3rd International Conference on Automation, Control, Engineering and Computer Science (ACECS'16)

Proceedings of Engineering & Technology (PET)
pp. 207-212

Influence of the magnets shape on the performance of a surface mounted permanent magnet motor

Mel Hajer
CES Laboratory
Engineering School of Sfax
Sfax, Tunisia
hajermel@gmail.com

Ali Mansouri
CES Laboratory
Engineering School of Sfax
Sfax, Tunisia
Mansouriali2002@yahoo.fr

Hafedh Trabelsi
CES Laboratory
Engineering School of Sfax
Sfax, Tunisia
Hafedh.trabelsi@yahoo.fr

***Abstract*—much attention has been recently paid to the design of electrical machines. Indeed, many researchers focus their efforts on making progress in this domain. In this paper, a permanent magnet synchronous machine (PMSM) is selected to be designed and studied. The machine features in terms of air gap flux density and torque production capability are investigated. A particular interest is paid to the magnetic configuration of the rotor. In this connection, an innovative magnets stricture is presented. Finally, and in order to show the influence of the magnets shape in the performance of a PMS motor, a comparison between the proposed topology and a standard one in term of performance is discussed.**

***Keywords*— Permanent magnet machine; Design; Output torque; Finite Element Analysis; Magnetic field; Magnets shape.**

I. INTRODUCTION

Nowadays, the design of electrical machines is evolving due to the increase of the industrial demands and the diversity of the domain of applications. So companies aim to accelerate the renewal of their products in the area of electrical machines to elaborate novel structures adaptable of each domain [1].

In this context, permanent magnet synchronous machines (PMSM) have wide range applications in different fields thanks to their advantages such as flexibility of control, higher torque capability, higher power density, higher efficiency, low weight and smaller size [2]. These machines are widely used in many applications such as electric and hybrid vehicle traction [3, 4], robotics, renewable energy and aerospace technology [5]. They tend to replace the conventional induction machines as they present extra features. Indeed, this choice is based on the rotor copper losses reduction compared to the conventional induction ones and the improvement of the torque production capability by this type of machines.

An investigation in literature reveals different permanent magnets machine configurations like radial flux, axial flux, transversal flux, slotted stator or a stator without slots, inner or outer rotor... Based on the arrangement of magnets in the rotor part, different topologies of PMSM are presented in [6].

In the present work, the proposed topology is a radial flux inner rotor surface mounted permanent magnets machine within stator slots. This choice is basically due to its low maintenance cost and mechanical robustness. The design process is based on the finite element analysis (FEA). Some machine characteristics such as torque production capability and air gap flux density are presented. Finally, a comparison between the proposed topology and a standard one in term of performance is mentioned.

II. STUDIED TOPOLOGY

The studied topology as it has been mentioned in the previous section is a synchronous surface mounted permanent magnets motor (PMS motor) with radial air gap flux with inner rotor. The studied machine data is a 3 phases, 4 poles, and 48 slots configuration.

The proposed topology is illustrated in the following figure.

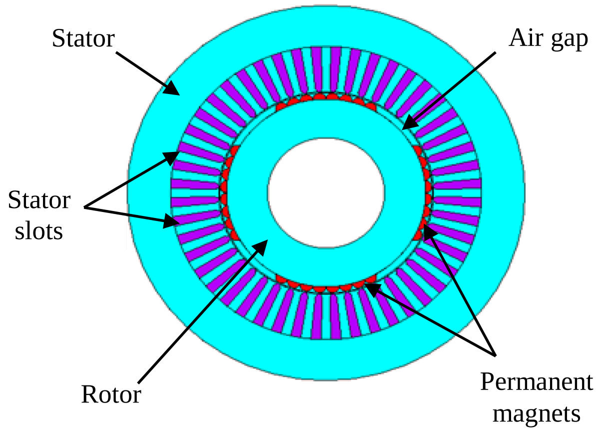

Fig. 1. Studied PMSM

The physical environment of the analyzed machine is defined using different materials models [7, 8]. The stator part is made up of non linear laminated iron and three-phase stator armature windings. The rotor part is constructed of iron core as well. The non linear model for ferromagnetic regions (rotor and stator core) is defined by a B (H) curve. The permanent magnets (rare earth Neodymium- Iron-Boron (NdFeB)) which are mounted on the rotor core surface are characterized by a constant value of a relative permeability μr (μr=1.05) and a constant value of a remanence flux density Br (Br =1.1).

In order to study the magnetic circuit of the selected PMSM, a 2D steady state finite elements analysis (FEA) is

ISSN: 2356-5608

carried out. The investigated magnetic circuit turns to be quite complex for modeling by (FEA) as it's characterized by complex phenomena [9] such as non linearity, saturation, and the complexity of the geometry… Hence, owing to the advantages of symmetry and periodicity of the proposed structure, the present work is limited to 2D and to one quarter of the machine. The studied domain is illustrated in Fig. 2.

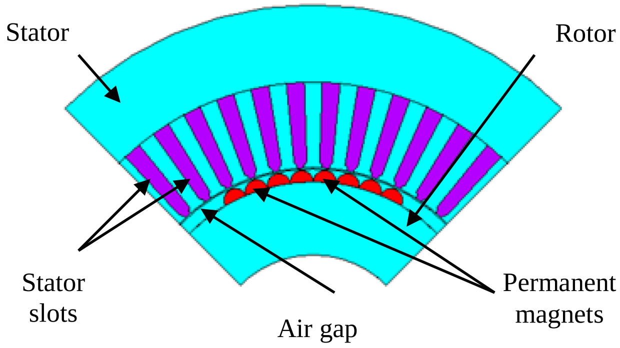

Fig. 2. Study domain

Fig. 2 shows that the small model is constituted of 12 stator slots and 8 magnets blocks which have a half circle shape.

