Improved Design of Three phase Hybrid Excitation Flux Switching Motor (HEFSM) with Segmental rotor

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Abstract. This paper presents the new design of Hybrid Excitation Flux Switching Motor (HEFSM) using segmental rotor structure. HEFSMs are those that consists all the excitation flux sources at their stator with robust rotor structure. The rotor is designed as segmental due to the reason that segmental rotor has ability to yield the magnetic path for conveying the field flux to nearby stator armature coil with respect to the rotation of the rotor. This design gives the clear advantage of shorter end winding compared to the toothed rotor as there is no overlap winding between field excitation coil (FEC) and armature coil. In this paper the initial design of HEFSM with segmental rotor has been improved by changing segment span, FEC slot area and armature slot area until maximum torque and power of 33.633 Nm and 8.17 KW respectively have been achieved. Moreover coil test analysis, induced voltage, cogging torque, magnetic flux characteristics, torque vs. field current density and torque vs. power speed characteristics are examined on the basis of 2-D finite element analysis (FEA).

Introduction

The first concept of flux switching machine FSM has been founded and published in the mid 1950s. A permanent magnet PM FSM i.e. permanent magnet single-phase limited angle actuator or more well-known as Laws relay, having 4 stator slots and 4 rotor poles 4S-4P has been developed [1], it has been extended to a single phase generator with 4 stator slots, and 4or 6 rotor poles [2]. Over the last ten years, many novel and new FSMs topologies have been developed for various applications, ranging from low cost domestic appliances, automotive, wind power, aerospace, etc. FSMs can be categorized into three groups that are permanent magnet PM FSMs, field excitation FE FSMs, and hybrid excitation HE FSMs. Both PMFSMs and FEFSMs have only PM and field excitation coil FEC, respectively as their main flux sources, while HEFSMs combines both PM and FECs [3-4]. Among all FSMs, the FEFSM offers advantages of magnet-less machine, low cost, simple construction, and variable flux control capabilities suitable for various performances. Moreover, to form the FEFSMs, the PM excitation on the stator of conventional PMFSMs can be easily replaced by DC FEC. In other words, the FEFSMs are a form of salient-rotor reluctance machine with a novel topology, combining the principles of the inductor generator and the SRMs [5-6]. The concept of the FEFSM involves changing the polarity of the flux linking with the armature coil windings, with respect to the rotor position. Early examples of single-phase 4S-2P FEFSM that employs with a DC FEC on the stator, a toothed-rotor structure and fully-pitched windings on the stator is shown in Fig. 1 [7]. From the Fig it is obvious that both armature coil and FEC windings are placed in the stator which overlapped each other. The viability of this design has been demonstrated in various applications requiring high power densities with a good level of durability [8-9].

Since FESFM and PMFSM discussed above posses an overlapped winding between DC FE Coil and armature coils that cause higher coil end length. To overcome this draw back a 12S-8P FESFM and PMFSM with adjacent DC FE coil and armature coils using segmental rotor have been proposed as illustrated in Fig. 2 and Fig.3 [10]. Segmental rotor has the ability to provide magnetic path for transmitting the field flux to nearby stator armature coil with respect to rotor position. This design presents shorter end windings with non overlapping coil when compares to salient rotor arrangement having overlapping coils. It has considerable gains due to the reason that it utilizes less conductor materials and has further improvement in overall machine efficiency [11-12].

While PMFSM and FEFSM using segmental rotor generate very low torque. To improve the torque generation a new structure of HEFSM using segmental rotor is proposed, in which effects of PM and FE coil are combine to produced maximum torque.

This paper presents the improved design and performance of 12S-8P HEFSM using segmental rotor as shown in Fig. 4. Furthermore coil test arrangement, cogging torque, induced voltage, torque at various field current densities and torque vs. power speed characteristics are observed based on 2D-finite element analysis (FEA).

