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# Modified Multiphase Induction Motor with High Starting Torque

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**ABSTRACT:** This paper present the development of prototype six phase induction motor using mat lab software and proved that the torque of this motor is superior than that of the three phase induction motor. Three phase induction motors are standard because it's cost, robustness, reliability and maintenance free operation. To improve the system performance facing the limits on power ratings of the power supplies and semiconductors motivates the phase numbers more than the conventional three phases and machine output power can be divided into two or more solid state inverters of the same power limits. More phases bring to control additional degree of freedom for the further improvements of the drive system.

**INDEXTERMS**—six phase induction motor, reliability, torque

## I.INTRODUCTION

In the environment of industrial drives, the Variable speed induction motors replaces DC motors drives because the DC motors have the inbuilt disadvantage of mechanical commutator, and brushes which undergo wear and tear with decade of time. In the fast decade years the technological opportunities in the area of multi-phase Induction Motors undergo important evolution but soft control of torque and speed of these multi-phase induction Motors have forever been a confront to the electrical engineers. The six phase AC induction Motors are used for high power high current industrial drive system. The inherent advantages of multilevel inverter fed six phase induction Motors are "improved torque density, enhanced system reliability, reducing the rotor harmonic current losses, lowering the dc-link current harmonics, reduced torque ripples, reduced harmonic power loss, better power distribution per phase, improved power characteristics and

improved efficiency" When compared with the three phase induction motors. The six phase induction Motors have several application were high power, high current and high starting torque are needed such as "Electric traction, hybrid electric vehicles, electric ship propulsion, and the more electric air craft."

## II.MODELING OF SIX PHASE INDUCTION MOTOR

The equations that describe the behavior of the six-phase induction machine when expressed in the arbitrary reference frame are listed in equations shown below:

$$v_{q1} = r_1 I_{q1} + p\lambda_{q1} + \omega_k \lambda_{d1} \quad (1)$$

$$v_{d1} = r_1 I_{d1} + p\lambda_{d1} - \omega_k \lambda_{q1} \quad (2)$$

$$v_{01} = r_1 I_{01} + p\lambda_{01} \quad (3)$$

$$v_{qr} = r_r I_{qr} + p\lambda_{qr} - (\omega_k - \omega_r)\lambda_{dr} \quad (4)$$

$$v_{dr} = r_r I_{dr} + p\lambda_{dr} - (\omega_k - \omega_r)\lambda_{qr} \quad (5)$$

$$v_{or} = r_r I_{0r} + p\lambda_{0r} \quad (6)$$

$$v_{q2} = r_2 I_{q2} + p\lambda_{q2} + \omega\lambda_{d2} \quad (7)$$

$$v_{q2} = r_2 I_{q2} + p\lambda_{d2} + \omega\lambda_{q2} \quad (8)$$

$$v_{d2} = r_2 I_{02} + p\lambda_{02} \quad (9)$$

Where ω_k is the speed of the reference frame, ω _r is the rotor speed. Also, the expressions for stator and rotor flux linkages are:

$$\lambda_{q1} = (L_{11} - L_{lm})I_{q1} + L_{lm}(I_{q1} + I_{q2}) + L_m(I_{q1} + I_{q2} + I_{qr}) \quad (10)$$

$$\lambda_{d1} = \left(L_{11} - L_{lm}\right)I_{d1} + L_{lm}\left(I_{q1} + I_{q2}\right) + L_m\left(I_{q1} + I_{q2} + I_{dr}\right) \quad (11)$$

$$\lambda_{01} = L_{11}L_{01} + L_{lm}\left(I_{01} + I_{02}\right) \quad (12)$$

$$\lambda_{q2} = \left(L_{12} - L_{lm}\right)I_{q2} + L_{lm}\left(I_{q1} + I_{q2}\right) + L_m\left(I_{q1} + I_{q2} + I_{qr}\right) \quad (13)$$

$$\lambda_{d2} = \left(L_{12} - L_{lm}\right)I_{d2} + L_{lm}\left(I_{q1} + I_{q2}\right) + L_m\left(I_{q1} + I_{q2} + I_{dr}\right) \quad (14)$$

$$\lambda_{02} = L_{12}L_{02} + L_{lm}\left(I_{01} + I_{02}\right) \quad (15)$$

$$\lambda_{qr} = L_{lr}L_{qr} + L_{lm}\left(I_{q1} + I_{q2} + I_{qr}\right) \quad (16)$$

$$\lambda_{dr} = L_{lr}L_{dr} + L_{lm}\left(I_{d1} + I_{d2} + I_{dr}\right) \quad (17)$$

$$\lambda_{0r} = L_{lr}L_{0r} \quad (18)$$

The electromagnetic torque equation is written in terms of λ_md and λ_mq as:

$$T_e = \frac{3}{2}\frac{P}{2}\left[\lambda_{md}\left(I_{q1} + I_{q2}\right) - \lambda_{mq}\left(I_{q1} + I_{q2}\right)\right] \quad (19)$$

