Simulation of Inverter Fed Five Phase Induction Motor

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Abstract: ***This paper presents dynamic simulation of inverter fed five phase induction machine based on mathematical modelling. Spwm Technique is used to generate the pulses for the inverter. 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.***

Keywords: Inverter, Spwm Technique, Five phase Induction Motor**.**

7. Introduction

Multi-Phase Machines are Ac machines characterized by a stator winding composed of generic number of phases. In today's electric drive & Generation technology Multiphase machine has several advantages over the traditional three phase machine such as reducing the amplitude and increasing the frequency of torque pulsation, reducing the rotor harmonic current per phase without increasing the voltage per phase, lowering the dc-link current harmonics and higher reliability, high fault tolerance. Earlier multiphase motor where not used widely because of the drawback that the supply for the multi phase motor was not available, With the Advancement in Power Electronics, interest in Multi-phase machine has been increased tremendously as high power electronic devices are used as a switch in voltage source inverter (VSI), the output of the VSI is given to the Multi-phase machine. The multiphase drive has special applications where high reliability is demanded such as electric/hybrid vehicles, aerospace applications, ship propulsion, and Locomotive traction & in high power application. In this paper modelling and simulation of five phase induction motor is been described which is fed from a voltage source inverter.

8. Voltage source inverter

The basic power circuit topology of five phase VSI is shown below. IGBT is used as the power switches. The anti parallel diodes provides reverse current path such that when a particular IGBT is gated on, one output terminal and one input terminal will be connected.

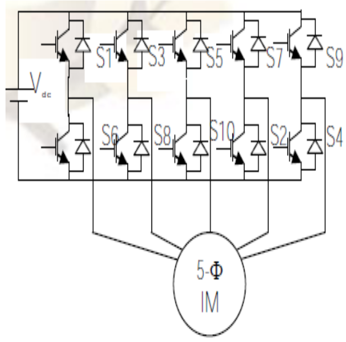


Figure 1: Basic Circuit Topology of Inverter Fed Five phase Induction Motor

In multiphase inverter we can generate n number of phase, as each leg of the inverter represent the phase, thus by increase the number of leg in the inverter we can increase the number of phases. For the five phase motor we require five leg inverter. The input to the inverter is a dc supply. The topology of five phase inverter is shown below

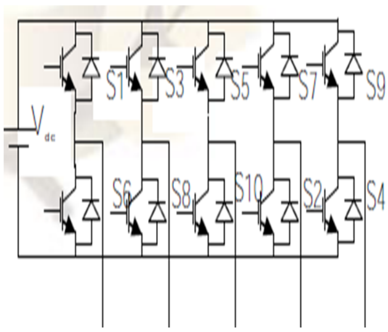


Figure 2: Five Phase Inverter

In five phase inverter three switches from the upper switches and two from the lower switches are turned on at a time and vice versa. The two switches which form the leg of the inverter are complimentary to each other, for example when switch S1 is on Switch S6 is off so as to avoid short circuit. The switching sequence & the mode of operation of a five phase inverter are shown below:-

Mode	Switches ON	Terminal polarity
9	1,7,8,9,10	$A^+B^-C^-D^+E^-$
10	8,9,10,1,2	$A^+B^-C^-D^-E^+$
1	9,10,1,2,3	$A^+B^+C^-D^-E^+$
2	10,1,2,3,4	$A^+B^+C^-D^-E^-$
3	1,2,3,4,5	$A^+B^+C^+D^-E^-$
4	2,3,4,5,6	$A^-B^+C^+D^-E^-$
5	3,4,5,6,7	$A^-B^+C^+D^+E^-$
6	4,5,6,7,8	$A^-B^-C^+D^+E^-$
7	5,6,7,8,9	$A^-B^-C^+D^+E^+$
8	6,7,8,9,10	$A^-B^-C^-D^+E^+$

