

## Modeling and Simulation of Five Phase Inverter Fed Im Drive and Three Phase Inverter Fed Im Drive

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### ABSTRACT

Whenever Three-Phase Induction Motor is in running condition, there is a problem which occurs due to the ripple torque & harmonics. This disturbs the smooth operation of the motor and it also increases the amount of heat generated in motor. The ripple content can be smoothed by supplying the motor with multi phase supply greater than three phase supply. Even number phase selection should be avoided, because it degrades the performance of motor as poles coincide with each other. So, Five Phase Supply/Odd Phases may be preferred. Here we propose a step by step simulink implementation of Three-Phase inverter drive and Five-Phase inverter drive. Five-Leg Inverter and Three leg inverter is a converter converts DC to variable AC (i.e., variable voltage and variable frequency). Output of the five leg inverter and Three leg inverter is controlled by SPWM control technique method. It is highly economical, has more Efficiency and fully controllable.

**Keywords** – Five Phase dq Induction Motor, Five phase SPWM Inverter, Three phase dq Induction Motor, Three phase SPWM Inverter.

### I. INTRODUCTION

Three-phase Induction motors have various advantages such as simple construction, reliable, rugged, low maintenance cost and lower manufacturing cost which has made induction motor popular to be used in many industrial applications. The major problem arises in this motor is their speed control as it is complicated in industrial drive applications [1-6]. However, with the advent of cheap and fast switching power electronics devices not only the control of induction machine became easier and flexible but also the number of phases of machine became a design parameter. Multi-phase machines (more than three-phases) are found to possess several advantages over three-phase machines such as lower torque pulsation [7-8], higher torque density [1][2][6], and lower current ripple [1],[6]. Thus multi-phase order machines are normally considered for niche application areas such as ship propulsion, „more electric aircraft“, and electric/hybrid electric vehicles etc. Detailed reviews on the research on multiphase machines are presented in [7-8]. Their applications are still limited to the lower end of the high-power range due to the limitations on the ratings of the gate-turn-off-type semiconductor power devices. To achieve a high power rating in such systems, is the multiphase inverter-fed multiphase (in excess of three) induction machine drive system. In addition to enhancing the power rating, a multiphase system also has the merit of high reliability at the system level. In particular, with loss of one or more of the stator winding

excitation sets, a multiphase induction machine can continue to be operated with an asymmetrical winding structure and unbalanced excitation.[2][5][6].

Here we focused on a difference between Three-Phase inverter drive and Five-Phase inverter drive. Inverter is a converter converts DC to variable AC (i.e., variable voltage and variable frequency). Some controller is used to control the induction motor and output of the five leg inverter and three leg inverter is controlled by PWM control technique method. A comparative analysis is made on different aspects.

### A. INDUCTION MOTOR DQ MODEL

#### B. Three Phase Induction Motor

The parameter equations (such as voltage and torque) that describe the dynamic behavior of an induction motor are time-varying in nature. Such equations involve complexity while solving such differential equations. A change of variables from time varying to time invariant can be used to minimize the complexity from the voltage equations of motor due to relative motion of electric circuit. By this technique, a multi-phase winding can be reduced to a set of two phase windings (q-d) which are quadrature to each other. In other words, the stator and rotor variables (voltages, flux linkages and currents) of an induction motor are transferred to arbitrary reference frame, which may be rotating with some angular velocity or stay stationary.

The dynamic analysis of the induction motor in the arbitrary reference frame has been widely used as a standard simulation. Matlab/Simulink has an advantage over other machine simulators in modeling the induction motor using dq0 axis transformation. Every equation in the model equations can be easily implemented in block so that all the machine variables can be used for control purposes.

The flux linkages can be as follows

$$\frac{dF_{qs}}{dt} = \omega_b \left[ V_{qs} - \frac{\omega_s}{\omega_b} F_{ds} + \frac{R_s}{X_{ls}} (F_{mq} - F_{qs}) \right] \dots\dots\dots(1)$$

$$\frac{dF_{ds}}{dt} = \omega_b \left[ V_{ds} + \frac{\omega_s}{\omega_b} F_{qs} + \frac{R_s}{X_{ls}} (F_{md} - F_{ds}) \right] \dots\dots\dots(2)$$

$$\frac{dF_{qr}}{dt} = -\omega_b \left[ \frac{(\omega_s - \omega_r)}{\omega_b} F_{dr} + \frac{R_r}{X_{lr}} (F_{qr} - F_{mq}) \right] \dots\dots\dots(3)$$

$$\frac{dF_{dr}}{dt} = -\omega_b \left[ -\frac{(\omega_s - \omega_r)}{\omega_b} F_{qr} + \frac{R_r}{X_{lr}} (F_{dr} - F_{md}) \right] \dots\dots\dots(4)$$

