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RESEARCH ARTICLE

DESIGN OF PMSM AND ITS APPLICATION

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ABSTRACT

In present and future market conservative motors like induction motor are replaced by permanent magnet motors for various applications like industrial, traction, hybrid electric vehicle, etc. The topical growth in Permanent Magnet machines has provided a result for the variable speed applications, which bid easy design for controller as well as operate at higher efficiency. In this paper, the basic introduction of Permanent Magnet Synchronous Motor (PMSM) is discussed. Permanent Magnet Synchronous Motor (PMSM) is selected due to various advantages like reduced cost, high speed and high power density. In recent days, neodymium-iron-boron (NdFeB) magnets become commercially available with a reasonable price. Performance comparisons between induction motors and Permanent Magnet motors are presented in this paper. The design parameters are analyzed using Finite Element Method (FEM).

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INTRODUCTION

Permanent magnet synchronous motors have been in use on machine tools and other production mechanism for many years, owing to their reliable performance, durability, relatively low cost, and superior power factor. These motors have been the standard in the machine device industry for many decades, used on the spindle, worktable rotation and in both rotary and linear applications of controlled motion. With the advent of the machine tool for materials handling, work piece and high-precision load and unload functions, and more, the use of these motors has grown increasingly over the years. Permanent Magnet Synchronous Motors are chosen due to their high speed, power density and efficiency. Permanent Magnet Synchronous Motor are preferred due to various advantages like less rotor losses, less heating, high efficiency, maximum saliency, no external excitation. The performance of the motor is enhanced due to less rotor losses and less heating. PMSM are smaller in size and lesser in weight and are mostly used in variable speed industry applications as the replacement of induction motor. To convince the requirements of various industries and in wind power generation PMSM motors are engaged (Li and Xu, 2013; Betin *et al.*, 2014). The improvements in PMSM can boost the reliability, torque/mass ratio can complete with mechanical, hydraulic in terms of compacity (Cao *et al.,* 2012). For electrical aircraft applications permanent magnet motor with high-power-density with fault tolerance capabilities is proposed.

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Permanent magnet synchronous torque motors classically have 30%-60% higher torque capacity and better torque utilization with faster acceleration and deceleration, compared to asynchronous induction type motors, and this has confirmed advantageous in the field, particularly with machine tools and other metal working production equipment. In addition, the production machine realm, plastics and rubber moulding and extrusion, papermaking, packaging, textiles, ceramic, glass, woodworking have been utilized these motors for motion control. Due to dominant improvements in magnetic and thermal properties of permanent magnet (PM) materials over the past 20 years, along with significant cost reduction, synchronous PM motors signify viable alternatives. The design of stator of the machine remains the same where the rotor construction is customized for its performance improvement. The projected design involves the injection of permanent magnet into the rotor flux barriers. To augment the efficiency of motor, certain amount of magnet is used which it improves the saliency ratio. The design of the PMSM rotor geometry is done by the numerical magnetic analysis with the help of finite element analysis. Normally, the no-load test, the thermal test, the loss test, the load test, the torque test, the inductance test, the acoustic test are used to examine the permanent magnet synchronous motor. The cost intensive dysprosium materials like neodymium-iron-boron (NdFeB) are used to raise the temperature stability (Von Malottki *et al.,* 2014; Chen *et al.,*). In order to develop the accuracy of the permanent magnet synchronous machines and to study the consequence of saturation in parameters, several studies are been carried out (Chen *et al.,* 2014 & 2015; Li and Li, 2012; Sizov *et al.,* 2012).

The finite element model is used for the design of PMSM (Myung-Seop Lim *et al.,* 2015).

Location of permanent magnets

Most of the PMSMs are constructed with the permanent magnets which are mounted on the periphery of the rotor core. When permanent magnets are obscured inside the rotor core the motor provides mechanical ruggedness and escalating torque capability. By designing a rotor magnetic circuit the inductance vary with respect to rotor angle, the reluctance torque can be created by the mutual reaction torque of synchronous motors. This type of Interior Permanent Magnet Synchronous Motors is considered as the mixture of Synchronous Motor and the Permanent magnet Synchronous motor. The proposed design called Permanent Magnet Synchronous Motor which involves embedding of permanent magnet in the flux barriers of the rotor.

