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Modelling and Simulation of Multiphase Induction Machine

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***Abstract* – Multiphase induction motor is a preferred choice for industrial process control due to its high reliability index. It is evident that, in multiphase machine the loss of one or two phases does not necessarily stop the system from running as in the case of three phase machine. In fact, multiphase machine offers numerous advantages compared to the conventional three phase machine. The quest for high power industrial drive created interest and attention towards multiphase systems. Among the multiphase machines, the six-phase category is more common due to the simplicity in converting a three-phase machine to a 'multiple of three' phase machine. By splitting the phase belt of a three phase induction machine, a six-phase machine is realised. The aim of this paper is to analyse and simulate performance of a 5Hp asymmetrical six-phase induction machine using the well known Park's transformation. A three phase asynchronous machine is reconfigured and modelled into a six-phase machine of the same volume as the three phase machine. Different tests are carried out on the sample machine to determine machine parameters. Simulation results, that predicts the dynamic performance of the machine using MATLAB, at start up are presented and discussed.**

***Keywords* – Multiphase Machines, dq-Transformation, Simulation, Transient Analysis, Reliability.**

I. INTRODUCTION

The induction machine is considered the workhorse of the industry, 65% of the total energy demand industrially is from induction motors. Induction machines has almost replaced the DC machines in the industry due to the simplicity of design, ruggedness, low cost, low maintenance cost and direct connection to AC power source compared to the DC motors. The application of induction machines in industrial, commercial and domestic sectors are numerous and as such research work becomes endless. Due to the importance of induction motors, new strategies and configurations of design are being sought that are capable of improving efficiency. In order to increase the power handling of electric drives, the idea of multiphase was conceived. Multiphase machines are more reliable compared to the traditional three phase machine. This is true because, the loss of one or two stator phases does not necessarily stop the machine from working as in three phase machines. Multiphase (>3) is becoming a popular choice in ac drives in industries, [1-2]. In existence is the 4-phase, 5-phase, 6-phase, 15-phase and so on [3,4,5]. In fact with the improved technology in power electronics, the number of phases is not limited.

The need to increase the power level of the drives system necessitate new machine design concept, this led to the need to double the stator winding of the induction machine. Another problem was the need to increase the efficiency and reduce the energy consumption. The use of a common magnetic structure shared by two sets of stator windings is not new but dated back to 1930 [6], where in an attempt to increase the power capability of a large synchronous generator, the stator winding has to be doubled. From that time to date, research activities in this area has receive much attention. The fault tolerant nature of these induction machines has created interest for multiphase (>3) machines. Among the groups of multiphase machines, the six-phase has received more attention due to its simplicity in converting a three phase machine to sixphase machine. This is achieved by splitting the phase belt of three phase machine, that is, two sets of three phase stator windings of the original three phase, with set II spanning 300 electrical from set I, having a common magnetic structure, [7-12]. In fact, any higher phase order in multiple of three is easily realizable using the conventional three phase machine. The analysis and modelling of induction machine is not new, numerous literature in electric machines abound. In [13-15], a mathematical modelling and computational analysis of a special six-phase synchronous generator for wind farm is presented. The analysis compared the special six-phase to a conventional three-phase synchronous generator performance. The technique of building special generators with more than three stator phases has been found attractive as reported in [18-21]. Five-phase induction machine is presented in, [4,5], while six-phase (double star) induction machine supplied from a six-phase inverter was examined in [22,23].