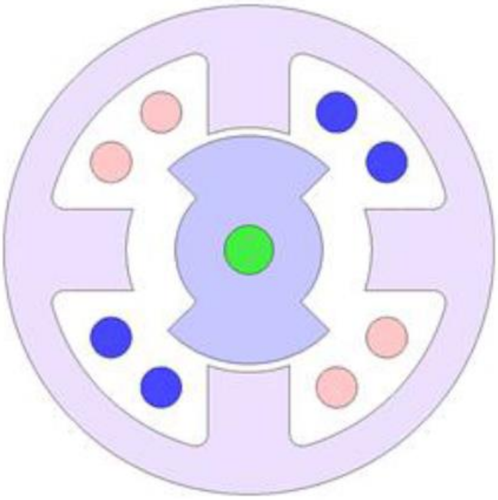

Fig. 1, Single phase 4S-2P FEFSM

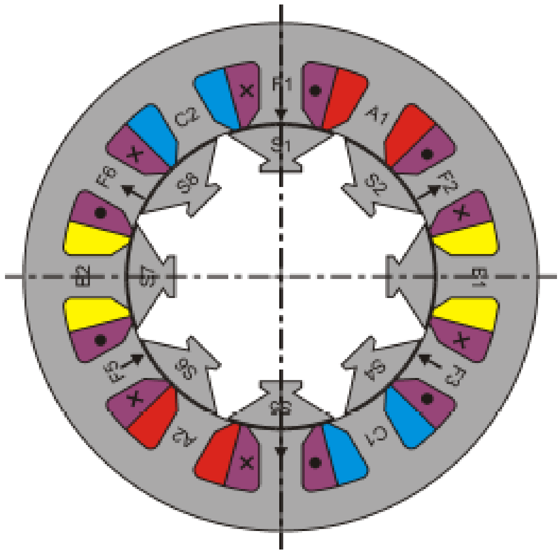

Fig. 2. 12S-8P FEFSM with segmental rotor

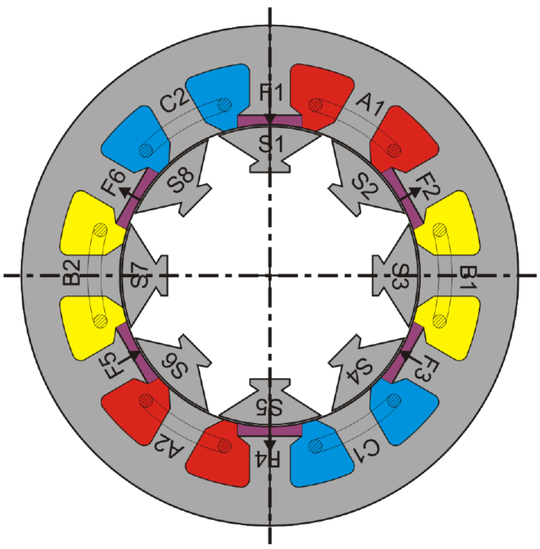

Fig. 3, 12S-8P PMFSM with segmental rotor

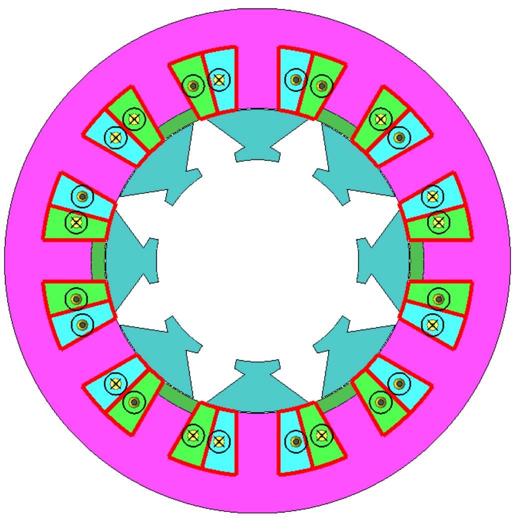

Fig. 4, Coil arrangements of HEFSM with segmental rotor

Coil test analysis

To verify the operating principle and to find the proper position of each armature coil phase of the proposed HE FSM with segmental rotor, arrangement of coil tests are performed separately as shown in Fig. 4. It is obvious that all armature coils and FEC are arranged in alternatively directions between adjacent slots while the PMs are alternatively arranged in the radial direction. With this arrangement of coils and PM direction three phase flux linkage is defined as U, V and W with maximum flux linkage of approximately 0.06Wb as shown in Fig.5.

