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Analysis of Various Modular Rotor Permanent Magnet Flux Switching Motor

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Abstract: In today's world, the Permanent Magnet Flux Switching Machine (PMFSM) has attracted researchers because of the high torque and power provided. In addition, the stator has both armature winding and PM excitation sources, and the salient pole rotor is relatively simple and strong. However, there is a major problem that occurs in the conventional rotor in the PMFSM such as a longer flux path, winding loss, and high iron loss. In addition, the conventional rotor has a higher weight which is not suitable for high-speed applications. Thus, this research introduced a new structure of the rotor called the modular rotor. The modular rotor has advantages that can reduce the mass of the motor and enables the reduction of iron losses. The performance of 6S-10P conventional PMFSM and 6S-10P, 6S-14P, and 12S-10P modular rotor PMFSM are analyzed at load and no-load conditions and the result for the maximum torque achieved, output power, and the weight of the PMFSM are observed. As a result, 6S- 10P conventional rotor design produced the highest maximum torque and output power among all the other designs with the value of 45.37 Nm and 10.77 kW. However, the total weight of conventional rotor PMFSM calculated is the heaviest which is 7.71 kg while 12S-10P modular rotor PMFSM has the lowest weight which is 6.42 kg.

Keywords: Flux Switching, Maximum Torque, Output Power, Iron Loss

1. Introduction

Permanent Magnet Flux Switching Motor (PMFSM) is a new type of motor having static armature winding and permanent magnets in the stator that provides large torque capability and high density of power which makes the PMFSM gained interest over the last few decades [1]. Flux switching occurs when the flux polarity is switched by the stator teeth, leading to the motion of a salient pole rotor. An excitation flux will be produced by a complete one cycle of rotation due to the flows of the permanent magnet from the stator to the rotor and oppositely. The principle of FSM is based on flux switching. The flux switching machine (FSM) is a type of salient rotor reluctance machine with a unique topology that combines the inductor generator and switched reluctance machine principles [2]. FSM is a brush-

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less machine with magnetic excitation and armature winding, such as a permanent magnet or field winding located in a stator [3] Although there are many advantages of PMFSM, unfortunately, the salient rotor in the PMFSM has a longer flux path, which results in significant winding loss and iron loss, resulting in poor motor performance [1]. Hence, a modular rotor intended as a new structure rotor will be designed in this project.

Modular rotor design comprises of non-overlapped winding arrangements between armature winding and a permanent magnet, and a modular rotor structure. In addition, due to the non-overlapped winding configurations, copper consumption is much decreased. Another advantage of a modular rotor is to light the rotor weight over the conventional rotor topology. Plus, iron losses and the rotor mass can be reduced significantly, and lower the use of stator back-iron without a diminishing in output torque. A modular rotor is convenient in reducing the mass of the motor and enables the reduction of iron loss so that motor performance can be increased. The modular rotor helps to decrease iron losses because it provides the shortest flux paths along the machine's iron core.

Basically, FSM is categorized into three internal sources which are Permanent Magnet Flux Switching Machine (PMFSM), Field Excitation Flux Switching Machine (FEFSM), and Hybrid Excitation Flux Switching Machine (HEFSM) [4]. PMFSM and HEFSM use a permanent magnet to generate the magnetic flux while FEFSM uses DC excitation to control the magnetic field density [5].