Where

$$F_{md} = X_{ml} \left[ \frac{F_{ds}}{X_{ls}} + \frac{F_{dr}}{X_{lr}} \right] \dots\dots\dots(6)$$

$$F_{mq} = X_{ml} \left[ \frac{F_{qs}}{X_{ls}} + \frac{F_{qr}}{X_{lr}} \right] \dots\dots\dots(5)$$

$$X_{ml} = \frac{1}{\left( \frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}} \right)} \dots\dots\dots(7)$$

Then the values of the currents;

$$i_{qs} = \frac{1}{X_{ls}} (F_{qs} - F_{mq}) \dots\dots\dots(8)$$

$$i_{ds} = \frac{1}{X_{ls}} (F_{ds} - F_{md}) \dots\dots\dots(9)$$

$$i_{qr} = \frac{1}{X_{lr}} (F_{qr} - F_{mq}) \dots\dots\dots(10)$$

$$i_{dr} = \frac{1}{X_{lr}} (F_{dr} - F_{md}) \dots\dots\dots(11)$$

Based on the above equations, the torque and rotor speed can be determined as follows:

$$T_s = \frac{3}{2} \left( \frac{P}{2} \right) \frac{1}{\omega_b} (F_{ds} i_{qs} - F_{qs} i_{ds}) \dots\dots\dots(12)$$

$$\omega_r = \int \frac{P}{2J} (T_s - T_L) \dots\dots\dots(13)$$

The three-phase stator voltages of an induction machine under balanced conditions can be expressed as:

$$V_a = \sqrt{2} V_{rms} \sin(\omega t) \dots\dots\dots(14)$$

$$V_b = \sqrt{2} V_{rms} \sin\left(\omega t - \frac{2\pi}{3}\right) \dots\dots\dots(15)$$

$$V_c = \sqrt{2} V_{rms} \sin\left(\omega t + \frac{2\pi}{3}\right) \dots\dots\dots(16)$$

These three-phase voltages are transferred to a synchronously rotating reference frame in only two phases (d-q axis transformation). This can be done using the following two equations.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \dots\dots\dots(17)$$

Then, the direct and quadrature axes voltages are

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \dots\dots\dots(18)$$

The values of the stator and rotor currents in three-phase system are calculated using the following transformation:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \dots\dots\dots(19)$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \dots\dots\dots(20)$$

**B. Five Phase Induction Motor**

Modeling of five phase induction motor is nearly same as that of the three phase induction motor hence before going for the modeling of five phase induction motor it was necessary to study the modeling of three phase induction motor. For five phase induction motor five phase supply is required which is then transformed into arbitrary reference frame. The only difference between the five-phase dq induction motor model and three phase dq induction motor model, given with (22)-(32), and the corresponding three phase dq motor model is the presence of x-y component equations in (27),(28),(29) and (30). Rotor x-y components are fully decoupled from d-q axes components and one

from the other. Since rotor winding is short-circuited or closed,  $x$ - $y$  components cannot see in the rotor winding. Zero sequence component equations for both stator and rotor can be removed from further consideration due to short-circuited rotor winding and star connection of the stator winding. Finally, since stator  $x$ - $y$  components are fully decoupled from  $d$ - $q$  components and one from the other and can be removed from further consideration. This means that the dq model of the five-phase induction motor in an arbitrary reference frame is same as the dq model of a three phase induction motor.

Therefore before going for the modeling of five phase induction motor we will first design inverter so as to get five phase supply. Equations (21 to 32) shows the mathematical equation involved in modeling of five phase induction motor whereas model of five phase induction is shown below, since modeling of five phase induction motor require five phase supply which is generated using inverter.

Five Phase Stator Voltage of induction machine under balanced condition is expressed as: -

$$V_a = \sqrt{2}V_{rms} \sin \omega t \quad (21)$$

$$V_b = \sqrt{2}V_{rms} \sin \left( \omega t - \frac{2\pi}{5} \right) \quad (22)$$

$$V_c = \sqrt{2}V_{rms} \sin \left( \omega t - \frac{4\pi}{5} \right) \quad (23)$$

$$V_d = \sqrt{2}V_{rms} \sin \left( \omega t + \frac{4\pi}{5} \right) \quad (24)$$

$$V_e = \sqrt{2}V_{rms} \sin \left( \omega t + \frac{2\pi}{5} \right) \quad (25)$$

