase Inverter

Equations of voltage, flux, torque and transformation matrix used to implement the model of a five-phase induction motor in MATLAB/Simulink. Five phase sinusoidal voltage supply is given to the stator of the five-phase induction motor as an input. Five phase to two-phase block transform the five-phase stator voltage into two phase d and q-axis voltage and this block give the stator current, rotor current, quadrature axis flux, direct axis flux. Current flux to torque speed block gives the rotor speed and torque using its respective equations. Simulation of five-phase induction motor is simulated at no load. Stator and rotor current dq-reference are transformed into the machine variables using an inverse transformation matrix. In fig. 6 shows model of five phase induction motor.

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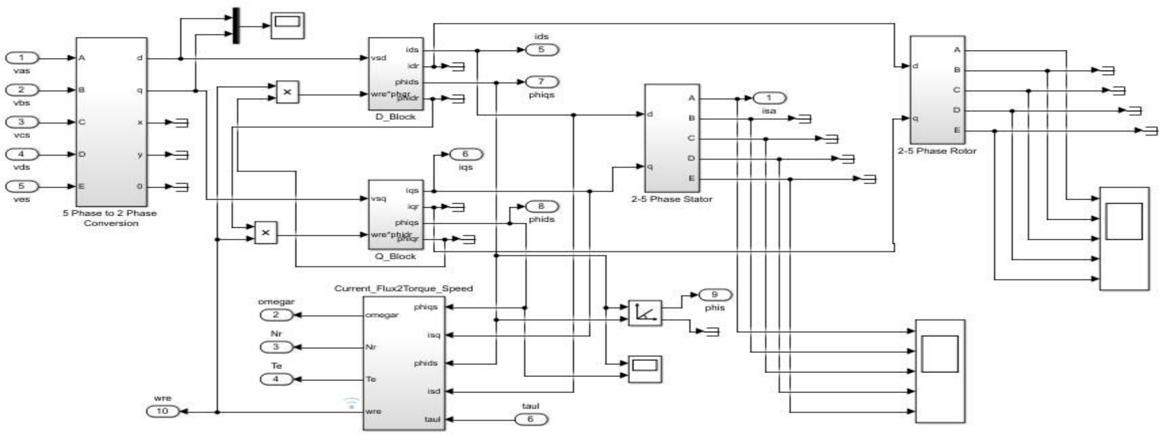

Figure 6: Model of Five Phase Induction Motor

V.RESULTS

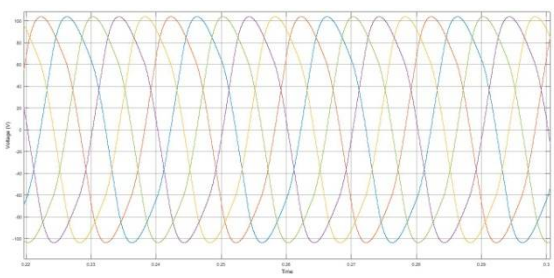

Figure 7: Five Phase Inverter Voltage

Fig. 7 deals with the five phase inverter voltage. At the starting time the induction motor act as the transformer whose secondary is short-circuited. Because of short circuit rotors, bars more current will flow. This current will vanish when motor attains its steady-state speed, after that a no-load current of the motor will be shown in fig. 8.

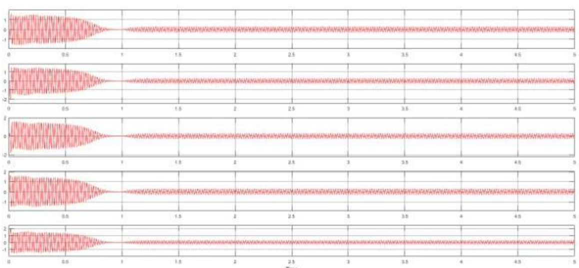

Figure 8: Rotor Current

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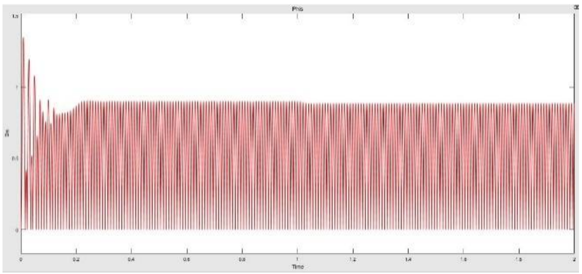

Figure 9: Stator Flux

The variation in the torque at the starting time due to the heavy magnetizing current. Torque will be at steady state when the motor attains it steady state speed is shown in fig. 10.

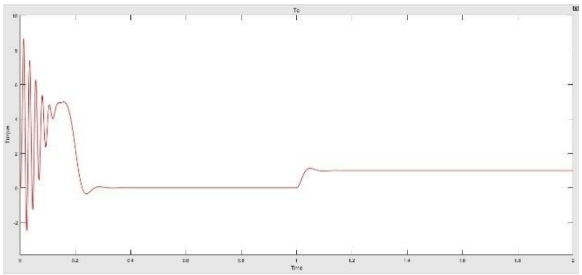

Figure 10: Electromagnetic Torque

Rotor speed is varied from the starting of the motor to the running of the motor. Small overshoot is observed in the speed response of motor as shown in fig. 11.

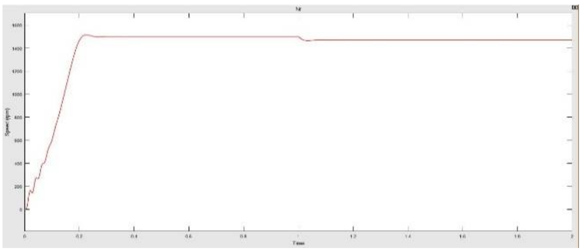

Figure 11: Rotor Speed

Fig. 12 shows the stator current. At the starting of the induction motor it draws the more magnetizing current. That magnetizing current will disappear after few cycles of current when motor attains its steady-state speed. The constant no load current will be shown after the high starting magnetizing current.

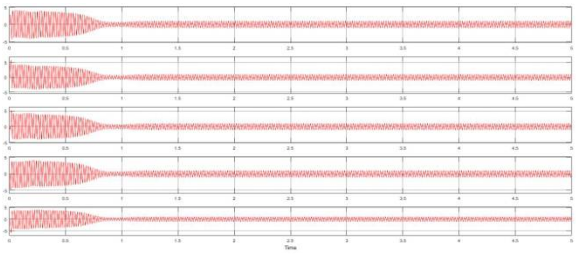

Figure 12: Stator Current

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Vol. 7, Issue 10, October 2018

VI.CONCLUSION

The investigation in the area of multiphase induction machine it is viable to use the higher number of phase more than three has advantages over by using conventional three phases like high reliability, run even when one of the phases is open-circuited or short-circuited, lower per phase current and the increase in the power rating of the machine in the same size of frame.

The mathematical mode of the seven-phase induction motor can be implemented using reference theory. In future the controlling of the motor by using Fuzzy logic can be a possible fabrication of the five-leg inverter for the supply of five-phase induction motor can be possible.

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