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Design of PMSM for EVs with its Mechanical Aspects

*1Mr. Chetan S. Chavan & 2Prof. Rupalee S. Ambekar

1M.tech student, Dept. of Electrical Engineering, Bharati Vidyapeeth (Deemed to be), College of Engineering, Pune (India)
2Assistant professor, Dept. of Electrical Engineering, Bharati Vidyapeeth (Deemed to be), College of Engineering, Pune (India)

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***Corresponding Author**
Email: chavanchetan3794[at]gmail.com

ABSTRACT

Electric machines are the main component of electric vehicles when performance of the system is being considered. Various thermal and mechanical aspects plays a vital role in the consideration of design of the machine. Now a days, various key parameters in designing of electrical machines got special attention when the efficiency and torque calculation has been incorporated. It is found that slight change in the physical dimension of constituent parts of the electric machines affects the key parameters and provide a way for designers to enhance the performance with all respect. This paper mainly focuses on the designing along with the mechanical aspects of Permanent Magnet Synchronous Machines (PMSM) by variation in the constituent physical change in the parameters. The paper also introduces the optimistic parameters by trial and error method. In the world, various countries uses different types of electric motors such induction motors, switch reluctance motors and wound field synchronous machines as per the vehicle requirements. Japan is only country incorporates the use of Permanent magnet machines instead of induction machines just because of their efficiency and its stability over wide conditions. In this research work, the performances and designing has been carried out with the help ANSYS 16.2 (Electromagnetic). The software provides large no of minor as well as major parameters variation thereby giving the results in the form of graphical representation.

1. Introduction

Electric vehicles are found to be the best replacement for conventional vehicles in this century. Conventional vehicles proven to be have various disadvantages beside reliability and stability [1]. The disadvantages for conventional vehicles are cost, pollution, maintenance as well high fuel consumption and hence it is necessary to have the vehicle which avoids these types of drawbacks by utilizing the other form of energy such electric energy. Major parts of electric vehicles are motors, batteries, cooling system, control unit, etc. Amongst these parts batteries and motors are the key parameters for the electric vehicle. There are many types of motors used in the electric vehicles based upon the requirements such as induction motors, DC motors, Switched reluctance motors, Permanent Magnet brushless DC motor. The basic requirement of motors used in electric vehicles are High torque for starting purpose at low speeds as well as at hill climbing and high power for the purpose of high-speed cruising[2]. The machine should also possess wide speed range operation which is around 3-4 times of the base speed. Motors used in electric vehicles also desired to give high efficiency over wide speed range and wide torque range. Along with addition to this the machine should have high reliability and robustness in order to operate in extreme situation.

Different motors used in EVs

DC motor

Before introduction of power electronic devices these motors mostly used in applications where speed varies over wide range. Due to the simple construction and robustness in nature they preferred in electric vehicles [3]. The two types consist of brushless and brushed motors. In which brushed motors gives high torque at very low speed but due to the disadvantages such as large size, low efficiency, low reliability, cost of the maintenance due to brush and collectors their use restricted to particular limit. Basic stator-rotor construction of DC motor is shown in fig.1

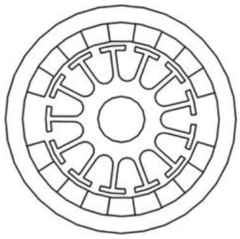

Fig.1. DC motor

Induction Motor

The simple construction, robustness, less maintenance cost, and best operation at worst environmental situations are the major advantages and the reasons behind the use of IM in electric vehicles. Variation in the speed can achieved by field weakening method in constant power region. The considerable difference between PMSM and IM is the efficiency i.e. IM has less efficiency than the PMSM along with low power factor and high losses as compare to the PMSM. France, USA, Germany are some the countries which utilizes IM in their automobile company. Constructional diagram is shown in fig.2

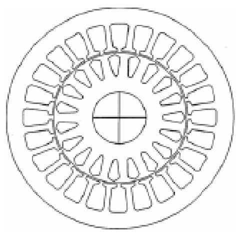

Fig.2. Induction Machine

PM Brushless DC motor

The considerable factor for PM brushless DC motor is high efficiency as well high power density [4]. Due limited field weakening capability PMBLDC has short but constant power range. Magnets of PMBLDC is the main obstacle reason behind obtaining high torque. Light in weight, smaller volume and high power density are the considerable advantages of PM BLDC. Schematic of PMBLDC used in EV is shown in fig.3

