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3D FEA Based Investigation of the Torque Production Capability of Different Rotor Topologies of Three Phase PMSMs

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Abstract: Permanent Magnets Synchronous Machines (PMSMs) are considered as the promising electromagnetic structure, especially for electric and hybrid propulsion applications. This work classifies the PMSMs in two topologies such the surface mounted and the flux concentrating machine. A 3D Finite Element Analysis (FEA) based investigation of the output torque of the proposed claw pole transverse flux permanent magnet machine (TFPM) topologies for Performance improvement by increasing the output torque, doing so the three phase machine output torque of these topologies are analyzed. The outer rotor design is analyzed also to compare the torque production capability between the inner and outer rotor structure.

Keywords: (PMSMs)claw pole(TFPM); two topologies ; three phases ; output torque; inner rotor; outer rotor.

INTRODUCTION

Compared to the induction and electrically excited machines PMSMs presents the advantages of high power density , no additional power supply for the field excitation and high efficiency. Different concepts in R&D are considered and discussed to address the features of different mechanical structures and to find the promising mechanical structure.

The PM machines are classified by both the direction of flux path and the structure as the following.

- The radial flux PM machine (RFPM),
- The axial flux PM machine (AFPM),
- The transverse flux PM machines (TFPM)

The transverse flux permanent magnet machine (TFPM), Introduced in the middle of the eighteenth's by Weh [1], is currently given an increasing attention, especially in electric and hybrid propulsion applications, Currently, many automotive manufacturers are involved in R&D projects focusing efficient and cost effective designs [2]. Although significant works have been carried out on the earlier topologies, much improvement of the TFPM performances is still required. Claw pole TFPM combine the advantage of high specific torque and the ease manufacturing, It allows an easy assembly of any number of axially arranged phases. Two topologies of claw pole TFPM are considered. The first one is the surface mounted magnets claw pole. The second one is the buried mounted magnet claw pole topology with flux concentrated design.

In a previous work [3]-[4], a claw pole with 234mm rotor diameter and 80 poles is studied for the choice of an optimized design, the rotor is made up of buried magnets alternated with soft magnetic composite (SMC) blocs, A 50 pole concept of claw pole TFPM is constructed at university of Newcastle, the flux leakage is studied in [6], the rotor is made up of surface mounted magnets. Guo with university of technology of Sydney [7] compared between two types of 20 poles TFPMs with surface mounted magnets. For instance, a comparison between the buried magnets claw pole topology and with surface magnets one is required considering the same dimensions and pole pair number and the same features of the used material. Although the claw pole with flux concentrating topology, exhibits at first glance a higher output torque, which reduces the magnet volume and machine cost, a comparative study and a FEA of the two topologies is required to improve the TFPM performances, the outer rotor structure with the same dimensions must be analyzed to compare the torque production capability and the torque density, the paper develops this idea.

INTRODUCED CLAWPOLE TOPOLOGIES

As illustrated in figure 1-a for a single phase 40 pole concept of a claw pole TFPM The stator magnetic circuit is made up of SMC Somaloy 500 (0.6% LB1) [5] which is suitable for high-frequency operation and offers the feasibility of smooth 3D flux path.. It consists of a cylindrical set cut into two parts with claw pole teeth facing the rotor magnetic circuit. The stator electrical circuit is a simple ring winding which is inserted in a circumferential slot, in between the two parts of the stator SMC-made magnetic circuit. The rotor magnetic circuit is made up of buried magnets with tangential magnetization mounted with opposite magnetization in a flux concentrating arrangement alternated by SMC-made blocs who represent the rotor poles. One other topology where the stator as previously described and the rotor magnetic circuit is made up of 40 surface magnets with radial magnetization, representing the rotor poles, the (Sm–Co)magnets are mounted with opposite magnetization and alternated by aluminum made blocs (non magnetic material). A necessity of an inner SMC cylindrical part is required for the flux continuity as shown in figure 1-b for a single phase concept.