Similarly, the mechanical model of this machine comprises of the equation of the motor and the driven load, and this is usually represented as:

$$J\frac{2}{P}\frac{d\omega_r}{dt} = T_{em} - T_L \quad (20)$$

Where J is the inertia and TL is the load torque.

### III. Simulation Equations

The equations that describe the electrical and mechanical behavior of the machines contain mixed variables (flux linkages and current).of these two quantities could be eliminated from the differential equation by algebraic manipulations of equations (1)-(18). Thus, the currents when solved in terms of flux linkages are obtained as:

$$I_{d1} = \frac{1}{L_\lambda}\left[\left(L_{12} + L_{lm}\right)\lambda_{d1} - L_{f2}\lambda_{md} - L_{lm}\lambda_{d2} - L_{dq}\left(\lambda_{q2} - \lambda_{q12}\right)\right] \quad (21)$$

$$I_{q1} = \frac{1}{L_\lambda}\left[\left(L_{12} + L_{lm}\right)\lambda_{q1} - L_{f2}\lambda_{mq} - L_{lm}\lambda_{q2} - L_{dq}\left(\lambda_{d2} - \lambda_{d12}\right)\right] \quad (22)$$

$$I_{d2} = \frac{1}{L_\lambda}\left[\left(L_{12} + L_{lm}\right)\lambda_{d2} - L_{f2}\lambda_{md} - L_{lm}\lambda_{d1} - L_{dq}\left(\lambda_{q1} - \lambda_{mq}\right)\right] \quad (23)$$

$$I_{q2} = \frac{1}{L_\lambda}\left[\left(L_{12} + L_{lm}\right)\lambda_{q2} - L_{f2}\lambda_{mq} - L_{lm}\lambda_{q1} - L_{dq}\left(\lambda_{d1} - \lambda_{mq}\right)\right] \quad (24)$$

$$I_{qr} = \frac{\lambda_{qr} - \lambda_{mq}}{L_{Ir}} \quad (25)$$

$$I_{dr} = \frac{\lambda_{dr} - \lambda_{md}}{L_{Ir}} \quad (26)$$

$$\lambda_{md} = L_D\left[\lambda_{d1}L_{12} + \lambda_{d2}L_{11} - L_{Idq}\left(\lambda_{q2} - \lambda_{q1}\right)\right] \quad (27)$$

$$\lambda_{mq} = L_Q\left[\lambda_{q1}L_{12} + \lambda_{q2}L_{11} - L_{Idq}\left(\lambda_{d2} - \lambda_{d1}\right)\right] \quad (28)$$

$$L_D = \left[\frac{L_A}{L_m} + \left(L_{11} + L_{12}\right)\right]^{-1} \quad (29)$$

$$L_A = L_{11}L_{12} + L_{lm}\left(L_{11} + L_{12}\right) \quad (30)$$

$$L_Q = \left[\frac{L_A}{L_-} + \left(L_{11} + L_{12}\right)\right]^{-1} \quad (31)$$

Substituting equations (21)-(28) into (1) – (8) and solving the equation in the rotor reference frame, (that is ω_k becomes
ω_r) the integral form of the machine voltage and torque equations with flux linkage as state variables is given as:

$$\lambda_{d1} = \int\left[v_{d1} + \omega\lambda_{q1}\frac{R}{L_\lambda}\left\{\left(L_{12} + L_{lm}\right)\lambda_{d1} - L_{12}\lambda_{md} - L_{lm}\lambda_{d2} - L_{ldq}\left(\lambda_{q2} - \lambda_{nq}\right)\right\}\right] \quad (32)$$

$$\lambda_{q1} = \int\left[v_{q1} + \omega\lambda_{d1}\frac{R}{L_\lambda}\left\{\left(L_{12} + L_{lm}\right)\lambda_{q1} - L_{12}\lambda_{mq} - L_{lm}\lambda_{q2} - L_{ldq}\left(\lambda_{d2} - \lambda_{nd}\right)\right\}\right] \quad (33)$$