Transformation equation to transform machine variable to the variable in the arbitrary reference frame is expressed as: -

$$\begin{bmatrix} V_d \\ V_q \\ V_{xs} \\ V_{ys} \\ V_{os} \end{bmatrix} = \begin{bmatrix} \cos \theta & \cos \left( \theta - \frac{2\pi}{5} \right) & \cos \left( \theta - \frac{4\pi}{5} \right) & \cos \left( \theta + \frac{4\pi}{5} \right) & \cos \left( \theta + \frac{2\pi}{5} \right) \\ \sin \theta & \sin \left( \theta - \frac{2\pi}{5} \right) & \sin \left( \theta - \frac{4\pi}{5} \right) & \sin \left( \theta + \frac{4\pi}{5} \right) & \sin \left( \theta + \frac{2\pi}{5} \right) \\ \cos \theta & \cos \left( \theta + \frac{4\pi}{5} \right) & \cos \left( \theta - \frac{2\pi}{5} \right) & \cos \left( \theta + \frac{2\pi}{5} \right) & \cos \left( \theta - \frac{4\pi}{5} \right) \\ \sin \theta & \sin \left( \theta + \frac{4\pi}{5} \right) & \sin \left( \theta - \frac{2\pi}{5} \right) & \sin \left( \theta + \frac{2\pi}{5} \right) & \sin \left( \theta - \frac{4\pi}{5} \right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} \quad (26)$$

$$v_{ds} = R_s i_{ds} - \omega_a F_{qs} + pF_{ds}$$

$$v_{qs} = R_s i_{qs} + \omega_a F_{ds} + pF_{qs}$$

$$v_{xs} = R_s i_{xs} + pF_{xs}$$

$$v_{ys} = R_s i_{ys} + pF_{ys}$$

$$v_{os} = R_s i_{os} + pF_{os} \quad (27)$$

$$\begin{aligned} v_{dr} &= R_r i_{dr} - (\omega_a - \omega) F_{qr} + pF_{dr} \\ v_{qr} &= R_r i_{qr} + (\omega_a - \omega) F_{dr} + pF_{qr} \\ v_{xr} &= R_r i_{xr} + pF_{xr} \\ v_{yr} &= R_r i_{yr} + pF_{yr} \\ v_{or} &= R_r i_{or} + pF_{or} \end{aligned} \quad (28)$$

$$F_{ds} = (X_{ls} + X_m) i_{ds} + X_m i_{dr}$$

$$F_{qs} = (X_{ls} + X_m) i_{qs} + X_m i_{qr}$$

$$F_{xs} = (X_{ls}) i_{xs}$$

$$F_{ys} = (X_{ls}) i_{ys}$$

$$F_{os} = (X_{ls}) i_{os} \quad (29)$$

$$F_{dr} = (X_{lr} + X_m) i_{dr} + X_m i_{ds}$$

$$F_{qr} = (X_{lr} + X_m) i_{qr} + X_m i_{qs}$$

$$F_{xr} = (X_{lr}) i_{xr}$$

$$F_{yr} = (X_{lr}) i_{yr}$$

$$F_{or} = (X_{lr}) i_{or} \quad (30)$$

The torque and rotor speed of five phase induction motor can be determined as follows:

$$T_e = \frac{5}{2} \left( \frac{P}{2} \right) \frac{1}{\omega_b} (F_{ds} i_{qs} - F_{qs} i_{ds}) \quad (31)$$

$$\omega_r = \int \frac{P}{2J} (T_e - T_L) \quad (32)$$

### C. Inverter Model

With the advancement in development of power electronics interest in multi-phase machine has been increased in last few years. Three phase supply is easy available but for multi-phase machine we require multiphase supply which was not possible before the development of power electronics. The main task of power electronics is to control and convert electrical power from one form to other. The power electronic converters are essentially power electronic circuit that converts voltage and current in one form into other form. In converter, at least one power semiconductor devices is used as a static switch. As each leg of the

converter represents phase, hence increasing the number of leg in the converter increases the number of phases.

SPWM technique is used for generation of pulses in which a carrier wave is compared with the sine wave. Simulation model of SPWM technique is shown in Fig.15 & corresponding output pulses waveform in Fig.16.