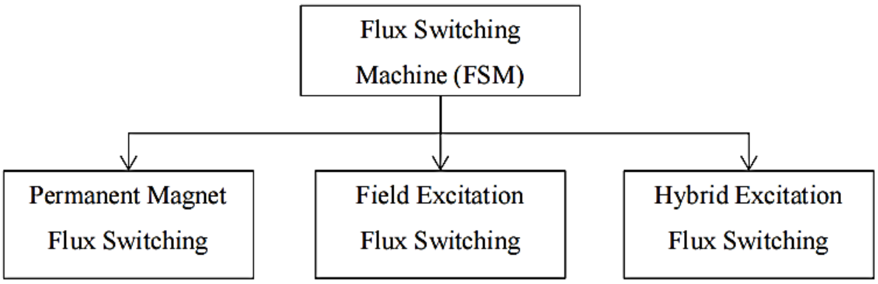


Figure 1: Categorization of FSM

2. Materials and Methods

2.1 Introduction to JMAG Software Version 16.0

JMAG is an electrical device development and design simulation software. JMAG was first introduced in 1983 as a design tool for devices such as motors, actuators, circuit components, and antennas. Plus, it is also utilized in motors, motor drives, big generators, transformers, solenoids, electronic devices, and induction heating. In addition, JMAG is capable of properly capturing and evaluating complicated physical events within machines. It has aided in the development of motors and actuators that are routinely used to operate electrical devices, as well as the design and development of hybrid automobiles and power electronics for Fuel Cell Vehicle (FCV) and Electric Vehicle (EV) applications. JMAG features a third-party software interface, and part of JMAG's analytical function may be implemented from a variety of CAD and CAE systems. Eventually, it is used as a link to the electronic simulator's power to examine the design at the system level, which includes the drive circuit.

2.2 Project workflow

This research focused on two parts, which are Geometry Editor and JMAG Designer. Geometry Editor is used to designing the 6S-10P conventional PMFSM and 6S-10P, 6S-14P, and 12S-10P modular rotor PMFSM. The workflow of this project is carried out according to the flowchart in Figure 2. The motor parts of the proposed design which are the rotor, stator, permanent magnets, and armature coils are drawn using the Geometry Editor. When the regions of each motorparts are correctly created, the materials, conditions, circuit, mesh and properties of the motor will be set using JMAG Designer then will be simulated and analyzed using 2D Finite Element Analysis (FEA) tools. After the running and simulation process of the motor has been done, the results for the proposed PMFSM design are compared in terms of the torque, speed and power of the motor.