One of the advantages of a multiphase motor drive over a three-phase motor drive is the improved reliability, [11,19]. The reliability and overall performance of multiphase machine is investigated in [29-32], and the result showed that multiphase machine has a lot of benefits compared to the conventional machine. Detailed studies of induction machine configurations using multiple sets of three-phase stator windings with common magnetic structure was presented [33,40] and [34], respectively. In high power drives, use of multiphase machines is getting popular due to their fault tolerant feature and due to size limitations of individual converters. Plenty of work has already been reported describing multiphase machines and their inherent benefits compared to the conventional three phase machine, [35-36]. Some useful surveys of developments in multiphase machine drives, highlighting issues such as control strategies, winding layouts, machine topologies, fault tolerance and reliability are given in [37-

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39]. Multiphase machines are perceived to offer many advantages such as improved magnetomotive force (MMF) waveforms, reduced line voltages and increased efficiencies. The consequential benefits of these are reduced torque pulsations, lower losses, reduced acoustic noise and reduced power ratings of supply converters [10,15]. The modelling of six phase split wound induction machine carried out here.

II. Multiphase Induction Machine Modelling

To model a six-phase induction machine, some researchers suggested equal number of phases in both stator and rotor while others maintain unequal number of phases. But using a three-phase rotor for the modelling of sixphase induction machine according to [39], gives a clear concept of per phase equivalent circuit or arbitrary rotating reference frame equivalent circuit. Improved reliability is a priority in the drive system of most induction motors like the compressors in methane tankers, electric propulsion of ship and railway traction, [16,17]. To achieve the desired reliability, the application of a dual three phase induction machine which is composed of two sets of star connected stator winding spatially shifted by 300 electrical with isolated neutral point was proposed in [19]. In [35] a comparative analysis of the performance of six-phase and the conventional three phase synchronous generator for wind farm application was carried out and the results presented. This result shows that the six-phase motor performance is better than the conventional three-phase. In this paper, the modelling of six phase induction machine is presented with improved load torque and efficiency. Generally, power generation, transmission and distribution which is conventionally three phase can receive a boost when multiphase generators (synchronous and induction) are adopted [15].

Dq Modelling of six-phase induction machine

For any multiphase machine analysis and modelling, the concept of variable transformation is being applied as in [41,42]. Induction motor configurations with multiple sets of three-phase stator windings and with an arbitrary number of phases have been extensively studied in [43]. A study conducted in [26], concluded that it is advantageous to use asymmetrical stator winding structure with two three-phase winding spatially shifted by 30^0, as against a symmetrical winding structure with a 60^0 spatial shift between any two consecutive phases. In order to model the six-phase induction machine, the dq transformation and the well known reference frame theory is adopted for modelling 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.

III. Rotor Reference Frame Model

The asymmetrical six-phase is a six-phase induction machine with a two three phase winding sets in the stator (set I and set II). The set II winding spans 300 elect from set I winding. The dq voltage equations of a sixphase induction machine are readily written as in [6-9]:

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

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

$$V_{q2}= r_2 i_{q2}+ \omega_k \lambda_{d2}+p\lambda_{q2} \quad (3)$$

$$V_{d2}= r_2 i_{d2}- \omega_k \lambda_{q2}+p\lambda_{d2} \quad (4)$$

$$V_{qr}=0= r_r i_{qr}+ (\omega_k-\omega_r)\lambda_{dr}+p\lambda_{qr} \quad (5)$$

$$V_{dr}=0= r_r i_{dr}- (\omega_k-\omega_r)\lambda_{qr}+p\lambda_{dr} \quad (6)$$

The flux linkage equations are given below;

$$\lambda_{q1}=L_{l1}i_{q1}+L_{lm}(i_{q1}+i_{q2})+L_{dq}i_{d2}+L_{mq}(i_{q1}+i_{q2}+i_{qr}) \quad (7)$$

$$\lambda_{d1}=L_{l1}i_{d1}+L_{lm}(i_{d1}+i_{d2})+L_{dq}i_{q2}+L_{md}(i_{d1}+i_{d2}+i_{dr}) \quad (8)$$

$$\lambda_{q2}=L_{l2}i_{q2}+L_{lm}(i_{q1}+i_{q2})+L_{dq}i_{d1}+L_{mq}(i_{q1}+i_{d2}+i_{qr}) \quad (9)$$

$$\lambda_{d2}=L_{l2}i_{d2}+L_{lm}(i_{d1}+i_{d2})+L_{dq}i_{q1}+L_{md}(i_{d1}+i_{d2}+i_{dr}) \quad (10)$$