$$\lambda_{d2} = \int\left[v_{d2} + \omega\lambda_{q2}\frac{R}{L_\lambda}\left\{\left(L_{12} + L_{lm}\right)\lambda_{d2} - L_{11}\lambda_{md} - L_{lm}\lambda_{d1} - L_{ldq}\left(\lambda_{q1} - \lambda_{nq}\right)\right\}\right] \quad (34)$$

$$\lambda_{q2} = \int\left[v_{q2} + \omega\lambda_{d2}\frac{R}{L_\lambda}\left\{\left(L_{12} + L_{lm}\right)\lambda_{q2} - L_{11}\lambda_{mq} - L_{lm}\lambda_{q1} - L_{ldq}\left(\lambda_{d1} - \lambda_{nd}\right)\right\}\right] \quad (35)$$

$$\lambda_{dr} = \int\frac{r_r}{I_r}\left(\lambda_{dr} - \lambda_{md}\right) \quad (36)$$

$$\lambda_{qr} = \int\frac{r_r}{I_r}\left(\lambda_{qr} - \lambda_{mq}\right) \quad (37)$$

$$\omega_r = \frac{P}{2J}\int\left[T_{em} - T_L\right]dt \quad (38)$$

$$\theta_r = \int\omega_r dt \quad (39)$$

Thus equations (19), (21)-(39) essentially will be used to simulate the six phase (dual) split winding induction machine. These equations are arranged in integral form rather than in the differential form so as to avoid having spikes as a result of differentiation of signals with ripples.

### IV. Proposed Scheme

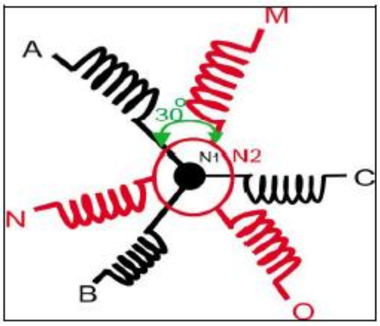


Fig.1.Winding disposition of six phase InductionMotor.

Fig.1. Shows winding arrangement of the six phase induction motor. The stator has the two identical three phase windings which has the phase displacement of 30 electrical degrees between them. The dual three phase groups named A, B, C group and M, N, O group have an angular separation of 30 electrical degrees between them.

The drive control scheme consists of model of two three phase inverters with 30 electrical degrees phase shift between them.

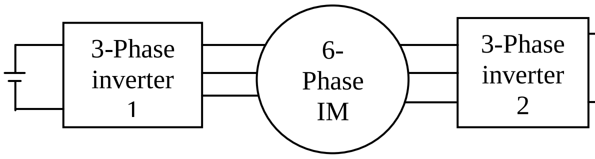


Fig .2.Dual inverter fed six phase induction motor.

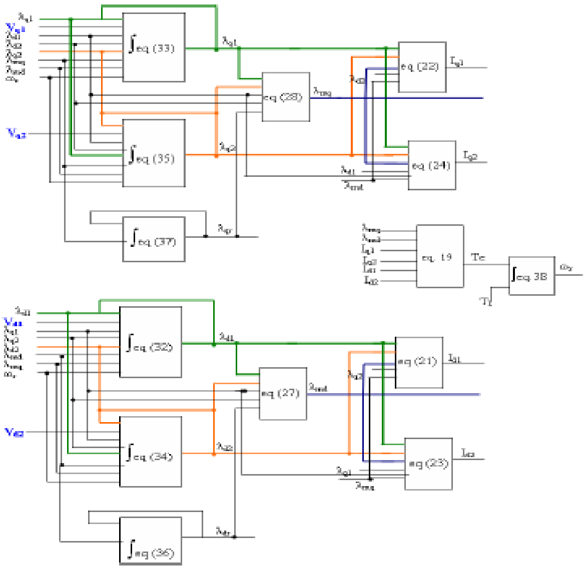

Fig.3. Flow diagram of the electrical part for the simulation of the six-phase machine.

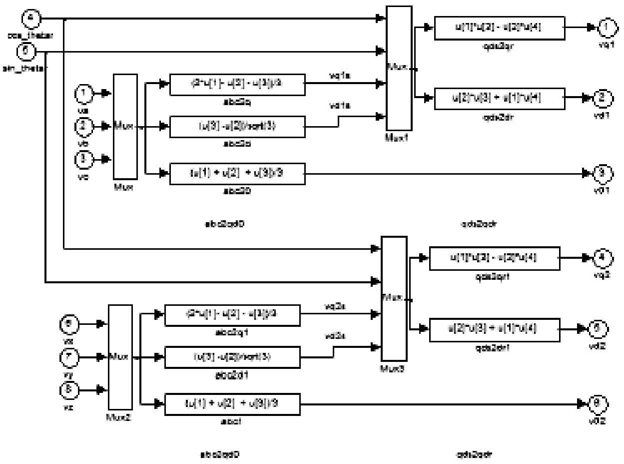

Fig.4. abc to dq transformation block.