Figure 3: Mode Of Operation Of Five Phase Inverter

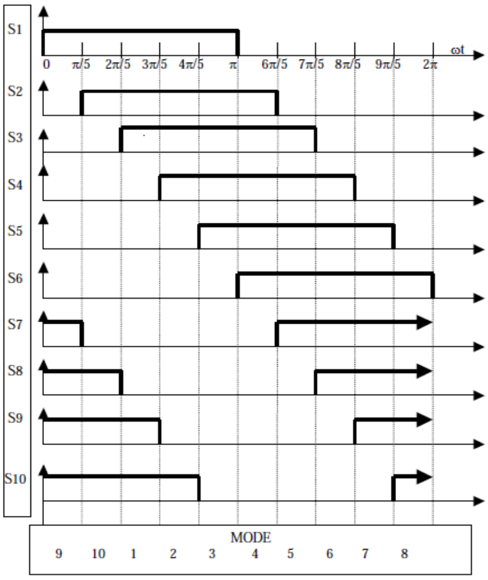


Figure 4: Switching Sequeance Of Five Phase Inverter

Sinosoidal pulse width modulation (SPWM) techique is used to generate the pulses power electronic switch i.e. IGBT. In this technique a carrier wave is compared with the sine wave. Simulink model of SPWM technique & its output is shown below:-

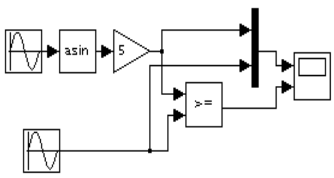


Figure 5: Simulink Model of SPWM Technique

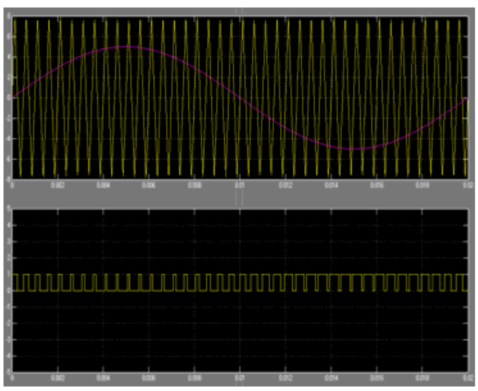


Figure 6: Output of SPWM Technique

9. Five Phase Induction Motor

The voltage and torque equation that describe the dynamic behavior of an induction motor are time varying. The equations involved have some complexity; therefore change of variable can be used to reduce the complexity of these equations by eliminating all time varying inductance from the voltage equation of the machine. By this approach a poly phase winding can be reduce to a set of two phase winding i.e. the stator and rotor variables of the induction machine are transferred to a reference frame which may rotate at angular speed or remain stationary.

10. Dynamic Equations

The output voltage of the inverter is the supply to the induction motor; these voltages are then transformed in arbitrary reference frame by eq-(1). The dynamic equation of five phase induction motor is shown below:

$$\begin{bmatrix} V_q \\ V_d \\ V_x \\ V_y \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{5}\right) & \cos\left(\theta-\frac{4\pi}{5}\right) & \cos\left(\theta+\frac{4\pi}{5}\right) & \cos\left(\theta+\frac{2\pi}{5}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{5}\right) & \sin\left(\theta-\frac{4\pi}{5}\right) & \sin\left(\theta+\frac{4\pi}{5}\right) & \sin\left(\theta+\frac{2\pi}{5}\right) \\ \cos\theta & \cos\left(\theta+\frac{4\pi}{5}\right) & \cos\left(\theta-\frac{2\pi}{5}\right) & \cos\left(\theta+\frac{2\pi}{5}\right) & \cos\left(\theta-\frac{4\pi}{5}\right) \\ \sin\theta & \sin\left(\theta+\frac{4\pi}{5}\right) & \sin\left(\theta-\frac{2\pi}{5}\right) & \sin\left(\theta+\frac{2\pi}{5}\right) & \sin\left(\theta-\frac{4\pi}{5}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix}$$

