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Performance Analysis on Different Rotor Topologies of Interior Permanent Magnet Synchronous Motor

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Abstract: A performance comparison between three different types of interior permanent magnet synchronous motor rotor topologies, namely InSet, Nissan LEAF, and Multiple-Barrier in the 2-dimensional model. This analysis was conducted to see which model design is the best among the three different IPMSM models of rotor topologies and the parameters observed parameters such as cogging torque, back electromotive force, three-phase test, zero rotor position test, flux line, and load parameters result such as torque versus armature coil current density and torque and power versus speed. This analysis was conducted by using JMAG Designer 16.1 software. The Geometry Editor will be used for sketching the models then import to JMAG Designer to perform the simulation by inserting the correct parameters such as materials, conditions, circuit, meshing and properties. Both studies are successfully simulated and manage to obtain the result. For the first study, which is for the 2-dimensional model, the analysis performed is a simulation test without load and also has loaded. After the simulation test is completed, the results obtained are being compared and analyzed to determine which design is the best and based on the analysis found that InSet design is the best design compared with the other two designs.

Keywords: Interior PMSM, Cogging Torque, Electric Vehicles

1. Introduction

Permanent Magnet Synchronous Motors (PMSM) are widely applied in industrial and robotic applications due to their high efficiency, low inertia, and high torque to volume ratio. PMSM has been researched for a long time because it has a high output power density with high efficiency and excellent flux weakening capability, which operates the motor in a wide constant power speed range by applying the appropriate control method [1].

The Permanent Magnet Synchronous Motor (PMSM) is an alternating current (AC) synchronous motor whose field excitation is provided by permanent magnets and has a sinusoidal back EMF waveform. The PMSM is a cross between an induction motor and a brushless direct current (DC) motor. Like a brushless DC motor, it has a permanent magnet rotor and windings on the stator. However, the stator structure with windings constructed to produce a sinusoidal flux density in the air gap of the

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machine resembles that of an induction motor. PMSM is typically used for high-performance and high-efficiency motor drives. High-performance motor control is characterized by smooth rotation over the entire speed range of the motor, full torque control at zero speed, and fast acceleration and deceleration [2].

There is a lot of type for PMSM. Interior Permanent Magnet Synchronous Motor (IPMSM) is one of them. IPMSM has been widely used in high-performance applications due to its advantages, such as high torque to current ratio, high power to current ratio, high efficiency, low noise, and structural robustness [3]. Interior PMSM also has been applied in electric vehicles such as BMW i3, Toyota Prius-III, Volkswagen e-Golf, and Nissan LEAF. Other than that, IPMSM also has a different kind of rotor topologies such as inset, spoke, single-barrier, multiple-barrier, and axially-laminated type [4]. Figure 1 and 2 show the example IPMSM of the electric vehicle motor and also different type of rotor.

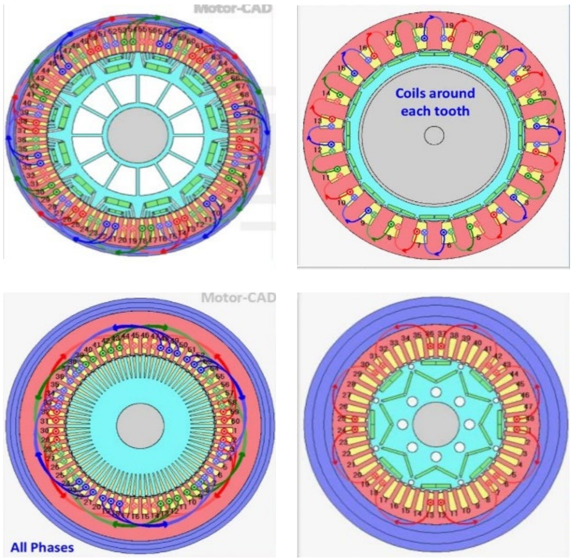


Figure 1: IPMSM of electric vehicle

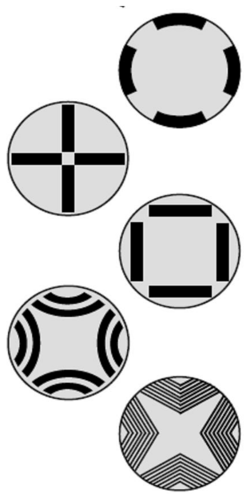


Figure 2: Different rotor type of IPMSM

2. Materials and Methods

The software used was JMAG-Designer 16. JMAG is used actively to analyze designs at a system level that includes drive circuits by utilizing links to power electronic simulators [5]-[10]. JMAG is also being used for the development of drive motors for electric vehicles [11]-[17]. The high quality of this software program is capable to extract data approximately such as complicated geometry, various material properties and the heat structure at the center of electromagnetic fields [18]-[22].