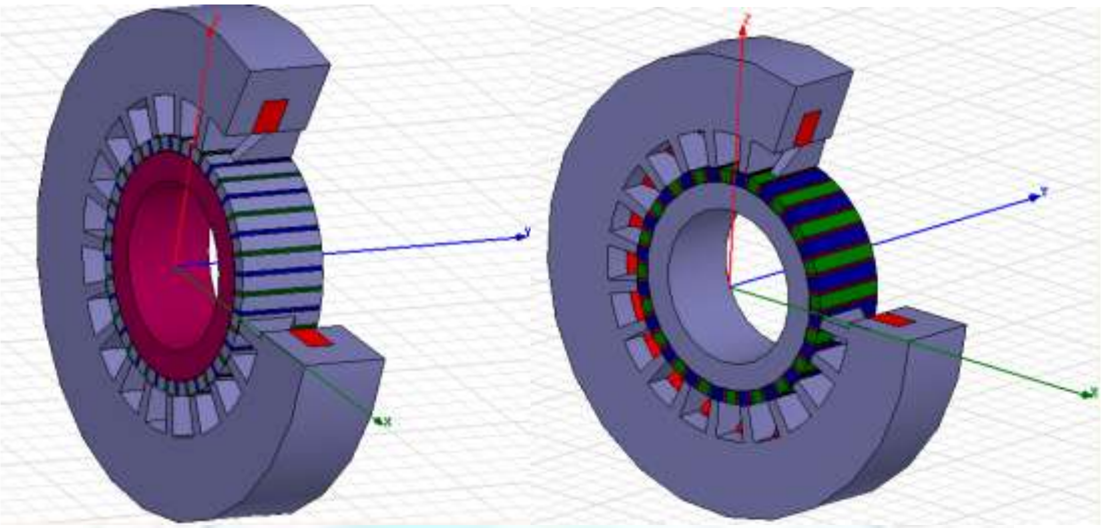


Fig 1: Single phase with (a) buried magnets topologyand (b) surface magnets topology

Flux Path Through the Claw Pole Magnetic Circuit

A. Buried Magnet Topology

The flux flows through the magnetic circuit within 3 D paths as illustrated in figure 2-a. These paths can be described as follows:

- Circumferentially through two adjacent magnets, into the rotor SMC-blocs which are considered as a rotor north poles,
- Radially across the air gap into the stator teeth considered as a stator south poles,
- Round the core back and into the two nearest teeth on the other side of the stator,
- Radially down these stator teeth (stator north poles),
- Back across the air gap and into the adjoining rotor SMC-blocs (rotor south poles) on the other side of the rotor,
- Finally, the flux flows circumferentially into two opposite paths to penetrate the buried magnets with opposite magnetization.

B. Surface Magnet Topology

The flux paths as illustrated in figure 2.b, these flows:

- Radially through the rotor magnets, witches are the rotor north poles,
- Radially across the air gap into the teeth
- Round the core back
- Radially down the stator north poles,
- Back across the air gap and adjoining rotor magnets (rotor south poles) on the rotor,
- Back through the magnets to adjoining the rotor magnetic circuit made of SMC,
- Finally, the flux flows radially and circumferentially into two opposite paths to penetrate the magnets with opposite magnetization (rotor north poles).

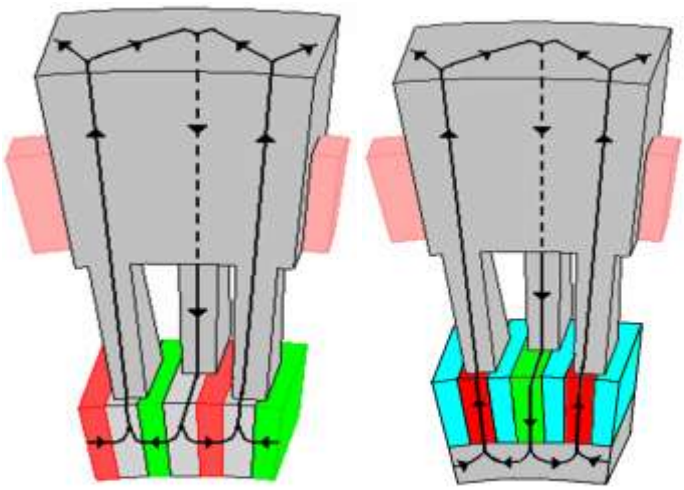


Fig 2: Flux path for (a) Buried magnet topology (b): Surface magnet topology

FEA of the Designed Topologies

A. FEA study domain

The FEA is limited to a study domain which represents two pole pitches of the total domain. The study domain presents 18°-mechanical angle. Figure 3 illustrate the rotor study domain of the claw pole with surface mounted magnets and the magnetic flux distribution. Figure 4 illustrate the flux distribution in the stator teeth and in the rotor study domain of the buried magnet topology.