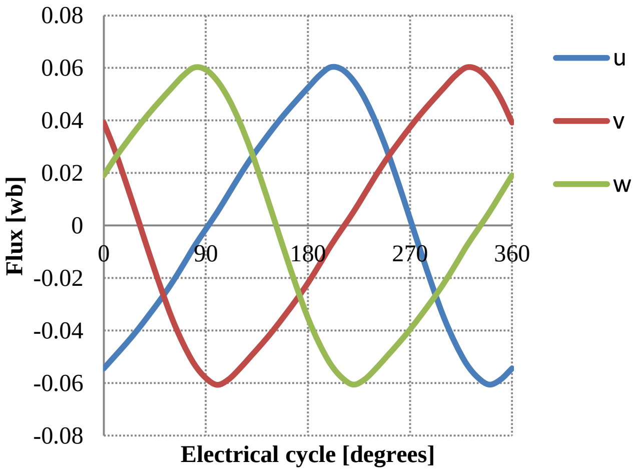

Fig. 5, Flux linkages of HE-FSM with segmental rotor in terms of U, V, W

Effects of segments span, FEC slot area and armature coil slot area on initial design

Segment span is the angle between two edges of the segment as shown in Fig. 6. Figure shows the segment span of rotor segments at 39^0 and 40^0. Fig. illustrates that by reducing the segment span of initial design from 40^0 to 39^0 the area of the segment is decrease and at same time distance between two segments is increased to avoid the flux leakage between two segments as shown in Fig. 7, and Fig.8. Red circles in Fig.7, shows the flux leakage between two adjacent segments. On the other hand by changing the slot areas of FEC and armature coil the optimum area is found to achieve the target and flux distribution is also improved as shown in Fig.8.