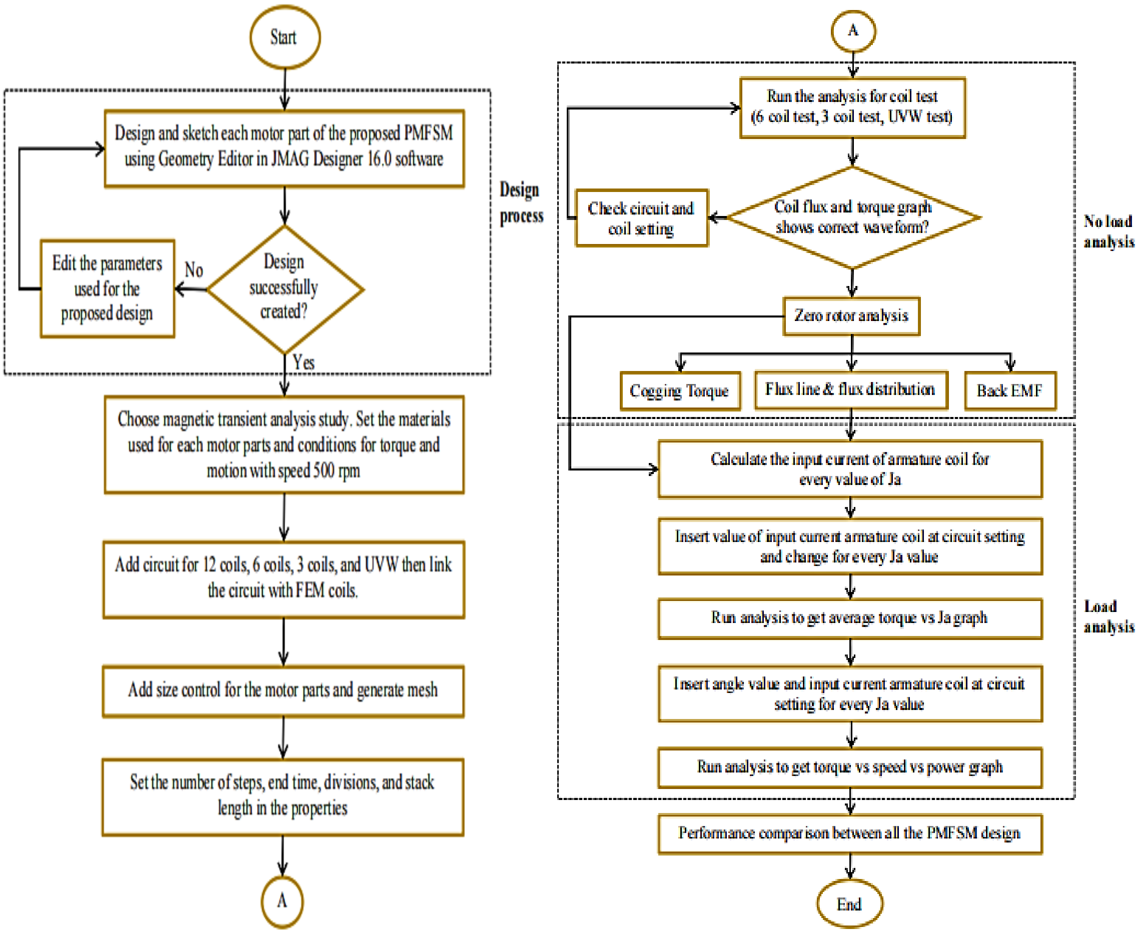


Figure 2: Workflow of PMFSM design

2.3 PMFSM Design

The proposed PMFSM design description and limitations are shown in Figure 3 and Table 1. Electrical restrictions associated with the inverter are set in the same way. Additionally, the current density for the armature coil varies from 0 A_{rms}/mm^2 to 30 A_{rms}/mm^2.

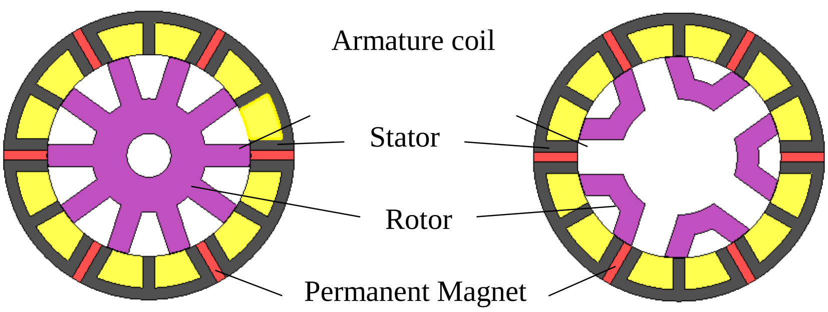


Figure 3: 6S-10P conventional PMFSM and 6S -10P modular rotor PMFSM

Table 1: Design parameters of all proposed PMFSM design

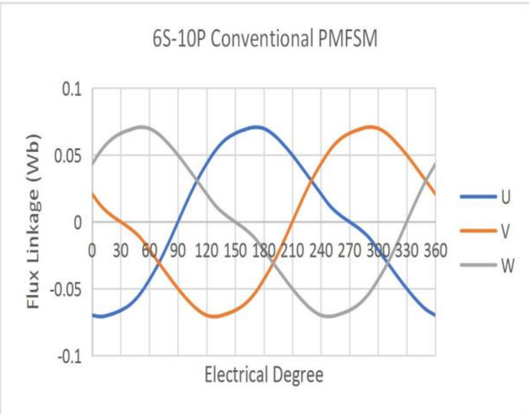
Parameters description	Unit	Conventional PMFSM
Stator outer radius	mm	75
Stator inner radius	mm	52.5
Stator back inner width	mm	6
Stator tooth width	mm	6
Stack length	mm	70
Air-gap length	mm	0.3
Rotor outer radius	mm	52.2
Filling factor	-	0.5
Speed of motor	rev/min	500