…………….. (1)

$$v_{ds} = R_s i_{ds} - \omega_a \psi_{qs} + p\psi_{ds}$$
$$v_{qs} = R_s i_{qs} + \omega_a \psi_{ds} + p\psi_{qs}$$
$$v_{xs} = R_s i_{xs} + p\psi_{xs}$$
$$v_{ys} = R_s i_{ys} + p\psi_{ys}$$
$$v_{os} = R_s i_{os} + p\psi_{os}$$

...……. (2)

$$v_{dr} = R_r i_{dr} - (\omega_a - \omega)\psi_{qr} + p\psi_{dr}$$
$$v_{qr} = R_r i_{qr} + (\omega_a - \omega)\psi_{dr} + p\psi_{qr}$$
$$v_{xr} = R_r i_{xr} + p\psi_{xr}$$
$$v_{yr} = R_r i_{yr} + p\psi_{yr}$$
$$v_{or} = R_r i_{or} + p\psi_{or}$$

…………… (3)

Equation 2 gives the stator side voltage while Equation 3 gives the rotor side equation.

$$\psi_{ds} = (L_{ls} + L_m) i_{ds} + L_m i_{dr}$$
$$\psi_{qs} = (L_{ls} + L_m) i_{qs} + L_m i_{qr}$$
$$\psi_{xs} = L_{ls} i_{xs}$$
$$\psi_{ys} = L_{ls} i_{ys}$$
$$\psi_{os} = L_{ls} i_{os}$$

…………………………
…… (4)

Eq-(4) gives the flux equation of stator side of five phase induction motor.

$$\begin{aligned}
\psi_{dr} &= (L_{lr} + L_m) i_{dr} + L_m i_{ds} \\
\psi_{qr} &= (L_{lr} + L_m) i_{qr} + L_m i_{qs} \\
\psi_{xr} &= L_{lr} i_{xr} \\
\psi_{yr} &= L_{lr} i_{yr} \\
\psi_{or} &= L_{lr} i_{or}
\end{aligned} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Eq-(5) gives the flux equation of rotor side of five phase induction motor.

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

$$T_e = \frac{5}{2}\left(\frac{P}{2}\right)\frac{1}{w_b}(\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}) \quad \ldots\ldots\ldots (6)$$

$$\omega_r = \int \frac{P}{2J}(T_e - T_L) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where P is the number of Poles; J moment of Inertia; T_L Load Torque;

T_e Electromechanical Torque; ω_r Rotor Speed.