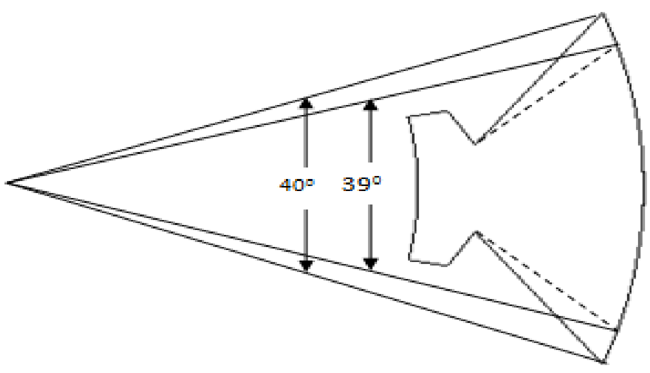

Fig. 6, Segment of the rotor at 39^0 and 40^0 span

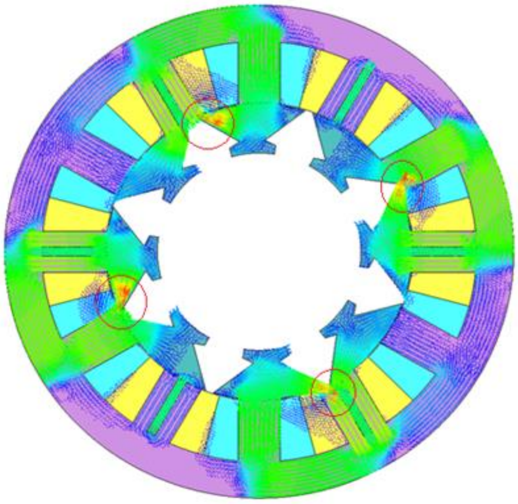

Fig. 7, Magnetic flux lines of Initial design of HEFSM with segmental rotor

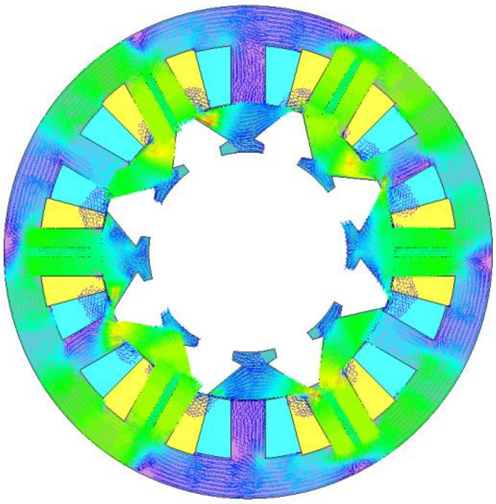

Fig. 8,.Magnetic flux lines of improved design of HEFSM with segmental rotor

Magnetic flux characteristics. Magnetic flux characteristics of initial design and improved design of HEFSM with segmental rotor are shown in Fig.9. It is obvious that improved design has high flux strength of approximately 0.06 Wb than initial design that has value of 0.049 Wb. Due to the effects of changing the slot areas of FEC and armature coils and segment span the flux strength is increased and target torque is also achieved but it is also estimated that this design also will be improved more by further optimization.

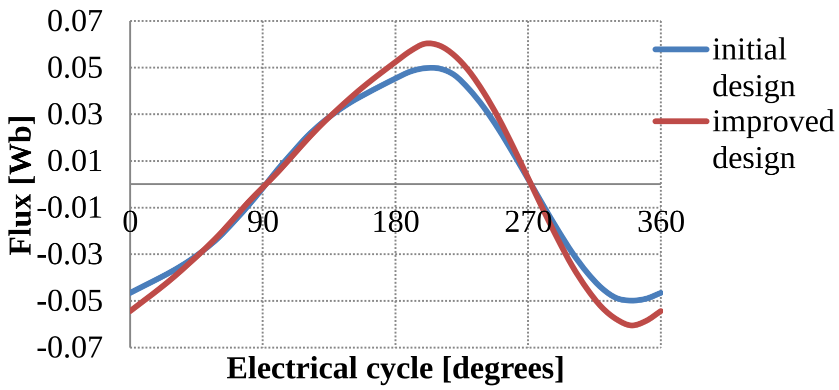

Fig. 9, Magnetic flux characteristics of Initial design and improved design of HEFSM with segmental rotor

Cogging torque analysis. Fig.10. shows the cogging torque of initial and improved design of HEFSM with segmental rotor. From Fig. it is clear that the improved design has best result of cogging torque approximately 3.3Nm where as the initial design has value of approximately 8.09 Nm that is more than improved design. It is also expected that this value will more reduced to the optimum value by future work.

Induced voltage at no load condition. The induced voltage produced from PM and FEC at maximum current density of Je=30A/mm^2 under speed of 500 rpm for initial and improved design of HEFSM with segmental rotor are illustrated in Fig.11. it is noticeable that the value of improved design is more that is approximately45.5V followed by initial design that has the value of 36.7 V. However there exists some distortion in the wave form due to odd harmonics but the values in both cases are less than the applied voltage that confirm the motor to be worked on safe region.