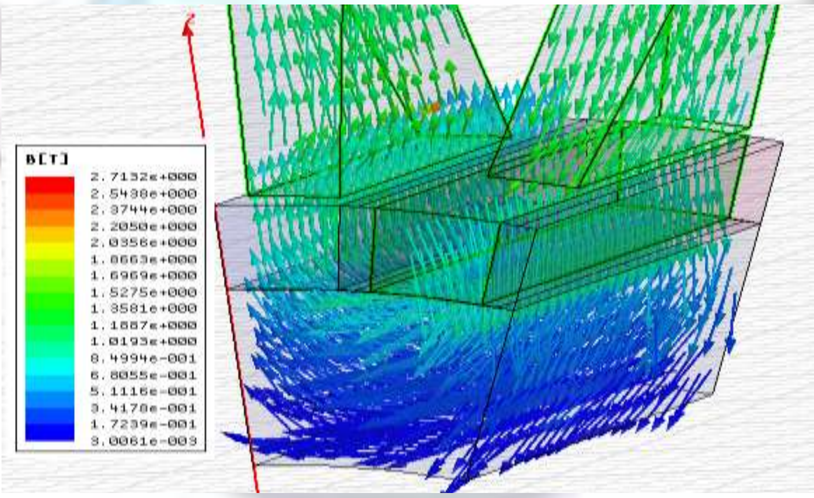


Fig 3: Study domain of the surface magnet topology

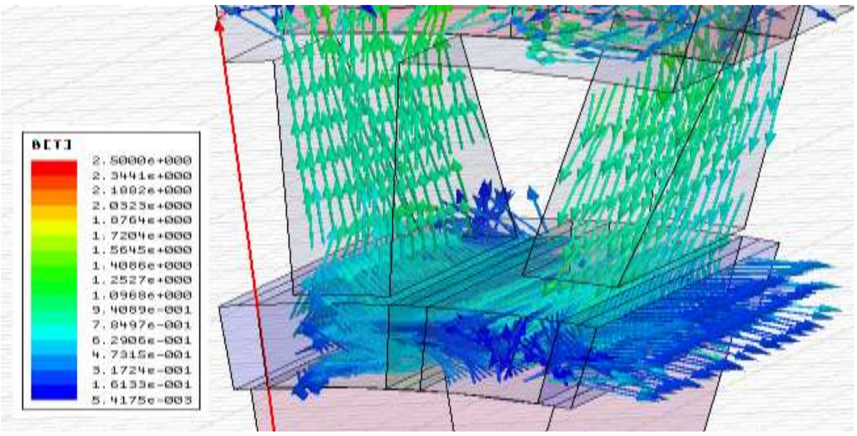


Fig 4: Study domain of the buried magnet topology

B. Influence of the Magnet Opening Angle

Varying the magnet arc angle is a technique applied in most permanent magnet machine to improve the machine performance[8]. This technique consist of the study of the influence of the magnet opening angle on the output torque and in what follows, be applied for the surface and the buried magnet claw pole topologies to analyze the influence of this parameter on the machine performance and cost effectiveness directly linked to the rotor magnet opening angle. While applying this technique for adjusting the magnet opening angle, the other dimensional parameters are kept constant.

C. FEA Results and Comparison

The magnet thickness of 5mm kept constant, for the two topologies, the same excitation current density of 6 106 A/m2 and the pole pitch angle is 9°-mechanical angle corresponding to 180°-electrical angle, considering the rotor position of 4.5°-mechanical angle while varying only the magnet opening angle the obtained results are illustrated in figure 5. The output torque of the buried topology is higher than the torque obtained with surface magnet one. Considering the opening angle of 90°-electrical angle one have up to three time greater torque, For performance improvement of the surface mounted topology using this technique, the torque is proportional to the magnet opening angle and the highest value is of 4.8 Nm for a 180° magnet opening angle (a pole pitch). From the point of view cost effectiveness the best choice is the buried magnet topology with 90° magnet opening angle because the highest torque is almost constant of 7 Nm while varying the magnet opening angle between 90° and 160°,