$$\lambda_{qr}=L_{lr}i_{qr}+L_{mq}(i_{q1}+i_{q2}+i_{qr}) \quad (11)$$

$$\lambda_{dr}=L_{lr}i_{dr}+L_{md}(i_{d1}+i_{d2}+i_{dr}) \quad (12)$$

If we define the following;

$$L_{dq} = 0 \quad (13)$$

$$L_m=L_{mq}=L_{md} \quad (14)$$

$$L_1=L_{l1}+L_{lm}+L_m \quad (15)$$

$$L_2 = L_{l2}+L_{lm}+L_m \quad (16)$$

$$L_3 = L_{lm}+L_m \quad (17)$$

$$L_r = L_{lr}+L_m \quad (18)$$

Putting (13) - (18), into equations (7) - (12) we have

$$\lambda_{q1}=L_1 i_{q1}+L_3 i_{q2}+L_m i_{qr} \quad (19)$$

$$\lambda_{d1}= L_1 i_{d1}+L_3 i_{d2}+L_m i_{dr} \quad (20)$$

$$\lambda_{q2}= L_2 i_{q1}+L_3 i_{q2}+L_m i_{qr} \quad (21)$$

$$\lambda_{d2}=L_2 i_{d1}+L_3 i_{d2}+L_m i_{dr} \quad (22)$$

$$\lambda_{qr}= L_r i_{qr}+L_m i_{q1}+L_m i_{q2} \quad (23)$$

$$\lambda_{dr}= L_r i_{dr}+L_m i_{d1}+L_m i_{d2} \quad (24)$$

We use state variable method to arrange equation (1) to (6) for computer simulation. The electromagnetic Torque, Te, is given as

$$T_e = \frac{3}{2}\frac{p}{2}\left[\lambda_{md}\left(I_{q1}+I_{q2}\right)-\lambda_{mq}\left(I_{d1}+I_{d2}\right)\right] \quad (25)$$

IV. Computer Simulation

The differential equations 1-6, where arranged using state variable analysis. MATLAB programs were developed to simulate the performance of the test machine. The result of the simulation is presented below;