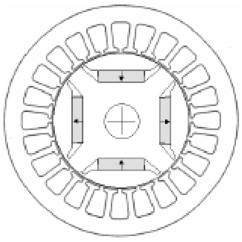

Fig.3. PM BLDC

Switched Reluctance Motor

Constant power with wide operating region at high speed, less chances of fault, robust construction are the main reasons behind use of Switched Reluctance Motor in electric vehicles. The efficiency of the SRM is almost equivalent to the IM. Holden/ ECOmmodore (Australia) is the only automobile company uses this type of motor. The constructional diagram of SRM is as shown in fig.4

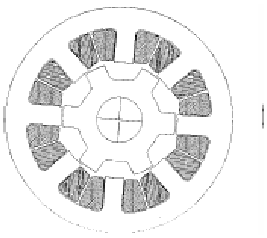

Fig.4. Switched Reluctance Motor

Permanent Magnet Synchronous Motor

PMSM is found to be the best machine for electric vehicles in order to obtain optimistic result in terms of key parameters. The machine possess reduced overall system weight as well as volume for same power density. The machine has highest efficiency as compare to all type machine. The desired goal highest efficiency and maximum speed range can be achieved by controlling the conduction angle of the power converter above the base speed. Hence it is possible to obtain the speed upto three to four times of the base speed. As far as construction is concerned it is classified as magnet mounted on surface and magnet buried mounted according to the permanent magnet arrangement [6]. When the magnets mounted on the surface of machine uses less number of magnet. Beside these two type one more type of PM machine is available named as Hybrid PM motor in which magnetic field of air-gap can obtained by the combination of field winding used and PM placed over the surface. The featured diagram of the PMSM is as shown in fig.5

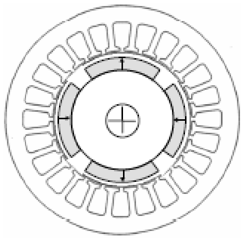

Fig.5. PMSM

2. Analysis in Software

The experimentation is totally depends on the analysis of PMSM with the help ANSYS Electromagnetic (16.2). The software enables user to enter the various constructional required inputs such magnet length used in the machine, depth of the slot used, reference input speed, stator input parameters, rotor input parameters, winding layouts, etc. The process of analysis is comparative in nature. Two types of existing electric vehicles are compared by entering the data obtained from their datasheets. Trial and error method is then carried out in which the input is taken randomly in order to check the result whether it is coming improved or not. When the results are found be better as compared with the results obtained from existing electric vehicle, the more no. of inputs are being given and same experimentation is carried out. In some cases, it is found that at some particular value machine providing the best results and the rest variations does not improved the effective value then these value are noted and named as optimistic values.

The mechanical aspects considered for the experimentation are as follows:

1) Change in the length of the magnet
2) Change in the length of the slot opening
3) Change in the reference speed

The experimentation with various mechanical aspects is as follows:

1) Change in the length of the magnet

Magnet is the main reason behind the production of flux and magnetic field in the machine. Change in the physical length of the magnet directly influences the air gap flux density [3], leakage reactance and various corresponding parameters. When PM is inserted into magnetic field changes the reluctance and produces large low permeability area which results in reduced leakage reactance. Due to this correct flux linkages enhances thereby increasing the efficiency. In the analysis process, for first vehicle, length of the magnet is taken as 40mm which gives efficiency about 96.71%. For second vehicle, the length of the magnet is taken as 38mm which gives efficiency of 96.80%. The optimistic result obtained at the length of 35mm giving efficiency 96.88%. The optimistic value of length of the magnet gives highest efficiency as shown in fig.6