2.1 Materials and conditions

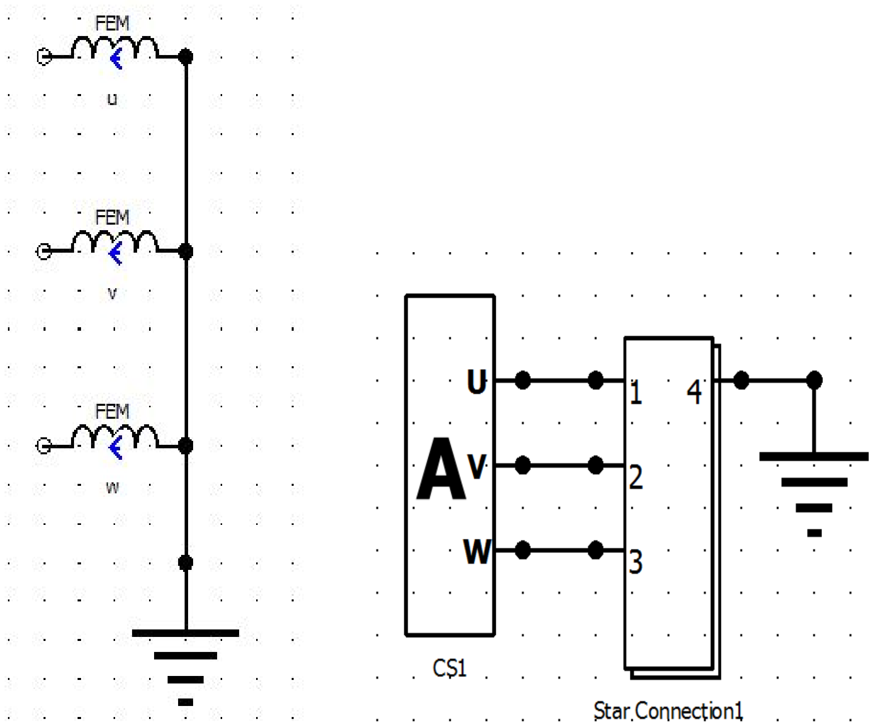
Table 1 below indicates the materials used and conditions for the motor. The material and condition settings used are the same for both the no-load and load test. The material and conditions used for the motor are set by dragging the item from the right-hand-side toolbox to its functional materials and conditions.

Table 1: Materials and conditions

Parts	Materials	Conditions
Rotor	Nippon Steel 35H210	Motion: rotation Torque: nodal force
Stator	Nippon Steel 35H210	—
Armature Coil	Conductor Copper	FEM Coil
Permanent Magnet	Neomax-35AH (irreversible) (Radial Anisotropic Pattern)	Motion: rotation Torque: nodal force

2.2 Circuit

Construct the circuit to be linked with the armature coil. The overview of the constructed circuit for the no-load test is shown in Figure 3 (a) meanwhile for load test circuit is shown in (b). Then choose FEM coil in the circuit toolbar and connect with the ground. After that linked all armature coils with the corresponding FEM coil.