11. MATLAB Model of Inverter & Induction Motor

5.1 Five Leg Inverter Model

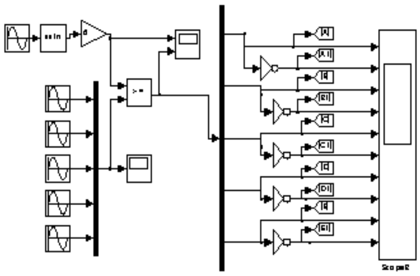


Figure 7: Simulation model of SPWM technique for five leg inverter

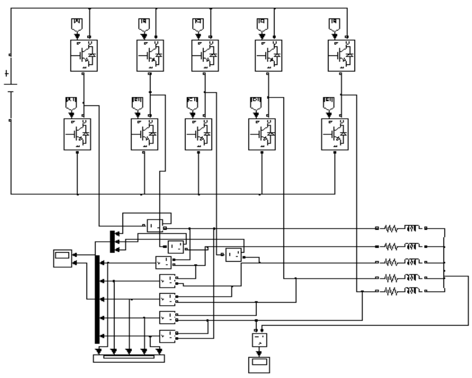


Figure 8: Five Phase Inverter with R-L Load

5.1.1 Output of Five Leg Inverter

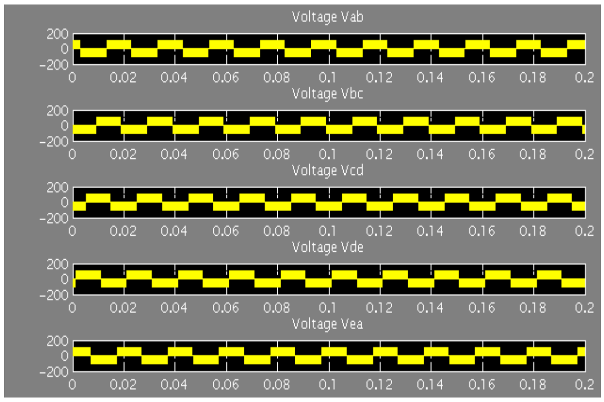


Figure 9: Output Line Adjacent Voltage

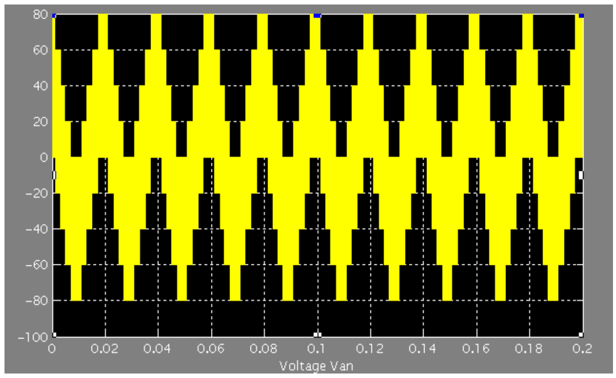


Figure 10: Output Phase Voltage

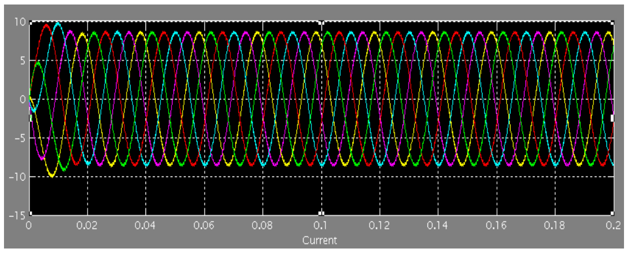


Figure 11: Output Current

5.2 Five Phase Induction Motor model

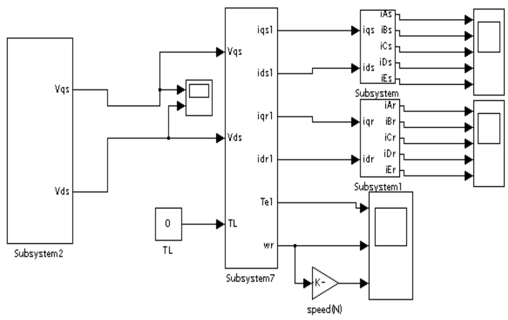


Figure 12: Five Phase Model of Induction Motor

In this model simulation starts with generation of five phase supply which is obtained by using five leg inverter, the output of five leg inverter is used as the supply to the five phase induction motor. Spwm technique is used to generate the pulses for the switches used in iverter. The five phase supply of the induction motor is transformed into d-q axis using transformation equation-(1) which is shown in figure 14&15. Once the supply voltage is converted into V_q &V_d

equation (4-7) are applied to obtain i_{qs}, i_{ds}, i_{qr}, i_{dr}, T_e, rotor speed which is shown in figure 16-23.