## II. MATLAB/SIMULINK IMPLEMENTATION

### A. Modeling of Three phase Induction Motor

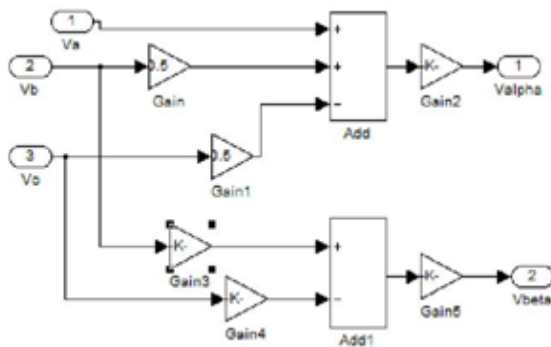


Fig.1. Computation of Park Transformation for three phase induction motor

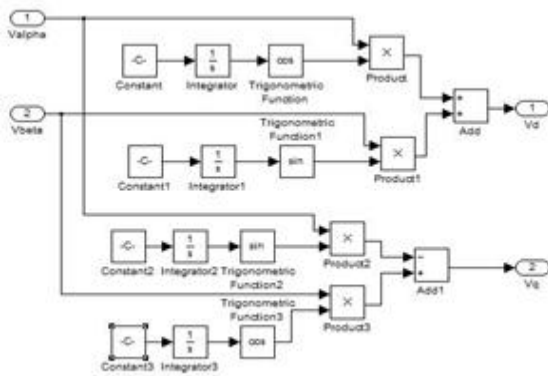


Fig.2. Computation of Clarke Transformation Equation

Once the stator voltage are transformed to d-q frame them we implement the flux linkage equations, current equations, torque equation and rotor speed equation so as to obtain current in terms of  $i_{qs}$ ,  $i_{ds}$ ,  $i_{qr}$ ,  $i_{dr}$  then we apply inverse Clark and Park transformation equation . The internal structure of induction motor d-q model is shown in fig.3.

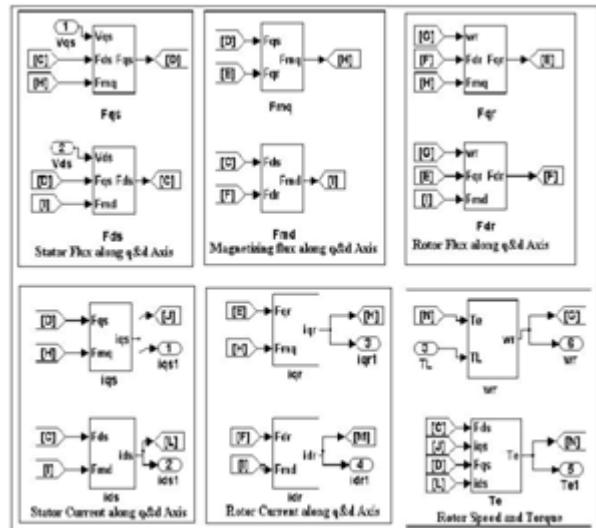
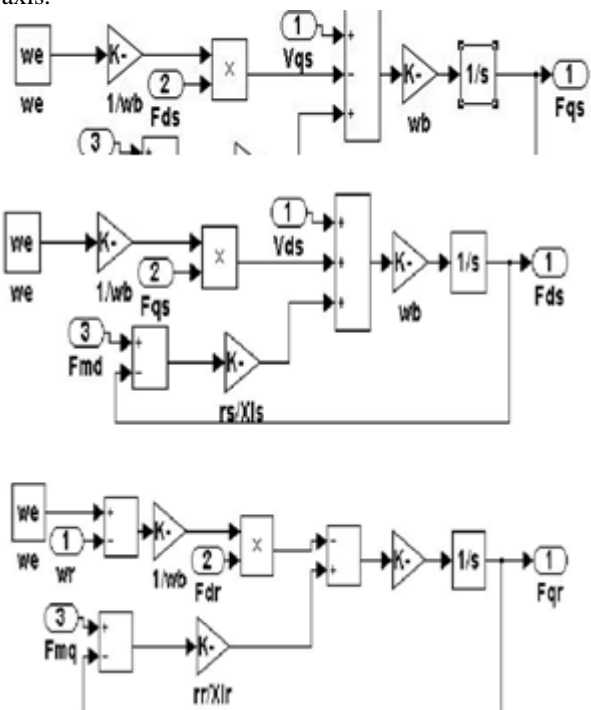


Fig.3. Internal structure of 3 phase induction motor d-q model.

Figure 4 shows the internal structure of stator and rotor flux linkage along q & d axis.