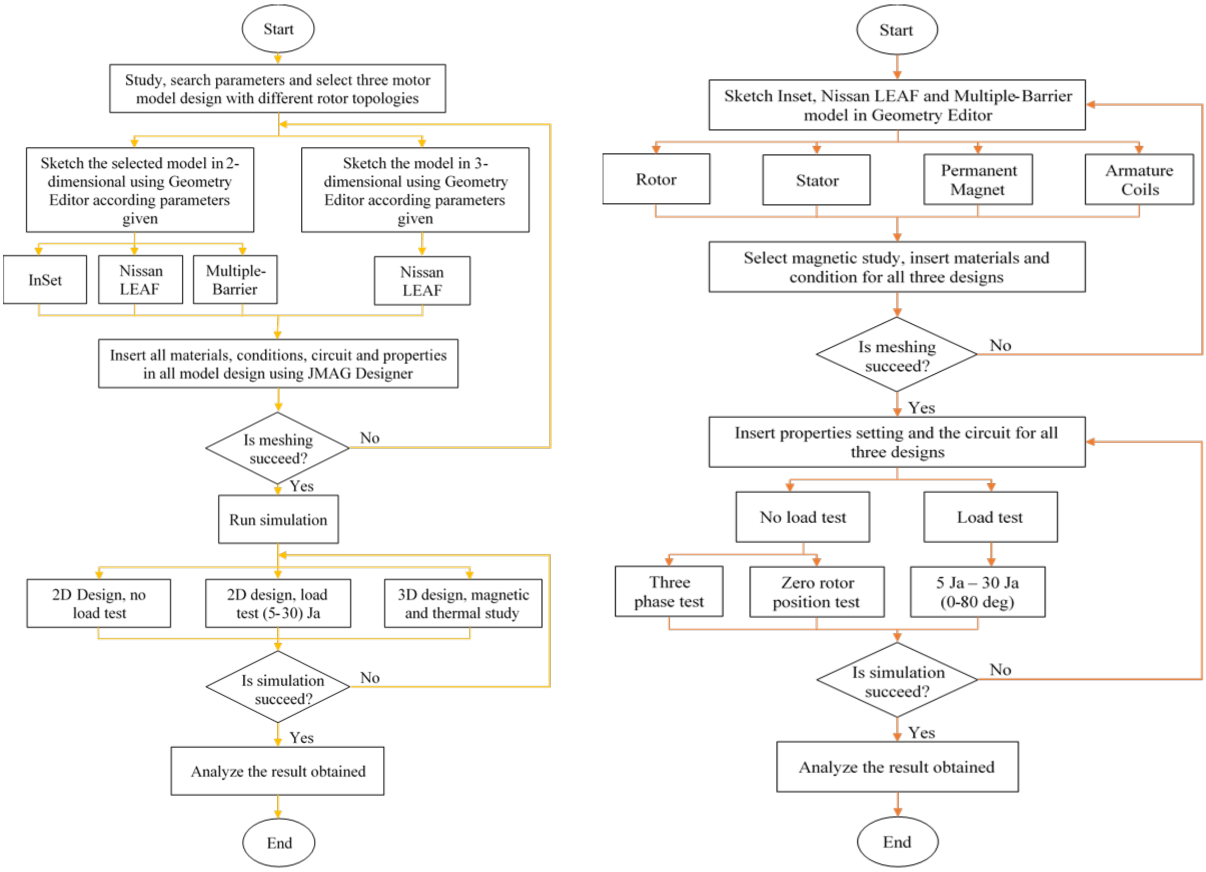


(a) (b)

Figure 3: Circuit configuration for (a) no load test (b) load test

2.2 Methods

Generally, the implementation of this project whether in 2-dimensional is divided into three phases that are design and investigation, performance and analysis. The general workflow of methodology as shown in Figure 4 (a). Meanwhile, in Figure 4 (b) shows the flowchart for making 2-dimensional models using JMAG software.



(a) (b)

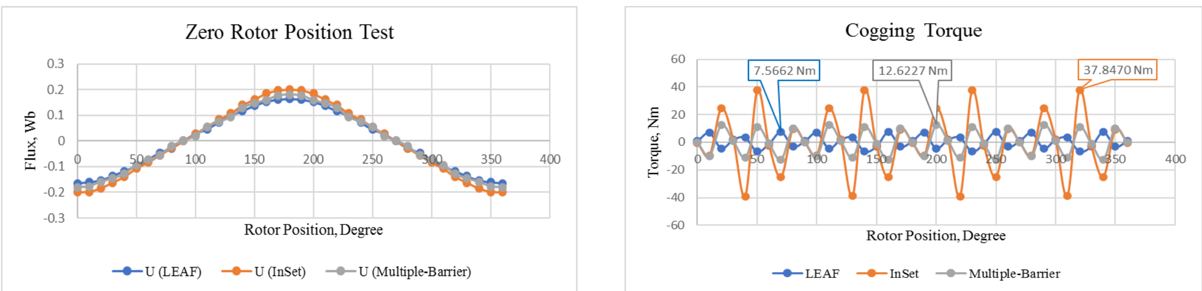
Figure 4: Flowchart of work for (a) general workflow of study (b) designing all 2-dimensional model

3. Results and Discussion

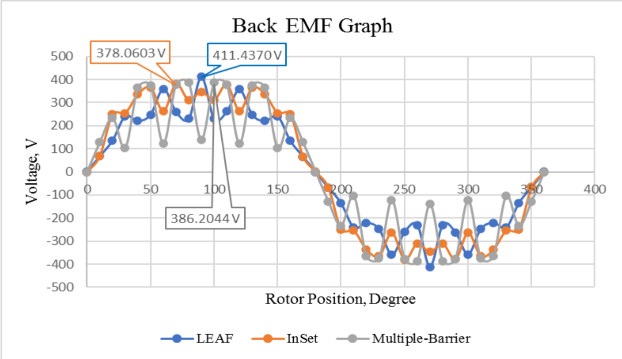
The design of the IPMSM motor for all design in 2-dimensional had been analyzed by using simulation software. In this chapter, a discussion about the design configuration that had been made will be presented.