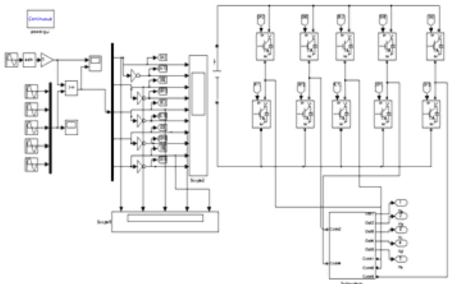


Figure 13: Inverter model used to provide supply to the Induction motor

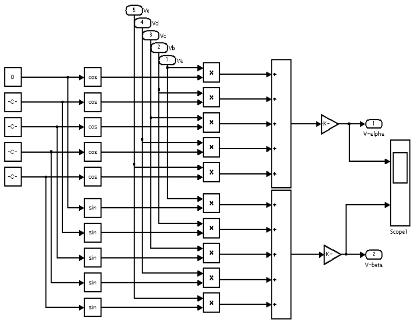


Figure 14: Conversion Model of Supply Voltage To arbitrary reference Frame

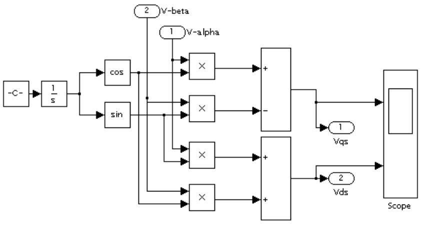


Figure 15: Conversion Model of Supply Voltage To arbitrary reference Frame

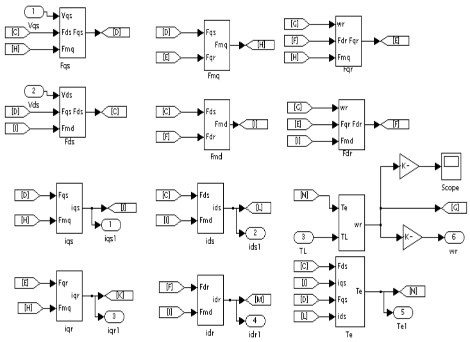


Figure 16: Structure of block to calculate i_{qs}, i_{ds}, i_{qr}, i_{dr}, T_e, rotor speed using Eq(2-7)

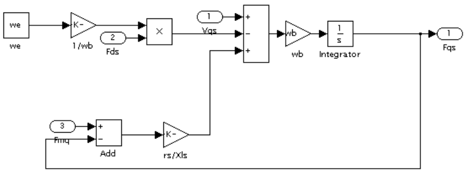


Figure 17: Internal Structure to Calculate Flux-qs

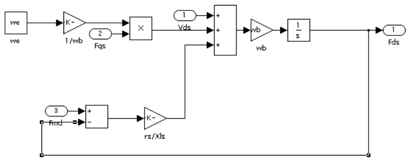


Figure 18: Internal Structure to Calculate Flux-ds

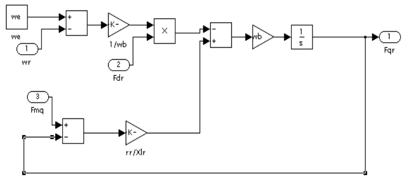


Figure 19: Internal Structure to Calculate Flux-qr

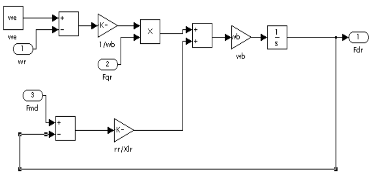


Figure 20: Internal Structure to Calculate Flux-dr

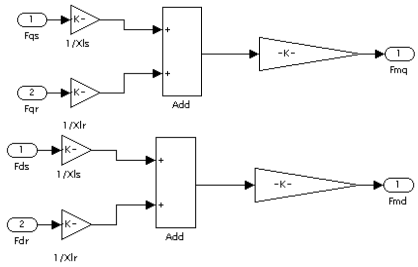


Figure 21: Internal Structure to calculate Mutual Flux-q & mutual Flux-d

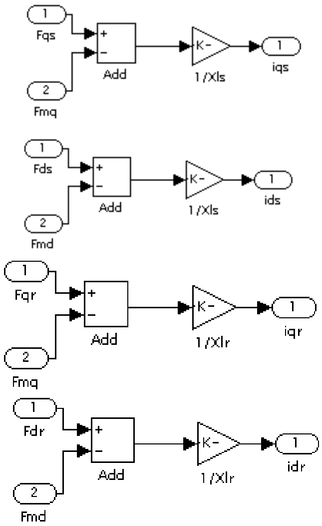
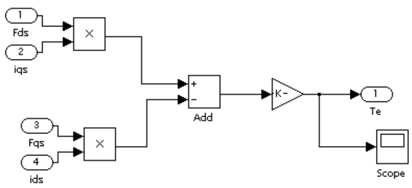