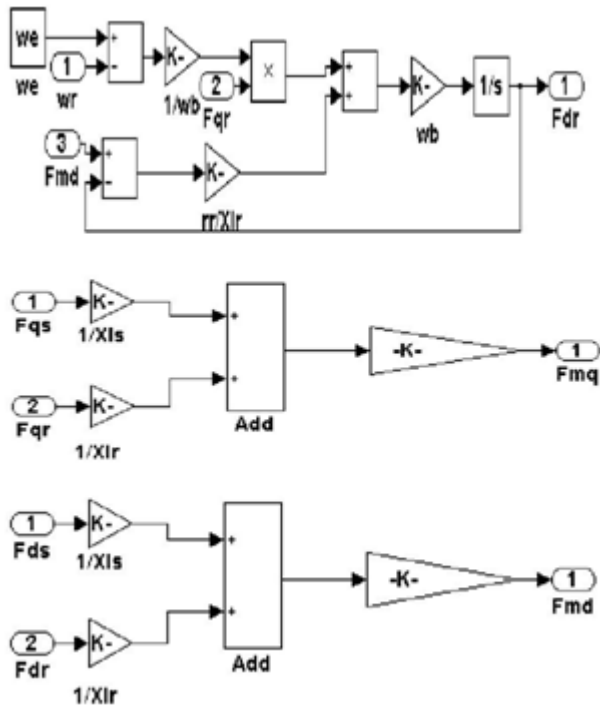


Fig. 4. Computation Of Stator & Rotor Flux Linkage along q & d Axis.

Figure 5 shows the internal structure of the Stator & rotor current Block along with the rotor speed and the electromagnetic torque.

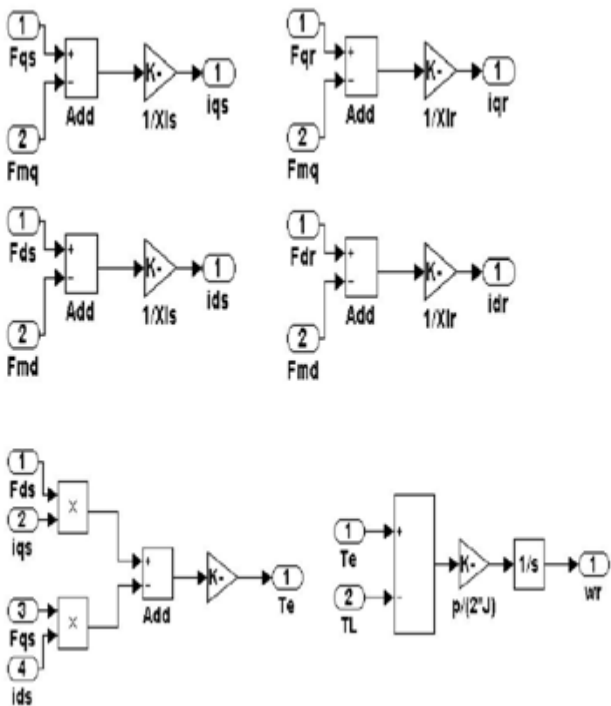


Fig.5. Computation of Current, Torque & Speed Equation (Eq. 16-18).

On implementing the Flux linkage, current, torque and rotor speed equation we get stator and

rotor current along d & q axis which is then again transformed using inverse Park and Clarke transformation to obtain  $I_{as}$ ,  $I_{bs}$ ,  $I_{cs}$  from  $I_{qs}$  &  $I_{ds}$ . The Output of modeling of three phase induction motor using three phase supply is shown below.

**B. Modeling of Five phase Induction Motor**

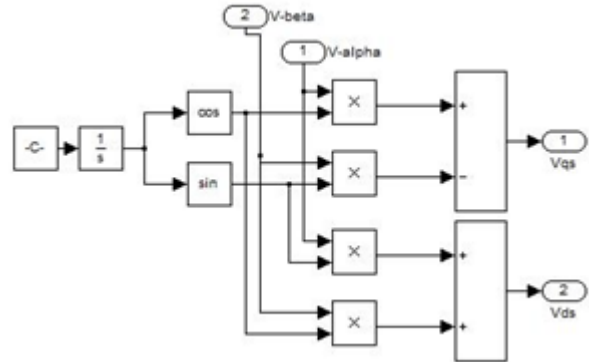


Fig.6. Computation of Clarke Transformation Equation

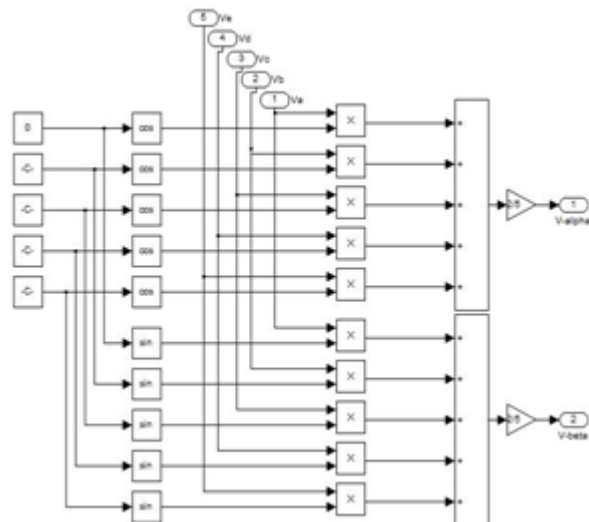


Fig.7. Computation of Park Transformation Equation for five phase induction motor

Once the stator voltage  $V_{abcde}$  are transformed to d-q frame then we implement the flux linkage equations, current equations, torque equation and rotor speed equation so as to obtain current in terms of  $i_{qs}$ ,  $i_{ds}$ ,  $i_{qr}$ ,  $i_{dr}$  then we apply inverse Clark and Park transformation equation. The internal structure of induction motor d-q model is shown Fig.8.