Analysis of PMSM

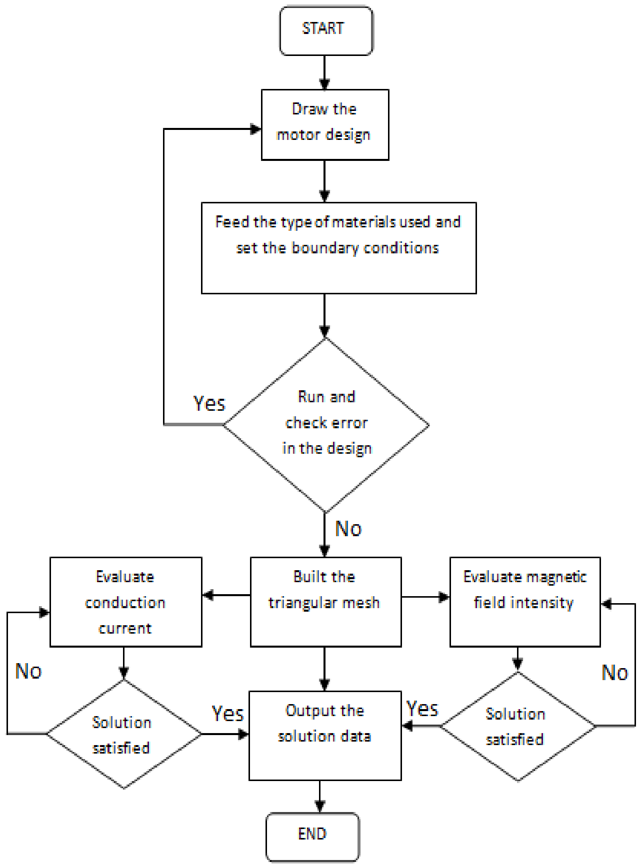
A four pole synchronous motors consist of 3-phase stator winding and a salient rotor. The Stator windings are indistinguishable and displaced by 120^0 from each other. The flux in the stator winding is sinusoid ally distributed and hence the air gap flux contributes to additional stator leakage inductance. The excitation winding does not exist in PMSM. The performance of the physical stator and rotor current in a reference frame which is rotating with the rotor of the machine is expressed in the d-q equation. In order to design rotor, the rotor must possess maximum L_d and minimum L_q.

The optimum way to improve the performance of the motor is by inserting the magnet in the rotor flux barriers. The rotor is placed in the opening of a stator; the rotor will rotate like an ac motor when alternating currents are supplied to the stator winding. There are two shapes of permanent magnet 1) Tile shape; 2) square shape. The parameters of PMSM can be determined by calculation or measurement. The parameters of the PMSM are armature resistance, flux linkage constant, armature inductance of d and q axis.

Finite Element Analysis

Finite element analysis is basically performed using FE method. A standard magneto static inception with vector potential is used. The flux in the coil is computed for various electrical rotor positions and distinct values of the direct and quadrature current components, and the result was saved. This results in the achievement of the direct and quadrature current components of the stator flux and their progression with the electrical position and currents. Concerning the mesh, it is already known that a correct organization of the machine allows decreased errors on the main variables. On the other hand, for losses or cogging torque, the proposed results robustly depend on the discretization.

It has been precise around all regions and a three-layer discretization is used to limit the consequence of the mesh. The width of the element must match the width step angle of the movement to decrease numerical errors. To limit a reliable harmonic valuation an acceptable number of elements are used on electrical period. First-order elements have been used.



Mathematical Model Of PMSM

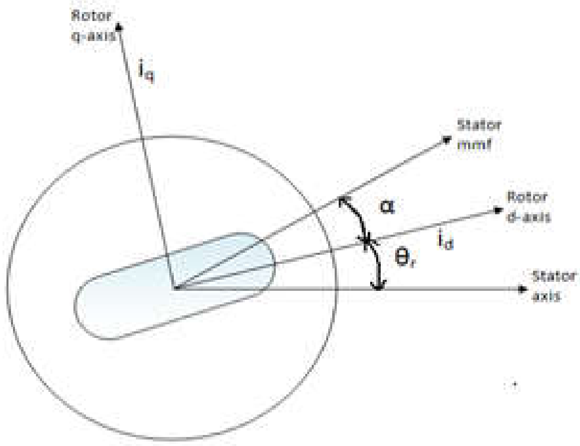


Figure.1. Motor axis

The d-q model on rotor reference frame is shown in Figure 1. At any time t, the rotating rotor d-axis form an angle θ_r with respect to fixed stator phase axis and rotating stator mmf form an angle α with respect to rotor d-axis. Stator and rotor rotates at the same speed. The PMSM has been modelled on the rotor reference frame by the different assumptions like neglecting saturation, the induced EMF is sinusoidal, hysteresis losses and eddy current are negligible, no field current dynamics. The Voltage equations of PMSM are:

