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# Mathematical Model of Three Phase Induction Motor Using Written Pole Technology

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***Abstract:*** **This paper presents the development model of a three-phase induction motor using written pole technology. The aim of this paper is to analyze and simulate performance of a 1Hp three phase induction motor using written pole technology. A three phase squirrel cage machine is reconfigured and modeled into a two three phase stator winding accommodate in same stator core of the same volume as the three phase machine. Various tests are carried out on the novel machine to determine machine parameters. Simulation results, that predicts the dynamic performance of the machine using MAXWELL 16.0, at start up are presented and discussed.**

**Keywords:-- Three phase induction motor with written pole technology, dq-Transformation, Simulation, Transient Analysis, Reliability.**

## I. INTRODUCTION

Written-Pole Single Phase Motors are generally used for high power applications and are located where there is only single phase a .c. supply available. The main and primary feature of single phase written pole induction motor is the design of ferrite layer on rotor periphery and the exciter coil . the exciter coil write extra poles on the ferrite layer of rotor which helps for high speed, high power factor , energy efficient operation of an ac permanent magnet motor without using power electronics reduced voltage starter phase converters [1].

In the literature [2], a dynamic model to simulate high-power single-phase “written pole” motors is presented. The basis of the model is the generalized theory of electrical machines. From this theory, the required equations governing the dynamic behavior of the motors are obtained. Then, the equations are solved in a special reference frame that is valid for the unique properties of single-phase written pole motors.

In the literature [3], the design and location of the exciter which is a special feature of a written-pole motor (WPM) is presented. Unlike all general permanent magnet motors, the ferrite rotor of written pole induction motor is demagnetized in start up of the stator field and hence there is no braking torque of the magnet which is interesting feature of written pole induction motor. The ferrite rotor is re magnetized when the exciter winding is turned on. Due to high efficiency, high power factor and operated on 220, 50Hz a .c. supply, written pole induction motor can be used for home appliances.

In the literature [4], the application of Synchronous motor with ferrite magnets for fan, pump and compressors are presented. The stator of synchronous motor is same conventional three phase induction motor . in the rotor , mechanical bridges between inclined magnets are designed. This design gives 22% higher air gap flux density compared to other geometrics of the same magnet volume. The simulation result shows 4% improvement in efficiency and 9% improvement in power factor.

In the literature [5],three phase induction motor with modified stator winding is presented. By using multi strand with multi turn coils of stator winding, the efficiency of motor is improved. The winding arrangement gives 1480 rpm steady state speed. By modified stator winding, the efficiency is improved to 87.8%.

In the literature [6], the new three winding induction motor is presented. In three winding induction motor, stator windings are designed to operate on 415V, 350V and 200V respectively. Accordingly the shaft loads are divides as low, medium and high.

In the literature [7], the multi phase induction motor which is a preferred choice of industrial applications is presented. Stator of multi phase induction motor accommodated two stator windings and the simulation results shows the efficiency and torque of motor are significantly improved.

The modeling of three phase induction machine with written pole technology is carried out here. The three phase induction motor with written pole technology consists of two three phase stator winding accommodate on same stator core and rotor with permanent magnet ferrite layer on its periphery. The d - q voltage equations in the arbitrary reference frame of a three phase induction machine with written pole technology are readily written as in equations (4 &5):

Voltage equation for main stator winding:

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$$V_{ABC} = Rs_1\, I_{ABC} + \frac{d}{dt}\lambda_{ABC} \qquad (1)$$

Voltage equation for exciter winding:

$$V_{XYZ} = Rs_2\, I_{XYZ} + \frac{d}{dt}\lambda_{XYZ} \qquad (2)$$

Voltage equation for rotor winding:

$$V_{abc} = R_r\, I_{abc} + \frac{d}{dt}\lambda_{abc} \qquad (3)$$

## 2. THREE PHASE INDUCTION MACHINE WITH WRITTEN POLE TECHNOLOGY MODELLING

To model a three phase induction machine with written pole technology, precise corporation, Florida patented written pole induction motor which works on single phase supply and having hp rating above 10 hp only. So, in this paper, a novel motor with two stator winding i.e. main winding and exciter winding are placed on same stator core. Main winding is placed in 36 stator slots with 4 poles and star connected for 1hp output and delta connected for 3 hp output and exciter winding is wound on three different stator teeth and is star connected. In novel motor, squirrel cage rotor with permanent magnet ferrite layer on its periphery is used.