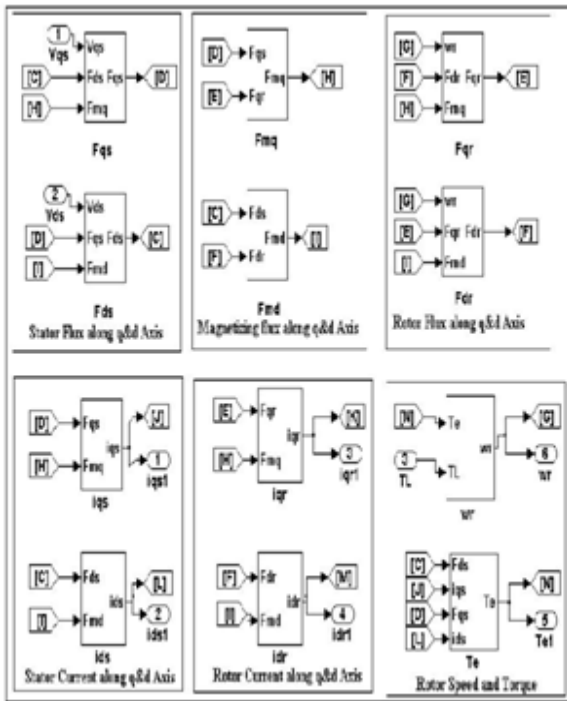


Fig.8. Internal Structure of Five Phase Induction Motor d-q Model.

The modeling of five phase induction motor is nearly same as that of three phase induction motor model. The five phase supply generated through the inverter is converted into  $d$  &  $q$  reference using parks and Clarke equation (Eq. 26 & 5). Later on implementing the flux linkage, current, torque and speed equation Eq. 27-32) as shown in figure 8 and at the end converting the  $d$  &  $q$  axis current to Stator and rotor current  $I_{as}$ ,  $I_{bs}$ ,  $I_{cs}$ ,  $I_{ds}$ ,  $I_{es}$ . Each block in internal structure of five phase induction motor are implemented in the same way as that of the three phase induction motor.

**C. Modeling of Three phase Inverter**

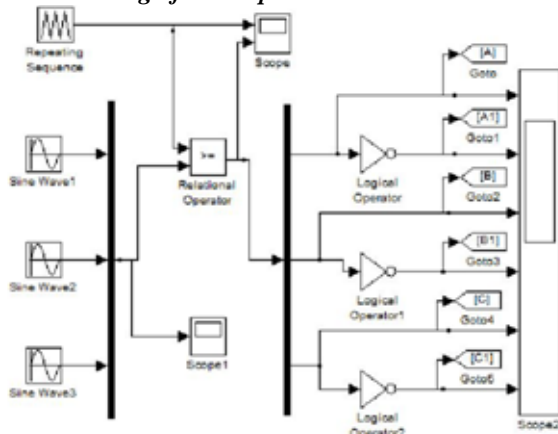


Fig.9. Simulation Model of SPWM Technique for Three Leg Inverter.