$V_q = R_s i_q + \omega_r \lambda_d \rho \lambda_q$ ……………………….. (1)

$V_d = R_s i_d - \omega_r \lambda_q + \rho \lambda_d$ ……………………….. (2)

The Flux Linkages are given by

$$\lambda_q = L_q i_q \quad \ldots\ldots\ldots\ldots (3)$$

$$\lambda_d = L_d i_d + \lambda_f \quad \ldots\ldots\ldots\ldots (4)$$

Where L_q and L_d are the quadrature inductance and direct inductance, R_s is the stator resistance. The developed electromagnetic torque equation of PMSM is

$$T_e = \frac{3}{2}\left(\frac{\rho}{2}\right)(\lambda_d i_q - \lambda_q i_d) \quad \ldots\ldots\ldots\ldots (5)$$

The mechanical torque equation is

$$T_e = T_L + B\omega_m + \frac{Jd\omega_m}{dt} \quad \ldots\ldots\ldots\ldots (6)$$

The Phasor diagram is drawn between stator voltage vector and the d-q is shown in Figure 2.

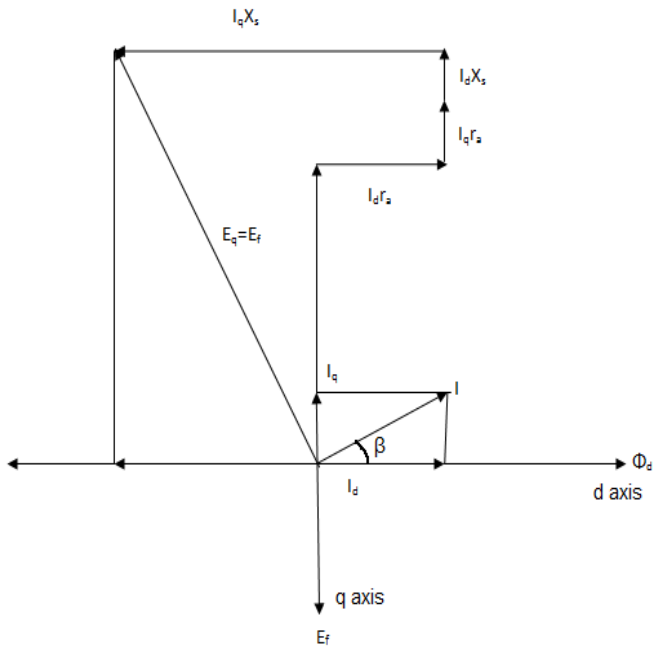


Figure 2. Phasor diagram of Permanent Magnet Synchronous Motor

In Phasor form,

$$V = (I_d r_a - I_q X_s) + j(|E_q| + I_q r_a + I_d X_s) \quad \ldots\ldots\ldots\ldots (7)$$

$I_d \rightarrow$ MMF along direct axis
$I_q \rightarrow$ MMF along quadrature axis

Neglecting the effect of resistance,

$$I = \frac{V - E_q}{jX_s} \quad \ldots\ldots\ldots\ldots (8)$$

Simulation results

The graph of Mechanical speed and electrical torque is shown in Figure 3 and Figure 4.