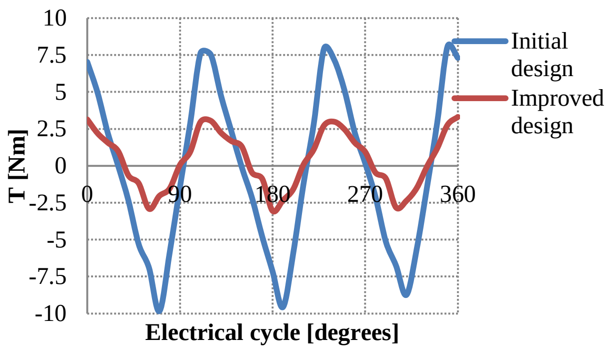

Fig. 10, Cogging torque of initial and improved design of HEFSM with

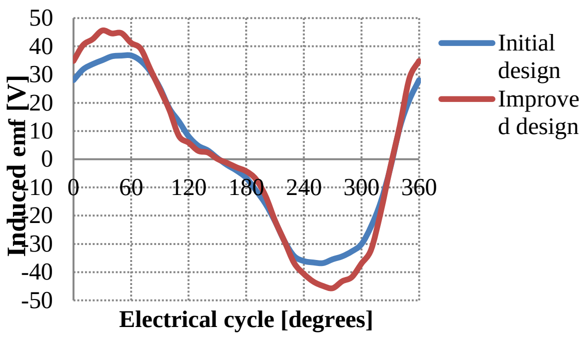

Fig. 11, Induced voltage of initial and improved design of HEFSM with segmental rotor

Torque vs. Field current densities Je, at armature current density Ja of 30 Arms/mm^2

Torque vs. field current densities Je, at armature current density of 30 Arms/mm^2 of initial design and improved design with segmental rotor structure is illustrated in Fig. 12. Fig. shows that initial design has value of torque approximately 32.25 Nm. On the other hand improved design of HEFSM with segmental rotor has attained the target value of torque and reaches to the value of approximately 33.633 Nm. It is also expected that value of torque will be improved further up to the optimum value by further optimization.

Torque and power vs. speed characteristics of improved design

The torque and power vs. speed characteristics of improved design of HEFSM with segmental rotor is shown in Fig.13. Blue curve shows the torque and red curve shows values of power. Fig.13. shows that at base speed of 1857.9 rpm the torque obtained is 33.633Nm as maximum and the corresponding power obtained is 6.543 KW. The graph of power is increased directly as the speed is increased and reaches at maximum value of 8.17KW and then started to reduce due to the core losses as the speed increased.

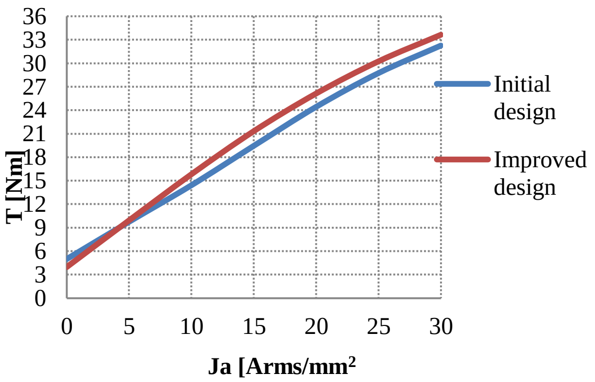

Fig. 12, Torque vs. Je at Ja of 30 Arms/mm^2 segmental rotor.

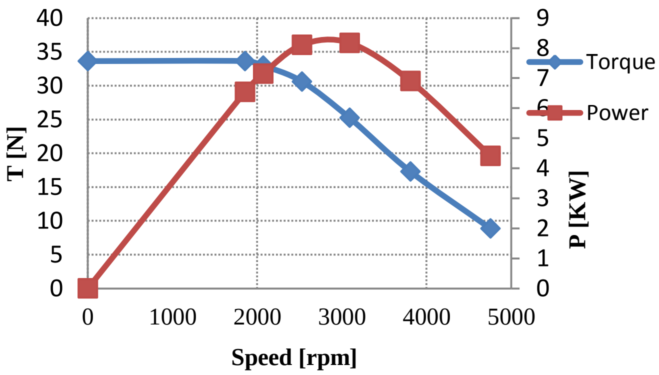

Fig. 13, Torque and power vs. speed characteristics of improved design

Conclusion

This paper has discussed and demonstrated the design improvement of 12S-8P HEFSM using segmental rotor. The objective of research was to find target values of torque and power that are achieved approximately 33.633 Nm and 8.17 KW respectively. It is also expected that these values will be further increased by further optimization. On the other hand flux is easily transferred through the segments of the rotor to make complete cycle and increases the torque value. Besides this coil test analysis, cogging torque, induced voltage, torque vs. field current density and power vs. speed characteristics are also examine on the basis of 2-D finite element analysis (FEA).

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