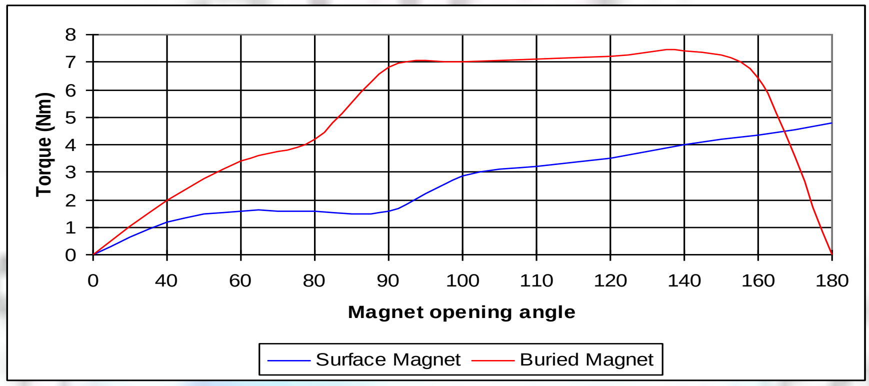


Fig 5: magnet opening angle influence on the output torque

D. Torque-Angle Curves

In what follow, we consider the torque-angle curves of the three phase topologies with 5mm height illustrated in figure 6, the magnet opening angle is of 90°for the buried magnet topology, the three phase surface magnet topology with 180° opening angle is considered also. The obtained results are illustrated in figure7. Of particular interest is the increase of the output torque which