Figure 22: Internal Structure to Calculate i_{qs}, i_{ds}, i_{qr}, i_{dr}



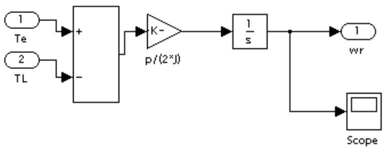


Figure 23: Internal Structure to Calculate Torque and Rotor Speed

12. Results of Five Phase induction Motor Fed From inverter

Induction Motor shown in the model has been tested for:

Hp =3;
Pole =4;
Inverter Voltage =100Vdc;
Frequency =50Hz;
Stator Resistance =1.26;
Rotor Resistance =1.03;
Stator Impedance =1.495;
Rotor Impedance =0.5340;
Mutual Impedance =47.595;
Moment of Inertia =0.0040;
Results after simulation are;

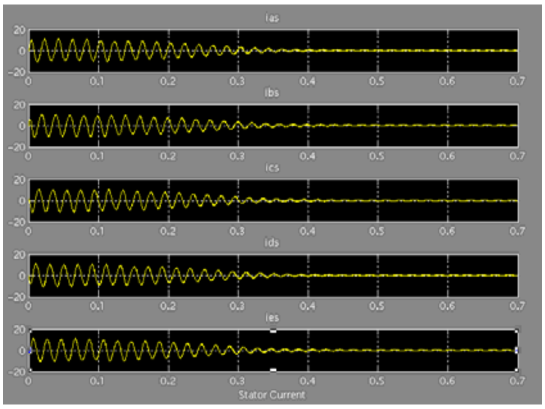


Figure 24: Stator Current

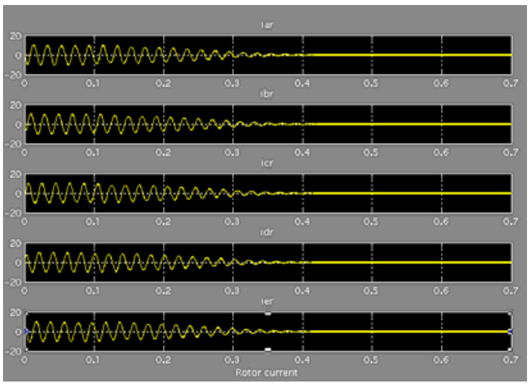


Figure 25: Rotor Current

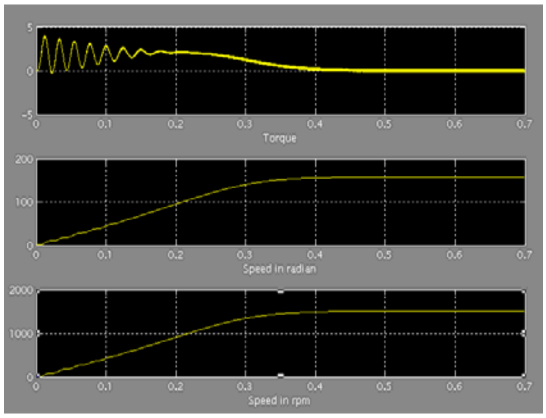


Figure 26: Torque And Rotor Speed

13. Conclusion

In this paper Implementation and Dynamic simulation of a five phase induction motor fed from five level inverter using Matlab is studied. The model was tested for 3hp motor, 50Hz. The result obtain are satisfactory.

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