3.1 No load test result

No-load analysis means no supply by the armature current density, JA. The IA is equal to 0A. The result for this analysis is zero rotor position, cogging torque and back EMF at the desired angle being compared between all models as shown in Figure 5.



(a) (b)

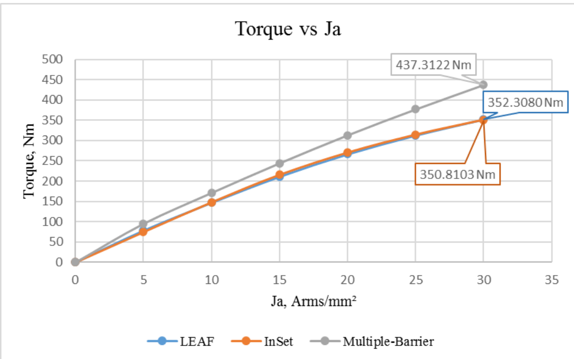


(c)

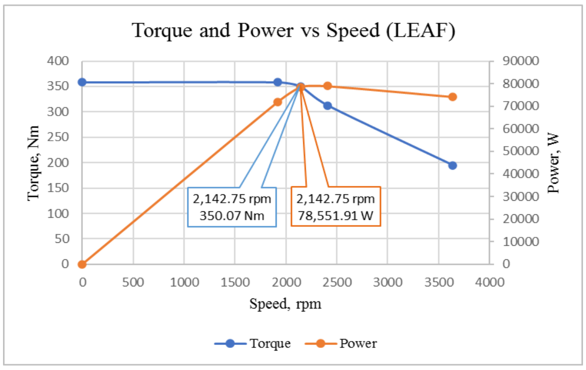
Figure 5: Result for no load test of (a) zero rotor position (b) cogging torque (c) back EMF

3.2 Load test result

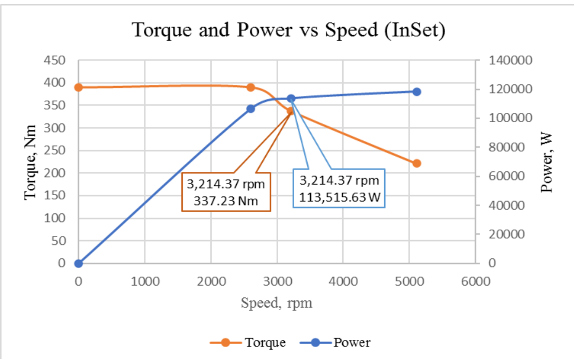
The load analyzes are based on a typical JA injection motor current density. Torque and flux connections at various JA sites are calculated for the injection in specific current value in the motor of the FEM coil to determine the pattern of torque variability. Check, and simulation for torque, power, and speed characteristics are performed in all three designs. During load checking, the power of the armature current is between 0 and 30 Arms / mm2. Figure 6 shows the result obtained after the simulation is done and comparison is made between all models.



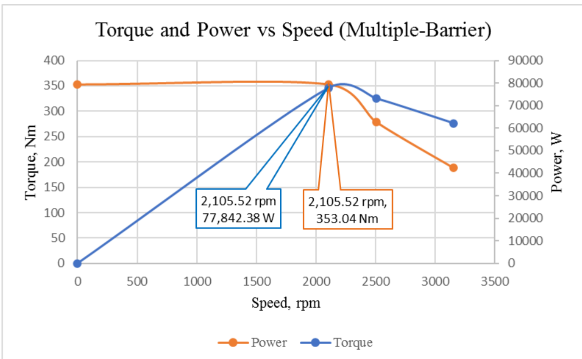
(a)



(b)



(c)



(d)

Figure 6: Result for load test of (a) toque vs Ja, (b)-(d) torque and power vs speed

4. Conclusion

In conclusion, the construction of three design of IPMSM for Nissan LEAF, InSet, and Multiple-Barrier and performance analysis such as no-load test and load test for all those three different rotor topologies in 2-dimensional design, succeed. Other than that, for the comparison of performance among three different rotor topologies in the 2-dimensional model that have been successfully analysed, based on the result obtained, InSet design was the best design of motor among Nissan LEAF and Multiple-Barrier design even though the cogging torque of InSet was higher. But still in overall InSet is the best design. For further recommendation, there is two suggestion that can be done for this project in the future which are all model can be designed in 3-dimensional to do thermal behavior analysis and water jacket can be added in all three designs so that the result obtained in a 3-dimensional model can be compared with the result obtain in 2-dimensional and the analysis can be done.

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