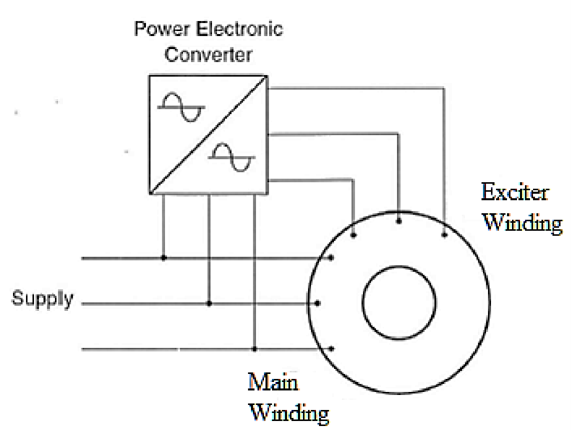


*Figure 1: Three Phase Induction motor with Written Pole Technology.*

## 3. D - Q MODELING OF THREE PHASE INDUCTION MOTOR WITH WRITTEN POLE TECHNOLOGY

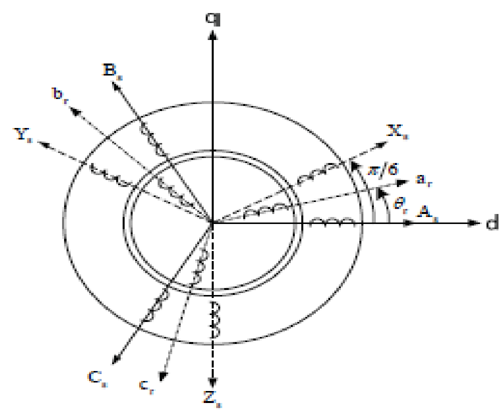


*Figure 2 : Stator main ,exciter windings ,rotor windings and phasors*

For three phase induction motor with written pole technology, the concept of variable transformation is being applied as in [21]. Induction motor configurations with multiple sets of three-phase stator windings and with an arbitrary number of phases have been extensively studied in [20]. A study conducted in [20], concluded that it is advantageous to use asymmetrical stator winding structure with two three-phase winding spatially shifted by 300, as against a symmetrical winding structure with a 600 spatial shift between any two consecutive phases. In order to model the three phase induction motor with written pole technology, the d - q transformation and the well known reference frame theory is adopted for modeling based on the operating condition of the sample machine. In this research work, different reference frames are developed and the rotor reference frame is used for analysis.

## 4. ROTOR REFERENCE FRAME MODEL

The three phase induction motor with written pole technology with two stator winding sets in one stator core. The voltage equations can be transformed in to arbitrary reference frame as

$$V_{q0abc} = R_r\, I_{qabc} + (\omega - \omega_r)\lambda_{dabc} + p\,\lambda_{qabc} \qquad (4)$$

$$V_{d0abc} = R_r\, I_{dabc} - (\omega - \omega_r)\lambda_{qabc} + p\, \lambda_{dabc} \quad (5)$$

The flux linkage equations are given below.

$$\lambda_{qABC} = (L_{1S} + L_m)\, I_{qABC} + L_m I_{qXYZ} + L_m\, I_{qabc} \quad (6)$$

$$\lambda_{dABC} = (L_{1S} + L_m)\, I_{dABC} + L_m I_{dXYZ} + L_m\, I_{dabc} \quad (7)$$

$$\lambda_{0ABC} = (L_{1S} + L_m)\, I_{0ABC} + L_m I_{0XYZ} + L_m\, I_{0abc} \quad (8)$$

$$\lambda_{qXYZ} = L_m\, I_{qABC} + (L_{2S} + L_m)\, I_{qXYZ} + L_m\, I_{qabc} \quad (9)$$

$$\lambda_{dXYZ} = L_m\, I_{dABC} + (L_{2S} + L_m)\, I_{dXYZ} + L_m\, I_{dabc} \quad (10)$$

$$\lambda_{0XYZ} = L_m\, I_{0ABC} + (L_{2S} + L_m)\, I_{0XYZ} + L_m\, I_{0abc} \quad (11)$$

$$\lambda_{qabc} = L_m\, I_{qABC} + L_m\, I_{qXYZ} + (L_{lr} + L_{mr})\, I_{qabc} \quad (12)$$

$$\lambda_{dabc} = L_m\, I_{dABC} + L_m\, I_{dXYZ} + (L_{lr} + L_{mr})\, I_{dabc} \quad (13)$$

$$\lambda_{0abc} = L_m\, I_{0ABC} + L_m\, I_{0XYZ} + (L_{lr} + L_{mr})\, I_{0abc} \quad (14)$$

Where ,

$$L_m = \frac{3}{2} L_{ms} \quad (15)$$

$$L_{mr} = \frac{3}{2} L_{mr} \quad (16)$$

Where, the subscripts '1' refers to main winding and '2' refers to exciter winding and 'r' refers to rotor winding. And $\omega$ is the rotational speed of reference frame and $\omega_r$ is the rotational speed of rotor.

