Simulation & Controlling of A Five Phase Induction Motor Fed By Five Phase Inverter

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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 five phase induction motor in MATLAB/Simulink. Reference theory is used for the simulation of the five phase induction motor. Dynamic model are employed for 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 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. The applications of induction motors are in pumps, fans, compressors, rolling mills, cement mills, mine hoists, etc. Induction motor has some special applications like ship propulsion, traction drives, hybrid vehicles, high power pumps and aerospace.

II. LITERATURE SURVEY

Kiran S. Aher [1], have presents modeling of five phase induction motor using reference frame theory. The mathematical equations defines the dynamic behavior of 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 induction motor is used to study the steady state analysis of induction motor. G. K. Singh[2], 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 same frame.

Construction of Five Phase Induction Motor is similar to the conventional Three Phase Induction Motor. It works on the faraday’s law and the Lorentz force on a conductor. The phase shift between in each phase is 72 degree while in case of Three Phase Induction Motor it will be 120 degree. 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 degree displaced. There are two kinds of inverters are available one is half bridge inverter and another one is full bridge inverter. But the advantage of 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 $\alpha=2\pi/5$.

III. MATHEMATICAL MODEL

Equations of induction motor like voltage, torque which describes the dynamic behavior of induction motor time varying in nature. But hose equations increases the complexity while solving the differential equation, because relative motion between the electrical circuit. 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 arbitrary reference frame.

Five phase stator voltage of induction motor at balanced condition is

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

$$V_b = \sqrt{2}\, V_{rms}\sin(wt-\frac{2\pi}{5}) \quad (2)$$

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

$$V_d = \sqrt{2}\, V_{rms}\sin(wt+\frac{4\pi}{5}) \quad (4)$$

$$V_e = \sqrt{2}\, V_{rms}\sin(wt+\frac{2\pi}{5}) \quad (5)$$

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

$$\begin{bmatrix} V_q \\ V_d \\ V_x \\ V_y \\ V_0 \end{bmatrix} = \frac{2}{5}\begin{bmatrix} 1 & \cos\alpha & \cos 2\alpha & \cos 3\alpha & \cos 4\alpha \\ 0 & -\sin\alpha & -\sin 2\alpha & -\sin 3\alpha & -\sin 4\alpha \\ 1 & \cos 3\alpha & \cos 6\alpha & \cos 9\alpha & \cos 12\alpha \\ 0 & -\sin 3\alpha & -\sin 6\alpha & -\sin 9\alpha & -\sin 12\alpha \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} \quad \ldots(6)$$

Where $\alpha = 2\pi/n$

The five phase voltage which is simulated in MATLAB whose is shown in fig. and after transformation of five phase supply into two phase (d-q axis) stator voltage shown in fig.

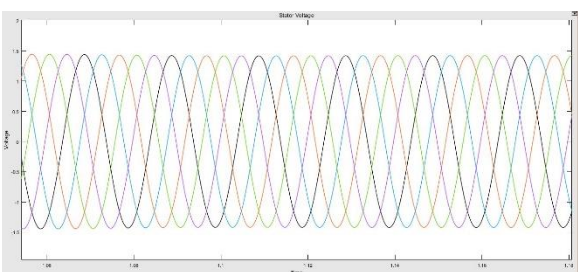

Figure 1: Five phase supply voltage

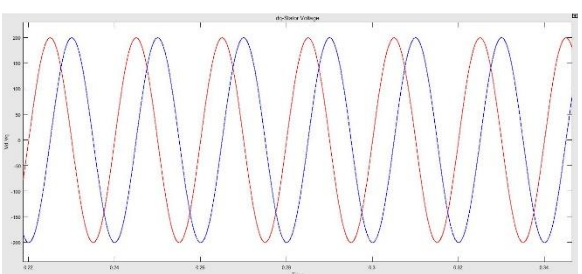

Figure 2: d-axis and q-axis stator voltage

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

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

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

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

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

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

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

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

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

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

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

$$V_{0r} = R_s i_{0r} + \rho\psi_{0r} \quad (16)$$

Flux equation of stator side is given as,

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

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

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

$$\Psi_{ys} = L_{ls} i_{ys} \quad (20)$$

$$\Psi_{0s} = L_{ls} i_{0s} \quad (21)$$

Flux equation of rotor side is given as,

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

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

$$\Psi_{xr} = L_{lr} i_{xr} \quad (24)$$

$$\Psi_{yr} = L_{lr} i_{yr} \quad (25)$$

$$\Psi_{0r} = L_{lr} i_{0r} \quad (26)$$

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 identifies leakage inductances.