3. Results and Discussion

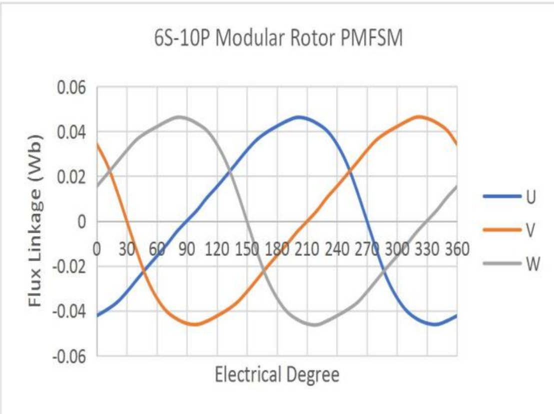
This section has examined the results of the proposed PMFSM. Results are shown in figures and graphs for better understanding.

3.1 Coil test and operating principle

Each coil underwent a coil arrangement test to confirm the armature coil placement and the principle of the proposed PMFSM. The main reason for this process is to categorize the like pattern flux linkage produced in each coil. The armature coil with the same pattern then is combined together to create U, V and W flux. Figure 4 shows the U, V, W test characteristics for 6S-10P conventional and modular rotor PMFSM. The maximum U flux observed for 6S-10P conventional PMFSM is 0.0708 Wb which is higher than 6S-10P modular rotor PMFSM with a flux linkage of 0.0463 Wb.



(a)



(b)

Figure 4: UVW test of (a) 6S-10P conventional PMFSM and (b) 6S-10P modular rotor PMFSM

3.2 Average Torque Vs Various Armature Coil Current Density

Torque is the amount of rotational force generated by a motor. In this result, the value of average torque at different armature coil current density are discussed. The input current of the armature coil will be higher when the J_A is increased. In addition, from the graph below, it can be seen that when J_A is increased, the average torque recorded also will be increased. The graph in Figure 5 shows the average torque vs various armature coil current densities for all the proposed design PMFSM. The average torque recorded at 6S-10P conventional PMFSM is the highest compared to other proposed designs which is 45.37 Nm. Then, it is followed by modular rotor PMFSM 6S-10P (35.27 Nm), 6S-14P (32.35 Nm), and 12S-10P (11.11 Nm). The higher the torque value produces in a motor, the greater its ability to perform.

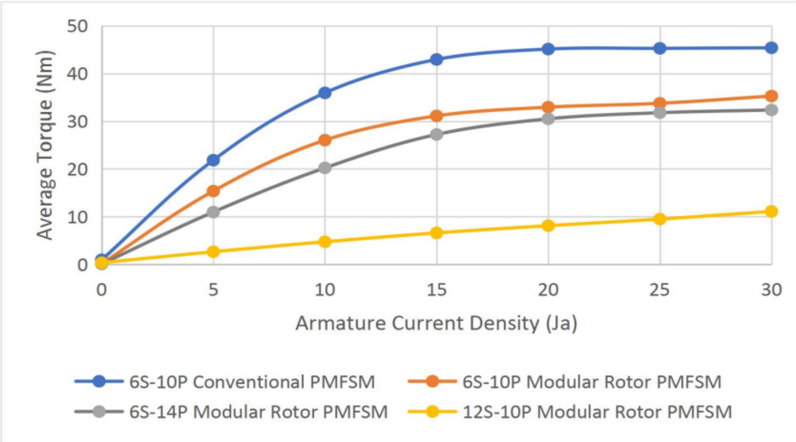
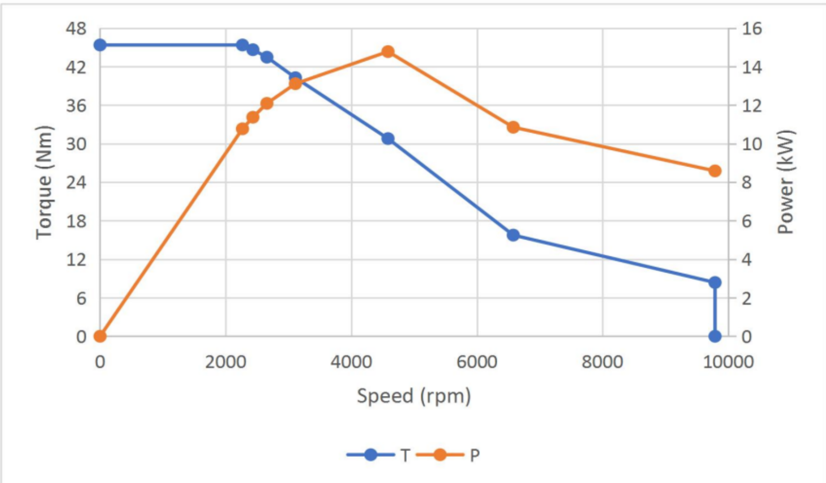