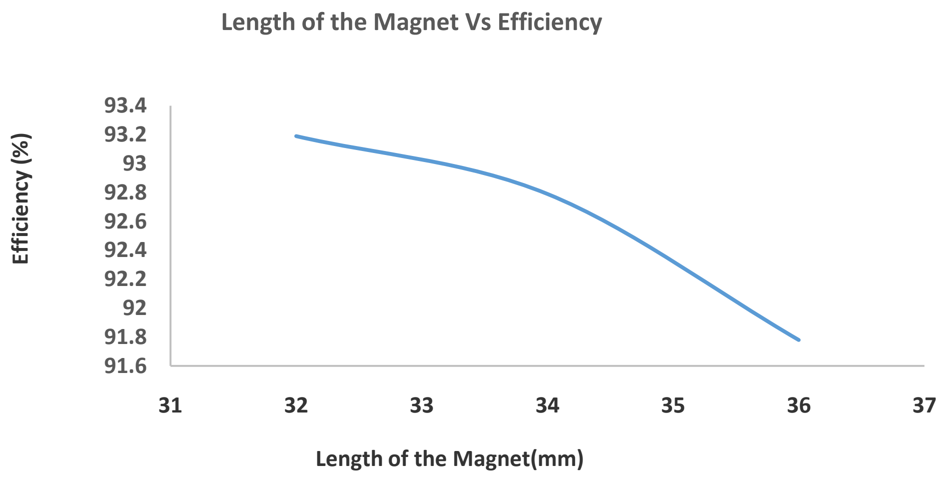

Fig.6. Graph for efficiency Vs length of the magnet

2) Change in the length of the slot opening

There are various types of slots has been used in the machine. Open, closed, semi-enclosed are most widely used configuration in the machines. The variation in the length of the slot opening influences the air gap flux density. As the length of slot opening reduces, path for the flux to flow also enhances thereby reducing the inductive reactance of the machine and hence this proven to be the motivation behind the improvisation in efficiency. When the length of the slot opening is taken as 14mm, the efficiency was found to be 96.83%. Whereas for the length of 11mm the efficiency is marked as 96.80%. The highest efficiency was obtained at intermediate value of 12mm with the efficiency of 97%. The efficiency variation is shown in graphical manner as follows:

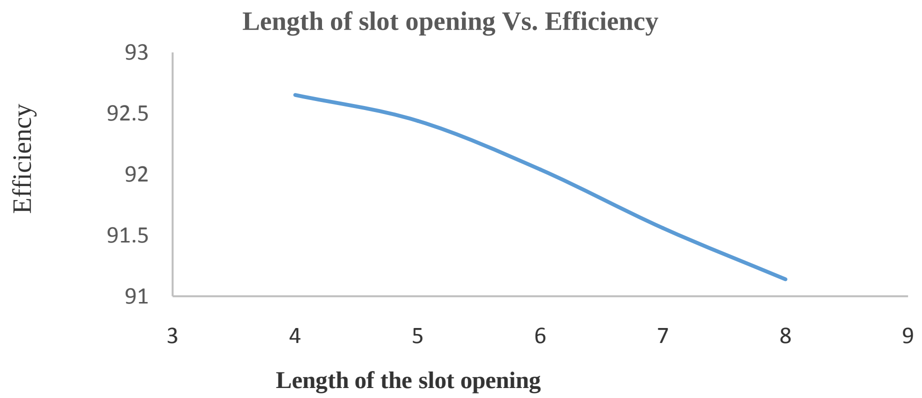

Fig.7. Graph for efficiency Vs length of slot opening

3) Change in the reference speed

From the experimentation it is been observed that operating the machine to its highest possible speed gives improved efficiency. Speed of the machine is in direct proportion with back EMF also with efficiency [7]. Therefore the relation gives satisfactory result in EVs analysis in terms of reference speed.

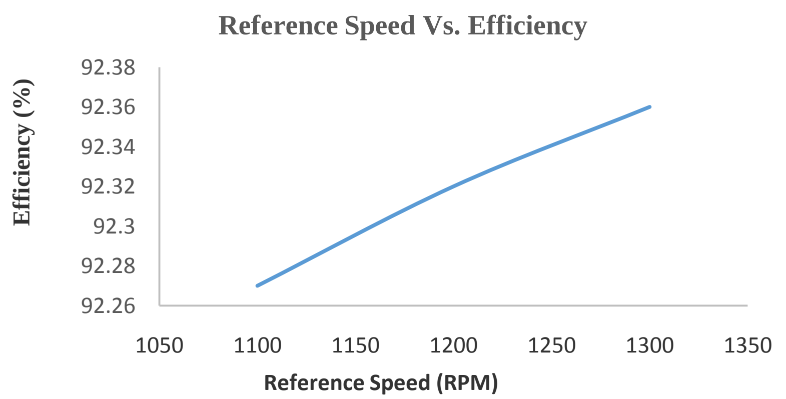

Fig.8. Graph for Efficiency Vs Reference speed

3. Conclusion

The experimentation and analysis shows that, slight change in the physical parameters of the Permanent Magnet Synchronous Machine (PMSM) changes the efficiency value and it is possible to enhance the performance of the motor thereby improving the value of the corresponding parameter. The key parameters are length of the magnet used in the motor, Reference speed given to the motor, Slot opening of the rotor. From the experimentation it is shown that as the length of the magnet reduces the efficiency get enhances. Also operation of the machine at highest possible speed gives the best efficiency. In case of the slot opening, the optimistic value obtained in between the value taken for two electric vehicles into the consideration. In the various electric vehicles, change in the parameters does affect the performances upto the considerable level. Hence it is not feasible to consider those changes. The mechanical analysis gives a way to move towards the thermal aspects as well as electromagnetic performance of the machine.

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