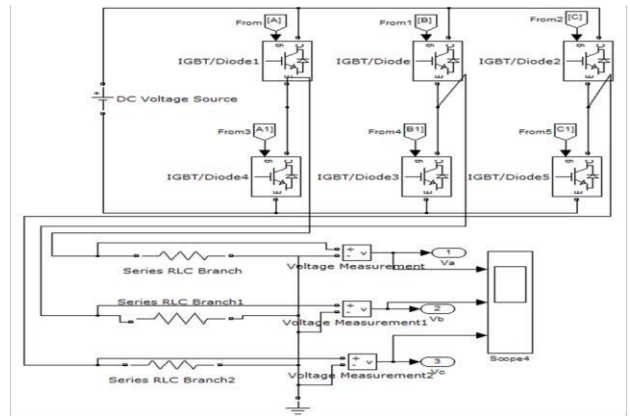


Fig.10. Simulink Model of Three Leg Inverter

**D. Modeling of Five phase Inverter**

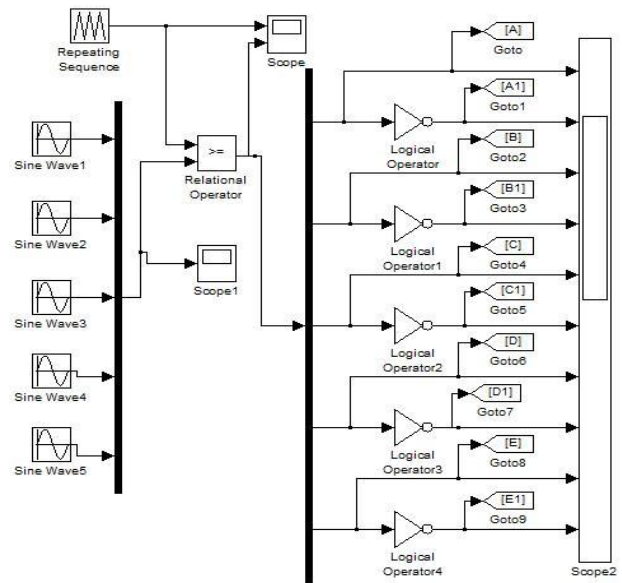


Fig.11. Simulation Model of SPWM Technique for Five Leg Inverter.

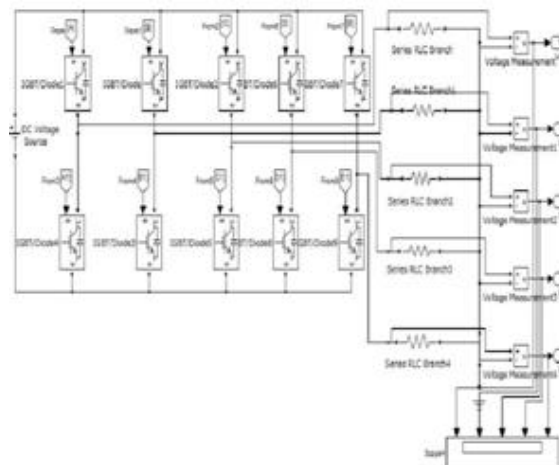


Fig.12. Simulink Model of Five Leg Inverter

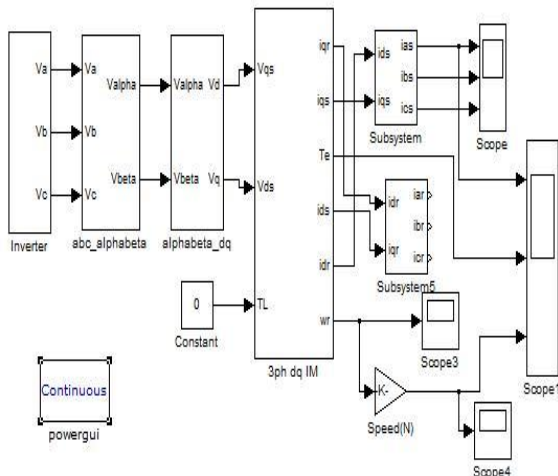


Fig.13. Three Phase Induction Motor Model.

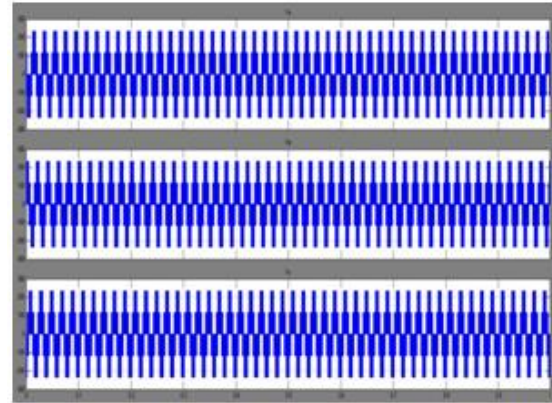


Fig.17. Output waveform of three phase inverter Stator Current

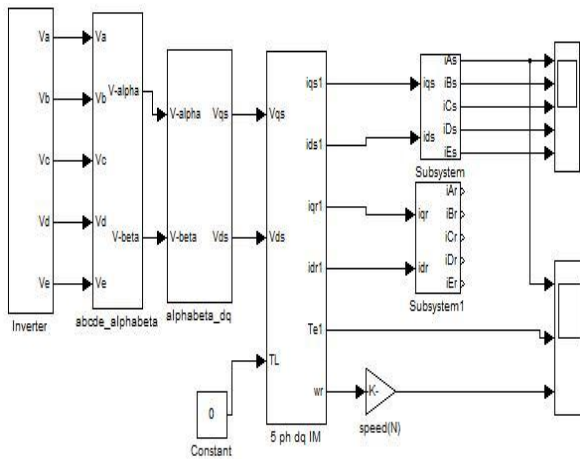


Fig.14. Five Phase Induction Motor Model.