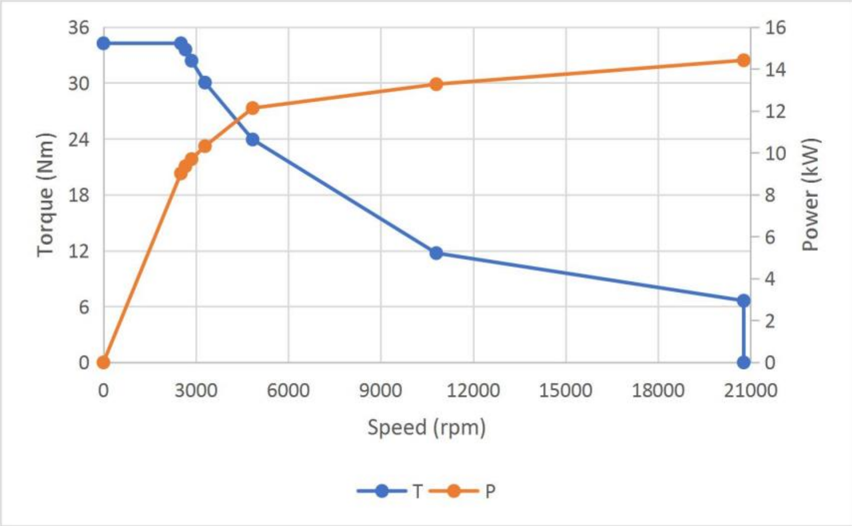
Figure 5: Average torque of all proposed design

3.3 Torque and Power vs Speed

The performance of torque and power vs speed for 6S-10P conventional and 6S-10P modular rotor PMFSM are analyzed in Figure 6. The blue line indicates the torque curve, while the orange line designates the power vs speed characteristic. For conventional motor 6S-10P, the maximum torque achieved is at 45.37 Nm at speed of 2267.2 rpm while the power obtained is 10.77 kW. The maximum power recorded is 13.11 kW at 3109.5 rpm. Next, for the 6S-10P modular rotor design, at speed of 2514.6 rpm, the maximum torque acquired is 35.27 Nm and the power obtained is 9.02 kW. As shown in Figure 6 (b), the power increases gradually until 14.42 kW when the speed increase.



(a)



(b)

Figure 6: Torque and Power vs Speed of (a) 6S-10P conventional PMFSM and (b) 6S-10P modular rotor PMFSM

4. Conclusion

In this research, the design study of 6S-10P conventional PMFSM and 6S-10P, 6S-14P, and 12S-10P modular rotor PMFSM has been analyzed at load and no-load conditions. The first objective which is to design 6S-10P conventional PMFSM, 6S- 10P, 6S-14P and 12S-10P modular rotor PMFSM has been conducted successfully. The final objective is to analyze and compare the performance of between 6S-10P conventional and modular rotor PMFSM. The analysis shows that the amount of torque and output power produced in the 6S-10P conventional rotor is higher than in modular rotor design. However, the 6S-10P conventional design has the highest weight compared to all modular rotor designs and is 1.07 kg higher than the 6S-10P modular rotor PMFSM. Furthermore, the performance of all the modular rotor designs also has been analyzed and compared. From the analysis, the 6S-10P modular rotor design has the highest torque and output power followed by 6S-14P and 12S-10P designs. Overall, all the objectives have been achieved in this study.

Acknowledgement

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