attempt 12.5Nm in the case of the buried magnet topology with buried magnets, compared to 9 Nm obtained with the surface magnet one. Such increase reaches about 3.5Nm in the maximum output torque. The torque-angle curve of a single phase surface magnet topology present a lower torque peak value of 5.5Nm compared to 9 Nm obtained with the half magnet volume of the buried magnet topology.

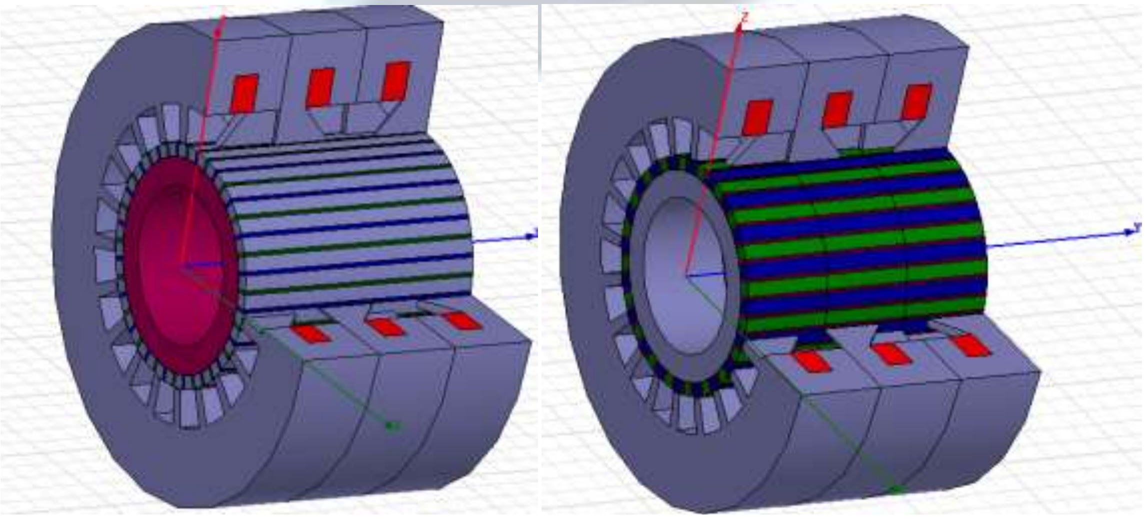
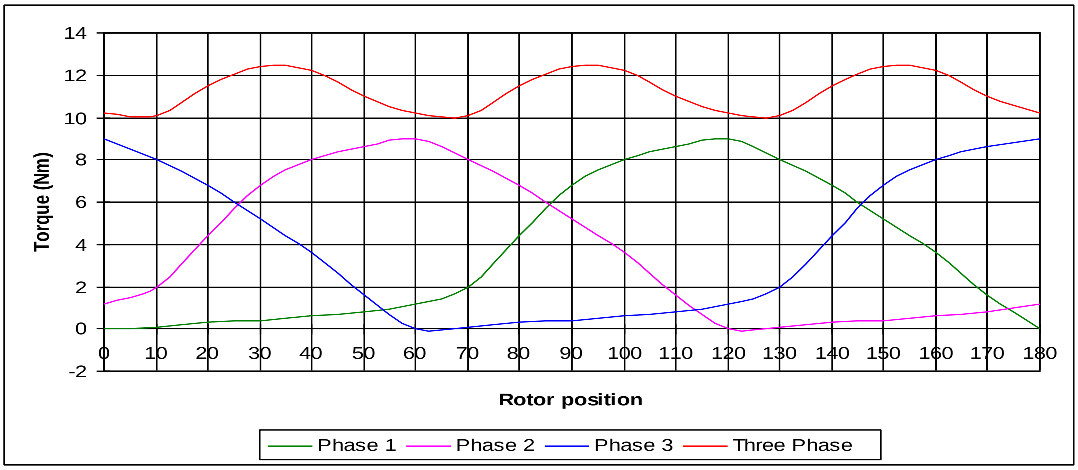
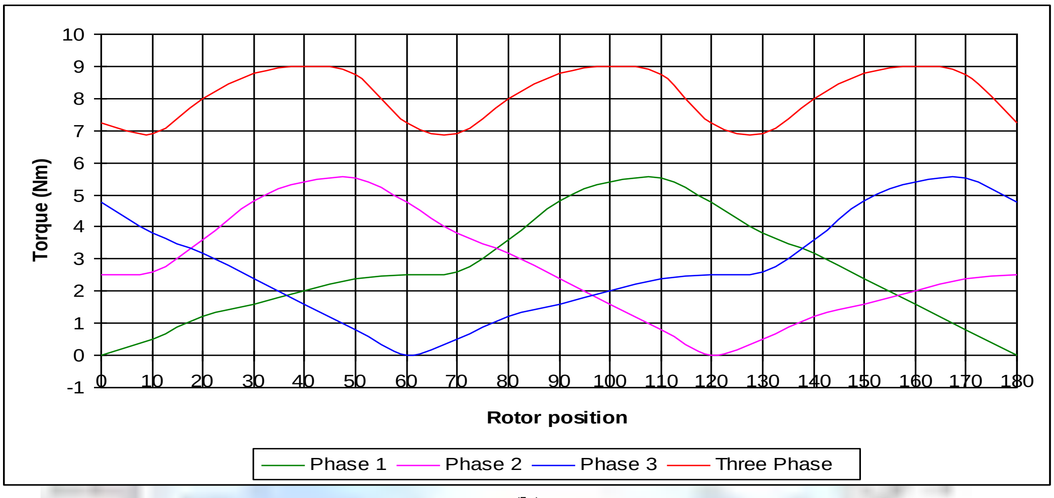