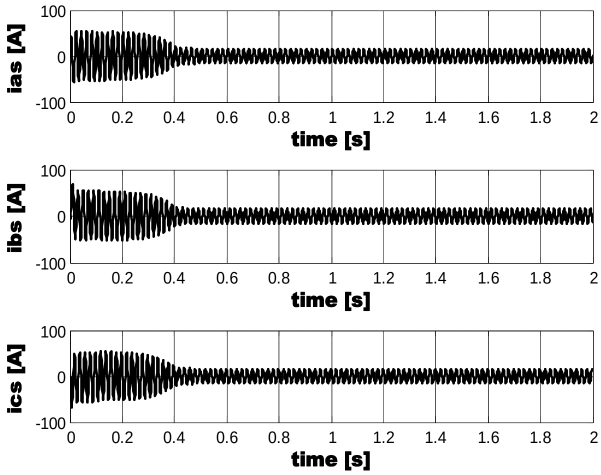

Fig.1. ABC phase current against time

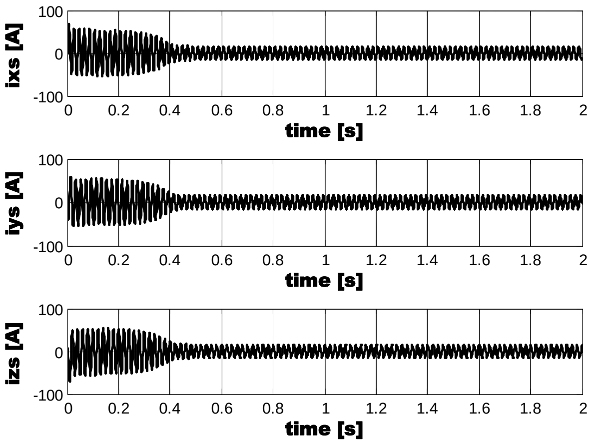

Fig.2. XYZ phase current against time

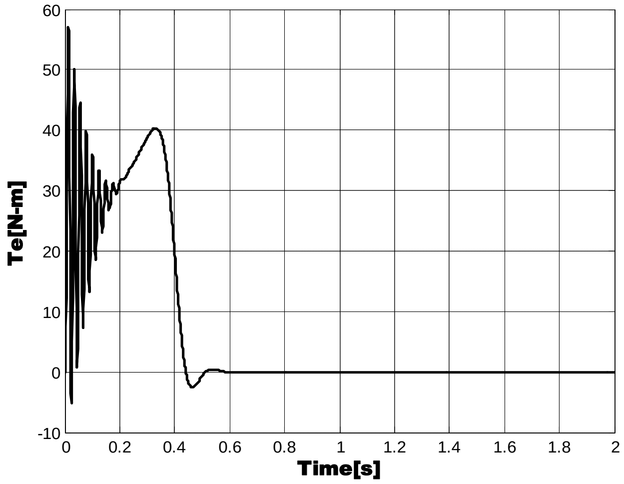

Fig.3. Electromagnetic Torque against time

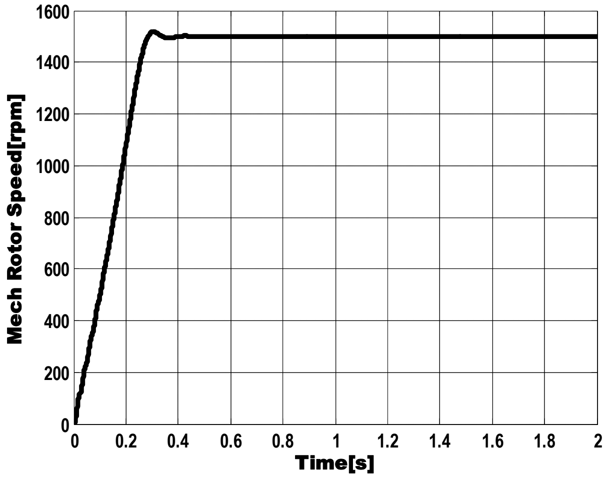

Fig.4. Mechanical Rotor Speed against time

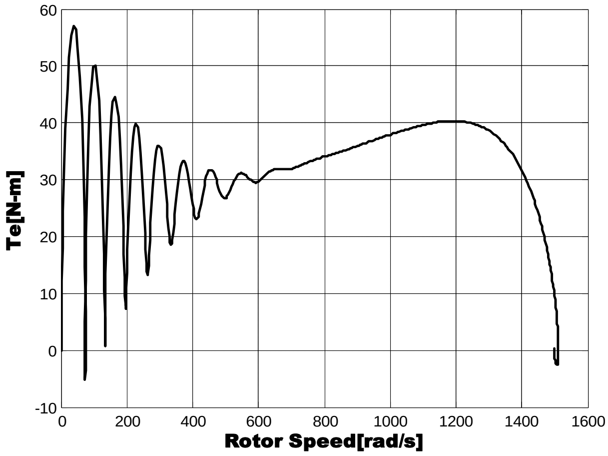

Fig.5: Electromagnetic Torque against Mechanical Rotor Speed

V. Discussion of Results

The test machine, six phase split wound induction machine 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 instance, the conventional model is simulated and the results show that; the dq currents assume steady state in 0.4secs, while the phase currents stabilizes at 0.25secs, the electromagnetic torque and the mechanical rotor speed reaches synchronism at 0.4secs.

VI. Conclusion

The application of multiphase induction motor is mainly in high power-high current applications so the use of inductor for current injection is uneconomical. Though the initial cost of six phase induction motor is increased as compared to 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. Multiphase electrical machine is a potential competitor with three phase machines mostly in areas where reliability is an issue.

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