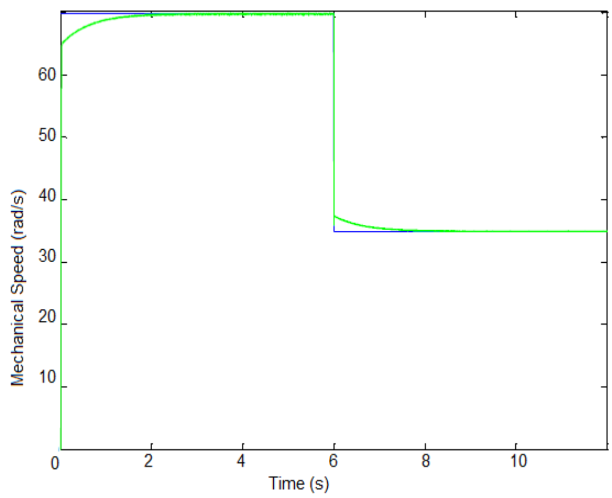


Figure 3. Mechanical speed

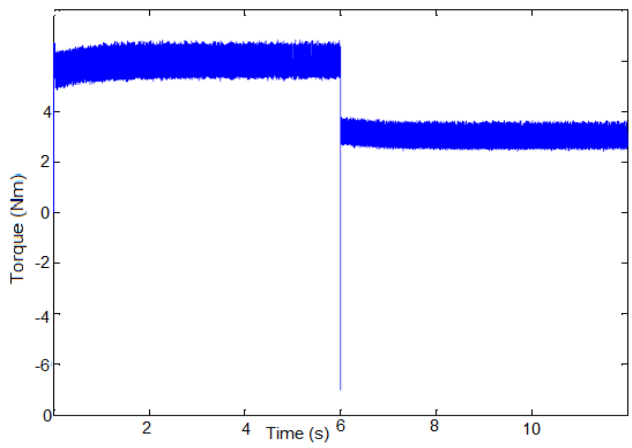


Figure 4. Electrical torque

Permanent magnet application

New market areas are emerging, however, where the use of permanent magnet (PM) motors is viewing great promise. These applications involve the use of PM motors for increasing machine productivity with enhanced operational efficiencies. One of the Permanent Magnet motor examples is the servo pump, where a mechatronic analysis concluded substantial energy savings and operational improvements could be realized, with the further use of environmental upsides. Typically, the pump motor runs only when the environments of the machine mechanics warrant. By utilize of a PM motor up to 50% savings are being accomplished on new and back fit machines, with the evident additional benefit of eliminating mechanical components, such as the gearbox. In the privileged power ranges today, these motors are also showing a much longer use life, owing to the greater degree of rotor tension compensation. In other words, the reduction of backlash (hysteresis) and the maintaining of precise position are improved. Drive technology improvements pushed for increased use of PM motors in applications such as spindle motion precision and accuracy in a machine tool. Besides, the complex current calculations for higher speed and rotor pole pair position description are being made in the drive for use with simpler encoders or even encoder less configurations in the machine. Use of the asynchronous induction motor is distant from outmoded, particularly with the advancements in motor system elements, such as variable frequency drives and inverters. Still, upgrading in magnetic configuration in drives technology is opening new applications for PM magnets daily.

Advantages of PMSM

The above industrial application has broadened and enlightened the application of PM technology and its advantages over the conventionally used induction principle. The main points which we can consider while summarizing this advantage are as:

- PMSM provides higher power density for their size compared to induction machine. This is because with an induction machine, in order to produce rotor flux, part of the stator current is required to "induce" rotor current. These added currents cause heat within the motor whereas; the rotor flux is already established in a PMSM by the permanent magnets on the rotor.
- With the low power density it aids compactness. This results in development of a PMSM with low rotor inertia, which is capable of providing faster response It is operating at a higher power factor compared to induction motor (IM) due to the absence of magnetizing current.
- The design of controller required for the design of speed control of the fan operated by PMSM is simple. The PMSM also provides a key feature of operating at high efficiency with low speeds.

Conclusion

Thus the PMSM has certain advantages over the preferred induction motor. The operation of PMSM discussed and has proved the overall compatibility and advantages over the IM's. Thus the permanent magnet motor application does not certainly limit but also used to various other applications, including domestic applications like washing machines. In other utilities where variable speed drives prove costly and inefficient, for e.g. electric traction, where speed control needs to be flexible and again with the provision of less weight and wear and tear. There are certain other advantages apart from those discussed above, which were for a particular application.

- PMSM does not require regular brush maintenance like conventional wound rotor synchronous machines.
- The PM rotor does not require any supply nor does it incur any loss.
- Low noise and vibration than induction motors.

Hence, from the discussed application with its in-depth graphical analysis, it procures a clear picture that the use of PMSM is inevitable so as to meet the current energy efficient systems and develop a smarter, compact and Effective grid altogether. Thus the design of the permanent magnet synchronous motor has been completed. Finite element method has been used to attain the inductance. In this paper simulation of permanent magnet synchronous motor and the results are shown. The performance of PMSM is improved.

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