Fig 6: Three phase machine (a) with buried magnets (b)surface magnets



(a)



(b)

Fig 7: Torque-angle curves of the three phase machine (a)buried magnettopology (b) surface magnet topology

The claw pole TFPMs suffers from the high value of the cogging torque which decreases the machine performances [9], the cogging torque amplitude is highest in the case of the buried magnet topology, the week value of the cogging torque of the surface mounted topology lead to the flux shuntage phenomenon, figure 8 illustrate the flux vectors in the rotor poles and the teeth ends to explain the phenomenon.

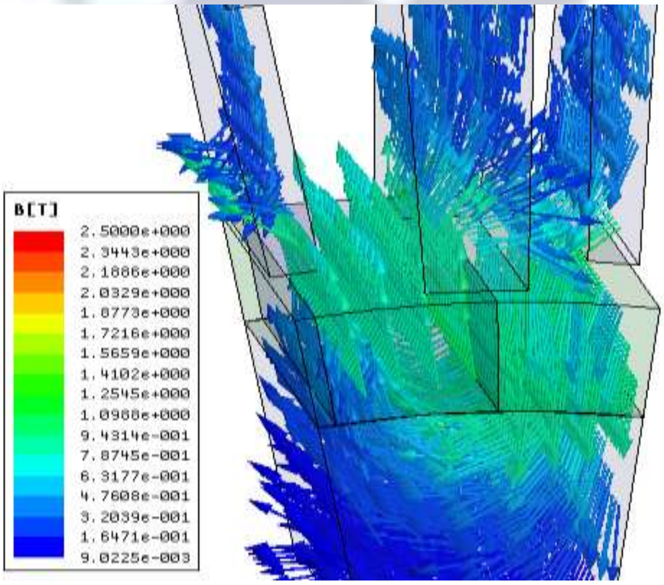


Fig 8: Flux shuntage phenomenon

Claw Pole with Outer Rotor Design

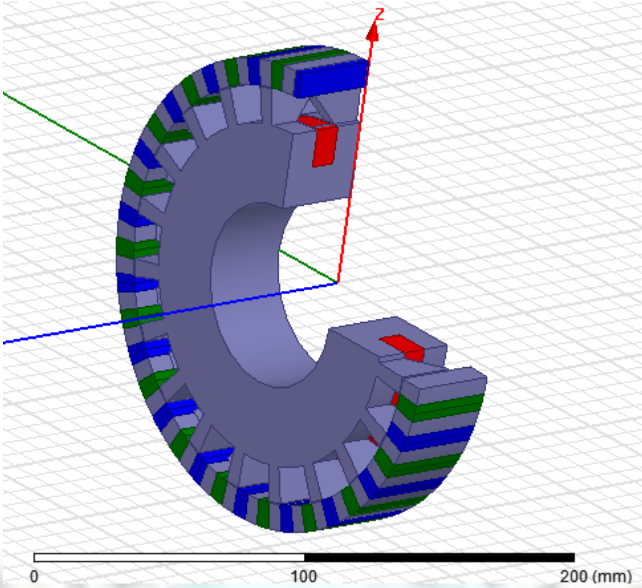


Fig 9: Outer rotor machine with buried magnets

As illustrated in figure 9 the outer rotor clawpole TFPM design consist of making the the two stator parts with the teeths fabricated over the winding and the rotor is in rotation outer the stator parts, for the comparison with the last presented topologies the used outer rotor diameter is equal to the stator outer diameter of the inner rotor design , the TFPM length is the same also to obtain the same machine volume, doing so only the airgap diameter is higher and the magnet volume is increased also, the FEA study of the designed machine gives the result obtained in figure 10 of the output torque –angle curve the peak value is almost ten time greater than the obtained with inner rotor, this is explained with the fact of the increase of the airgap diameter and the rotor larger depth of magnets , this higher torque production capability unfortunately accompanied with a high amplitude of the resulting cogging torque, the skewing technique present a solution to this problem by inclining the rotor elements with one slot pitch [4].

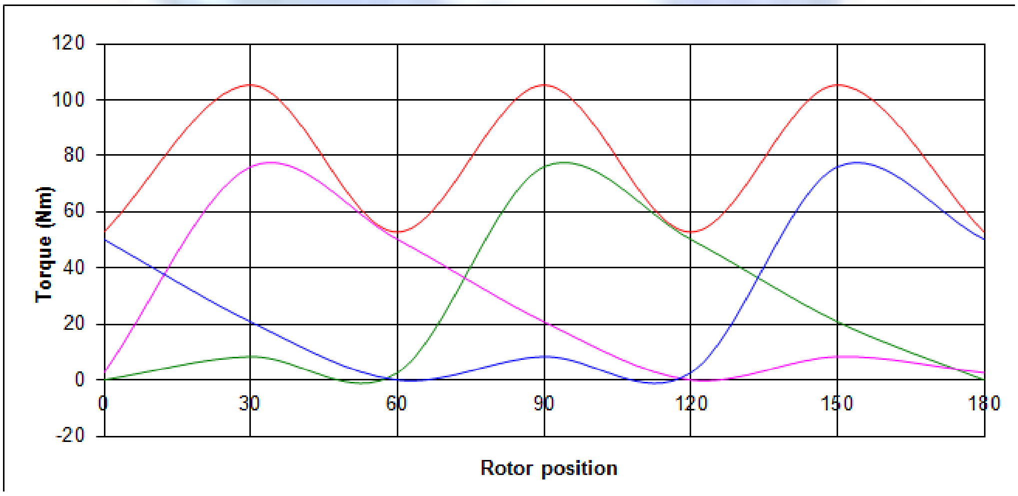


Fig 10: Torque-angle curves of the three phase outer rotor machine with buried magnet topology

Conclusion

Two topologies of the claw pole TFPM are distinguished, the structure and flux path are different. The magnet opening angle technique is applied in the case of the two claw pole TFPM topologies. Doing so, the magnet arc has an important effect on the machine torque production capability. For performance improvement of the surface mounted topology, a highest torque is obtained for a 180° magnet opening angle, with a week value of the cogging torque due to the flux shuntage phenomenon. In spite of the buried magnet topology with a half magnets volume (90° magnet opening angle, 5mm height) exhibits 7 Nm as a highest torque, and for almost the same magnets volume (90° magnet opening angle, 10mm height) we obtain 12 Nm as highest torque, but the cogging torque amplitude reach important values which degrading the motor performance. This problem is solved with a three phase machine as mentioned above. The study of the outer rotor structure of the claw pole TFPM with the same volume gives a torque peak value almost ten time greater than the obtained with inner rotor, this is explained with the fact of the increase of the air gap diameter and the increase of the magnets depth and volume in the rotor, giving so a higher torque production capability and a higher torque density.

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