From above equations torque and rotor speed can be determined as,

$$T_e = \frac{5}{2}\left(\frac{P}{2}\right)\frac{5}{w_b}(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) \quad (27)$$

$$w_r = \int \frac{P}{2J}(T_e - T_L) \quad (28)$$

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

Mathematical model equation for d-q component and torque equation are identical for three phase induction motor. Only difference between 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 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. It means the model of five phase induction motor is similar to the model of the three phase induction motor in arbitrary reference frame and some of the control schemes are used for multiphase motor as for three phase motor. Existence of xy equation means that utilization of voltage source that create stator voltage xy component will lead to flow of potentially large stator xy current component, since these are by stator leakage impedance.

Once the stator voltage is transformed to d-q frame then we implement the flux linkage equation, current equation, torque equation and rotor speed equation in 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,

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

IV. SIMULATION

Equations of voltage, flux, torque and transformation matrix used to implement the model of five phase induction motor in MATLAB/Simulink. Five phase sinusoidal voltage supply is given to the stator of 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 gives 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 simulating at no load. Stator and rotor current dq-referance is transformed into the machine variables using inverse transformation matrix.

SIMULINK MODEL

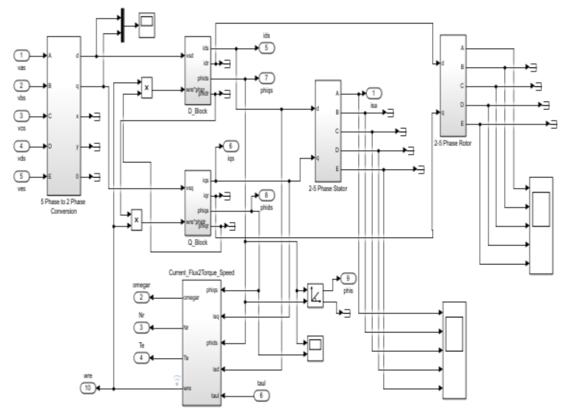

Figure 3: Model of Five Phase Induction Motor

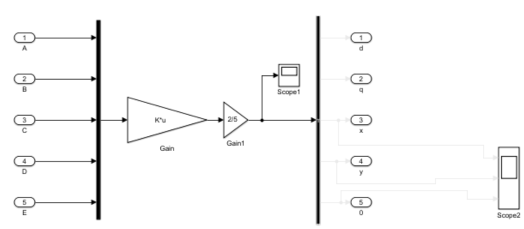

Figure 4: 5 Phase to 2 Phase conversion

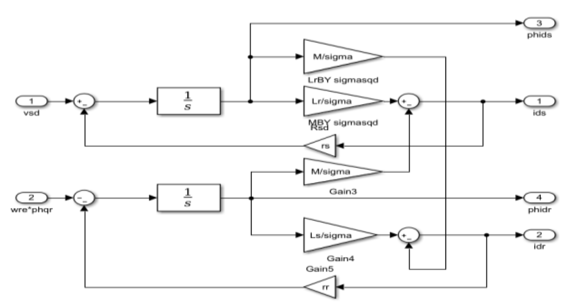

Figure 5: D block

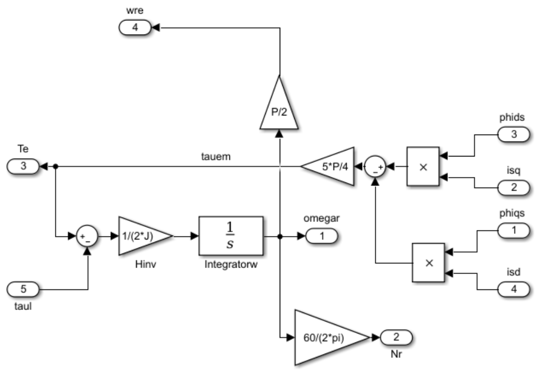

Figure 7: Current Flux to Torque Speed

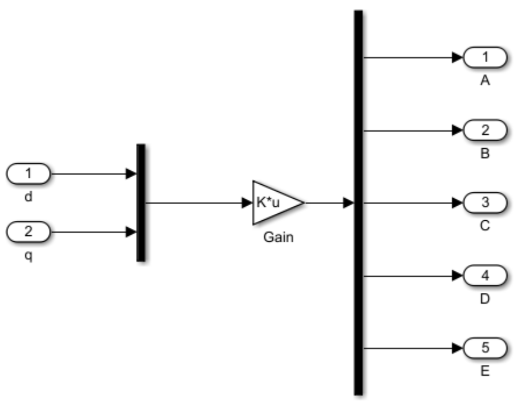

Figure 8:2 Phase to 5 Phase Stator Current

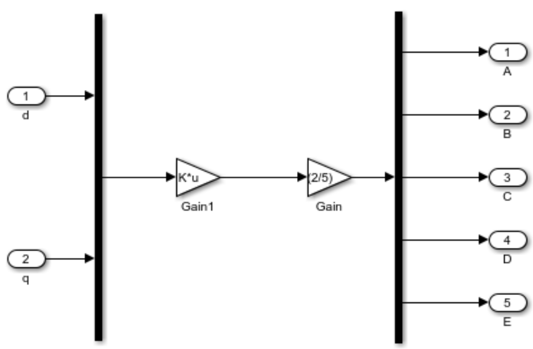

Figure 9:2 Phase to 5 Phase Rotor Current

V. RESULTS

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.

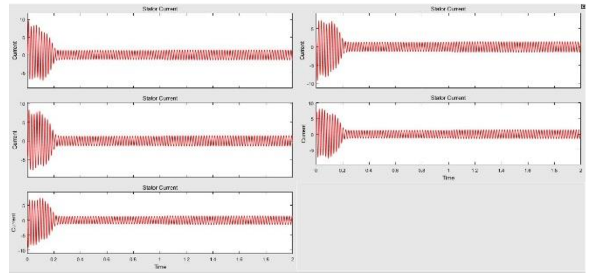

Figure 10: Stator Current

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 be vanishes when motor attains its steady state speed, after that a no load current of motor will be shown.

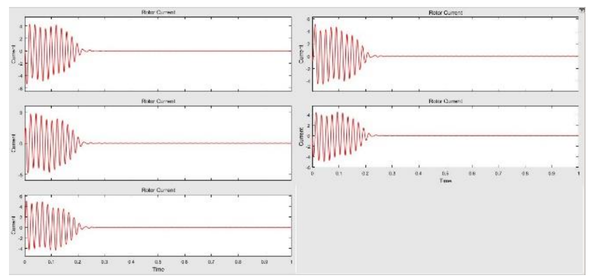

Figure 11: Rotor Current

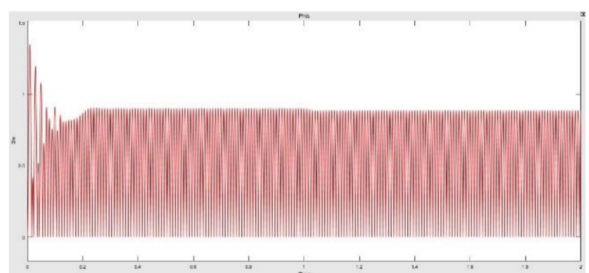

Figure 12: Stator Flux

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.

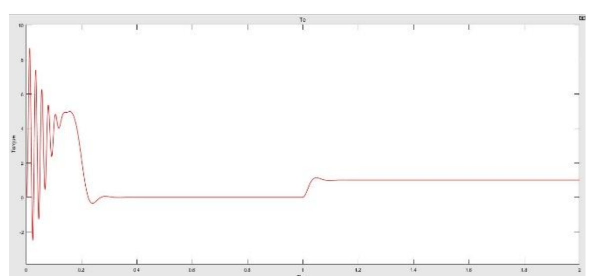

Figure 13: Electromagnetic Torque

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

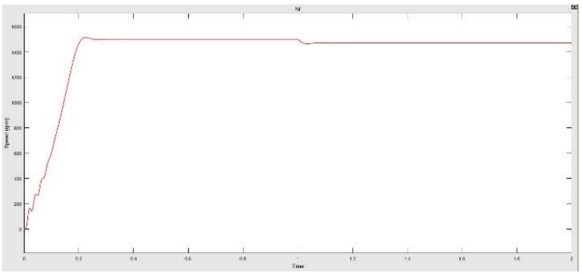

Figure 14: Rotor Speed

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 the one of the phase is open circuited or short circuited, lower per phase current and the increase the power rating of the machine in same size of frame.

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

The mathematical model of five phase induction motor can simulate in the Simulink. To simulate the model the five phase is converted into the dq model of five phase induction machine. It can be seen that the dq-model of five induction motor and the three phase induction motor is same

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