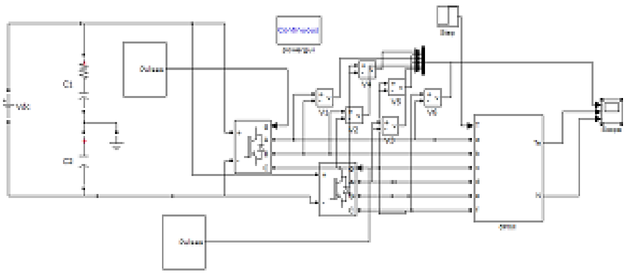

Fig.5. Simulation circuit of six phase induction motor.

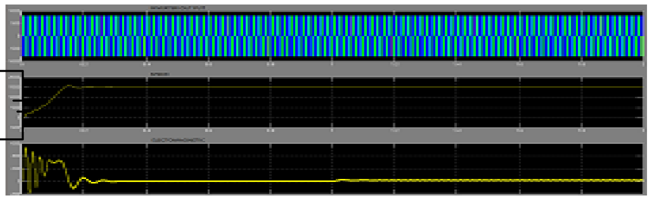

Fig.6.Out put wave form of six phase induction motor.

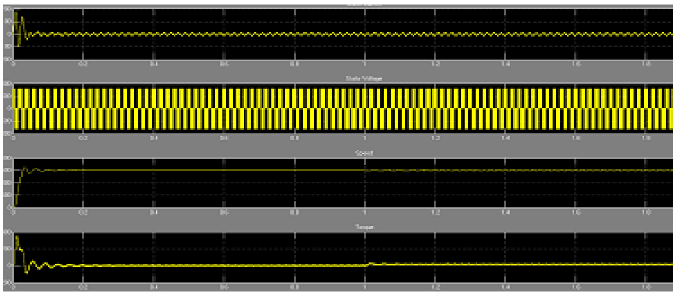

Fig.7.Out put wave form of three phase IM.

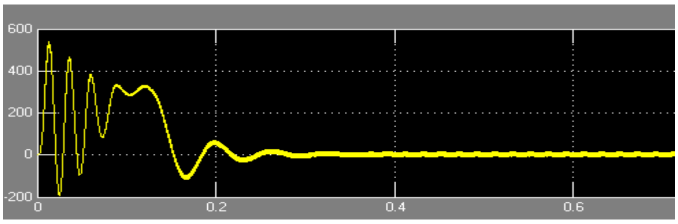


Fig.8.Torque of six phase IM.

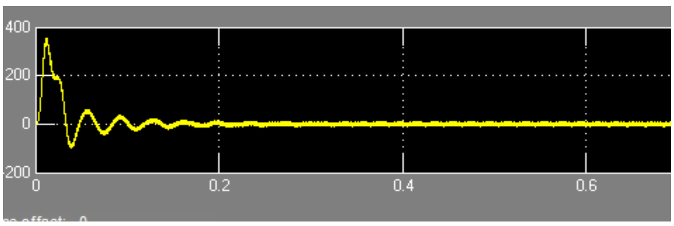


Fig.9. Torque of three Phase IM.

## V. Simulation Results And Discussion

Rectified voltage is fed to the two voltage source inverters and the output of the inverters is connected to the six phase induction motor. The output of the one inverter is shifted 30 electrical degrees from other. If there is no phase sift between the inverters the motor act as the three phase induction motor. The motor is modeled using the above equations. The motor simulation results are shown on the figure ( 6) and(7).Fig (6) shows the result of the six phase induction motor and fig (7) shows the output of the three phase induction motor. The torque of the six phase and three phase induction motors are shown on the figure (8) and (9) respectively. From the torque wave forms (fig

(8) and (9)) the starting torque of the six phase induction motor is about 565 N-m and the torque of the three phase induction motor is about 345 N-m. i.e. six phase induction motor torque is almost 1.6 times greater than the three phase induction motor torque.

## VI. CONCLUSION

Six phase induction motor finds its application in the area of high power high current applications. Because of its high torque it is suitable to be used in electric ship propulsion, Hybrid electric vehicle, more electric aircraft etc. We are able to compare the torque of three phase induction motor with torque of six phase induction motor with the help of Mat lab software.

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