We use state variable method to arrange equation (1) to (5) for computer simulation. The electromagnetic Torque, $T_{em}$, is given as

$$T_{em} = \frac{3}{2}\ \frac{P}{2}\ \left( \lambda_{dABC} I_{qABC} - \lambda_{qABC} I_{dABC} + \lambda_{dXYZ} I_{qABC} - \lambda_{qXYZ} I_{dXYZ} \right) \quad (17)$$

## 5. EQUIVALENT CIRCUITS:

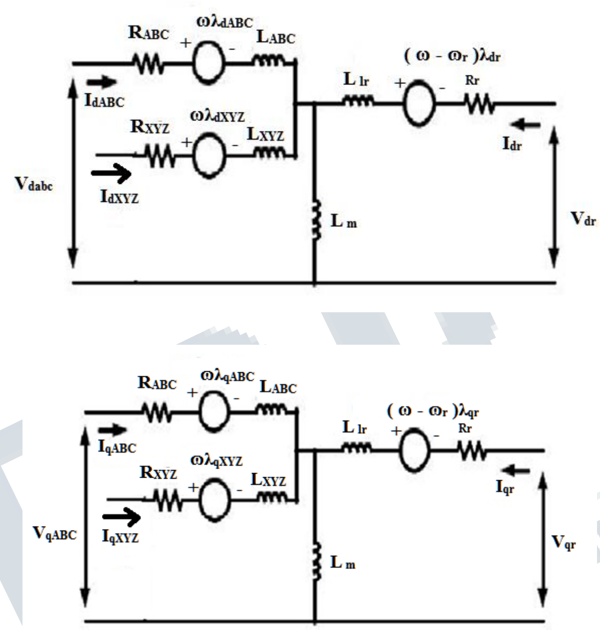


*Figure 3 : Equivalent 'qd' circuit diagrams*

## 6. COMPUTER SIMULATION

The differential equations 1-5, where arranged using state variable analysis. ANSYS programs were developed to simulate the performance of the test machine. The result of the simulation is presented below;

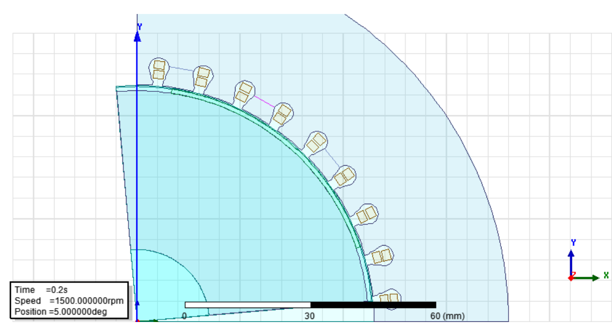


*Figure 4: Modeling in Maxwell Ansys 16.0*

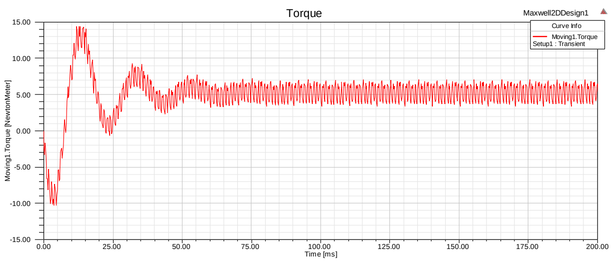


***Figure 5.Moving Torque of Motor***

## 7. DISCUSSION OF RESULTS

The test machine, three phase induction motor with written pole technology is described by a system of differential equations. The number of equations predicting the performance of the machine is equal to the number of winding sets in the stator and rotor circuits. In the first instant , the conventional model is simulated and the results shows that the phase current stabilizes at 0 seconds , the moving torque reaches synchronization at 50 mseconds.

## 8. CONCLUSION

The application of three phase induction motor with written pole technology is mainly in high power-high current applications so the use of inductor for current injection is uneconomical.

Though the initial cost of three phase induction motor with written pole technology is increased as compared to conventional three phase induction motor, at the same time efficiency and torque are significantly improved, the energy savings in applying energy efficient motors will pay off the additional cost of the machine. Hence, three phase induction motor with written pole technology is a potential competitor with three phase machines mostly in areas where reliability is an issue.

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