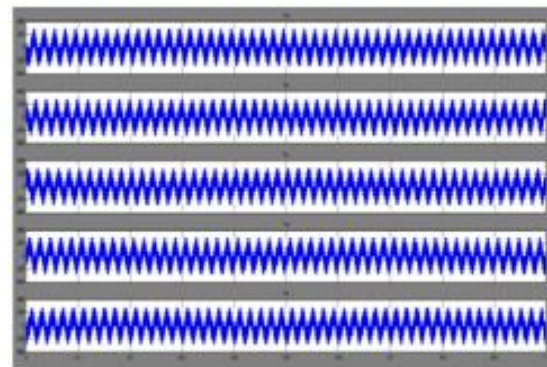


Fig.18. Output waveform of five phase inverter

### III. MATLAB/SIMULINK RESULTS

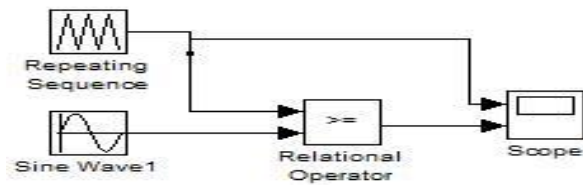


Fig.15. SPWM Technique

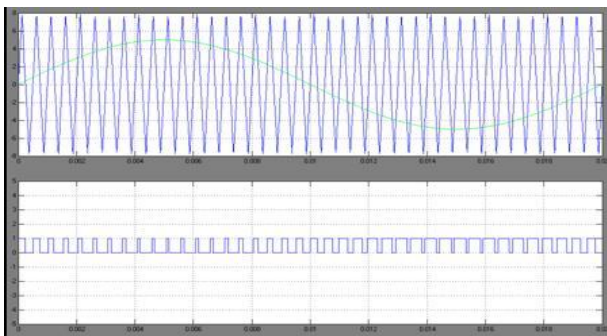


Fig.16. Pulses generated using SPWM Technique

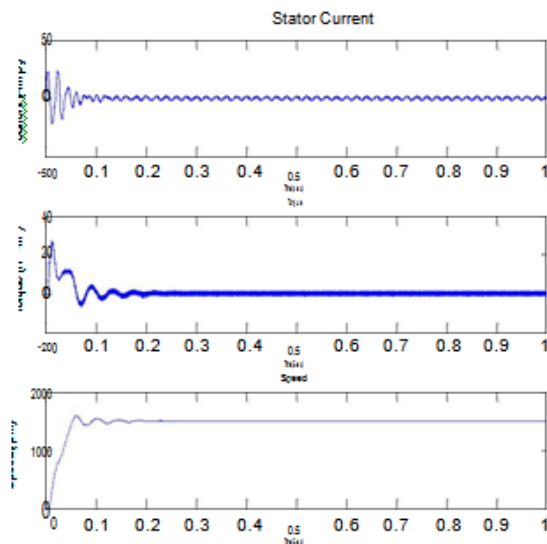


Fig.19. Output waveform of three phase inverter fed induction motor drive at No load

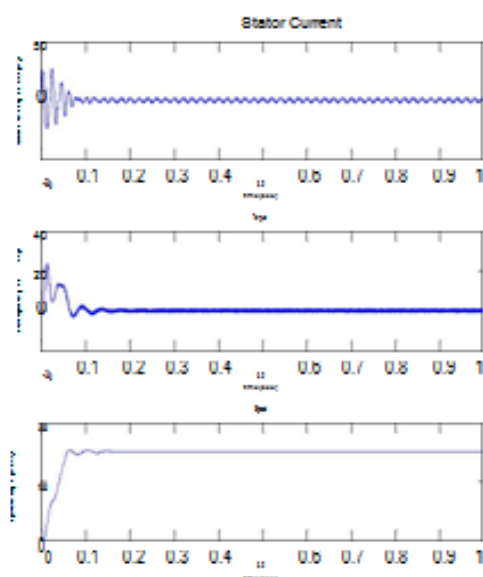


Fig.20. Output waveform of Five phase inverter fed induction motor drive at No load

#### IV. CONCLUSION

This paper presents a complete simulation model to simulate a three phase and five-phase inverter fed induction motor drive. The simulation model is developed using simpower system block sets of the Matlab/Simulink software. Step by step model development is elaborated. A detailed simulation results are presented to validate the modeling procedure. The ripple content of various parameters(current, torque and speed) can be smoothened by supplying the motor with Five phase supply than three phase supply as shown in waveform.

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