As it has been previously mentioned, the finite element analysis is employed to investigate the features of the selected topology.

Indeed, this technique is a numeric one. It consists in dividing the studied domain into small areas. The obtained subdivisions are called finite elements which are jointed. These joints are called nodes.

In our study, we are interested in the dynamic concept. For this purpose, a particular attention is given to the meshing technique. The adopted technique consists in constructing a sliding line in the mid of the air gap, so that the mesh of the studied area does occur at every step of the rotor motion. Otherwise, the integrity of the mesh structure remains stationary. It can not be destroyed because of the rotating movement of the rotor. Concerning the rotor mesh and the stator one, meshes are generated such as the half of the air gap belongs to the rotor part and the other belongs to the stator part. Both meshes are bounded by constraints equations [4]. The meshed study domain is shown in the following figure.

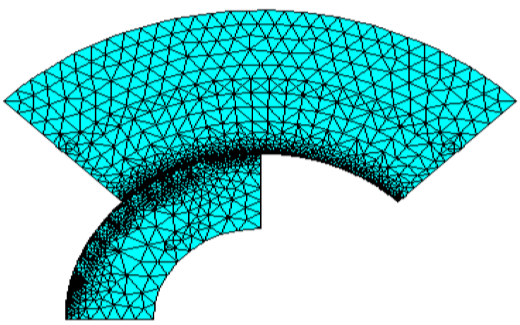

Fig. 3. The meshed study domain

Fig. 3 shows that the rotation of the rotor is guaranteed.

To ensure the dynamic concept and the continuity of the FEA model when the rotor moves [8], an interpolation technique [10] is used to equalize the magnetic field between the stator and rotor regions. A set of coupled degrees of freedom is defined between coincident nodes with a tolerance. All nodes are selected for coincidences using a defined command [11]. The used boundary conditions in the present work are:

- Dirichlet condition: $A_z = 0$ on the exterior sides of the rotor and the stator domain (the boundary of the domain).
- Neumann condition: $A_z = -A_z$.

These boundary conditions are shown in Fig. 4.

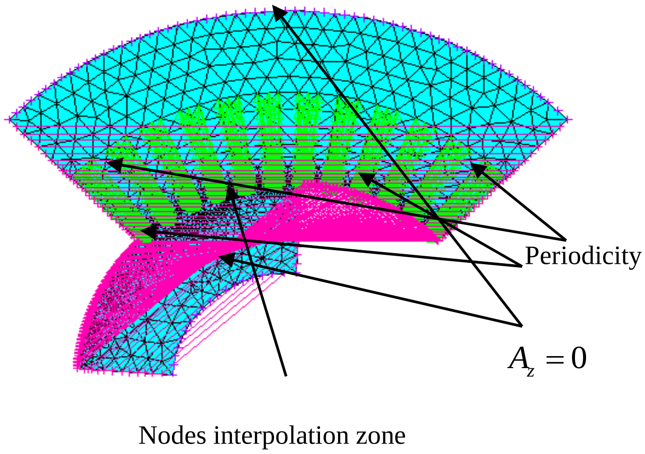

Fig. 4. Boundary conditions

Referring to Fig. 4, one can deduce that these boundary conditions change at every step, so that the rotor moves and the dynamic modeling concept is conserved.

The proposed topology has a particular geometry. Every magnet block has a half circle shape. The ray of each block is 2.78 mm. The geometrical parameters of this topology are given by the following table.

TABLE.I Machine Parameters

Outer stator diameter D_y	170 mm	Stator tooth width b_{ts}	2.4 mm
Inner stator diameter D	91.8 mm	Slot wedge height h_{sw}	1.4 mm
Height of the stator yoke h_{sy}	18.6 mm	Slot opening angle	30°
Height of the stator slot h_{ss}	20.5 mm	Stator slot area A_{sl}	188mm^2
Number of stator slots N_s	48	Stator slot pitch τ_s	15 mm
Active machine length L	160 mm	Slot opening factor k_{open}	0.57
Airgap length δ	0.62 mm	Magnet thickness h_m	2.78mm
Rotor core diameter D_{rc}	85 mm	Half pole angle α	60°
Shaft diameter D_i	50 mm	Rotor yoke height h_{ry}	17.5mm

III. SIMULATION RESULTS

Concerning the solving processor, it is important to choose a sufficient number of time steps over one electrical period. In the present work, 48 time steps are chosen over one electrical period to make one time step every 3.75 degrees. The time step is evaluated as follows:
For each time step the rotor will rotate 3.75 degrees at 1500 rpm.

In order to examine the performances of the proposed concept, the output torque delivered by the motor is investigated.

For a synchronous surface-mounted permanent magnets motor, the torque is given by the following equation [9]:

$$T = \pi \frac{(D-\delta)^2}{4} l \hat{S}_1 \hat{B}_\delta k_{w1} \sin(\beta) \tag{1}$$

Where is $\hat{S}_1$ the peak current loading, k_{w1} is the fundamental air gap flux density and β is the angle between the current vector and the magnet flux vector. The maximum torque is achieved when β is equal to 90°.

The fundamental flux density of the air gap is expressed by the following formula [9]:

$$B_\delta = \tfrac{4}{\pi} B_m \sin(\alpha) \tag{2}$$

Where B_m is the flux density peak.

In the present work a sinus current wave form is used. The obtained result is shown in the following figure.

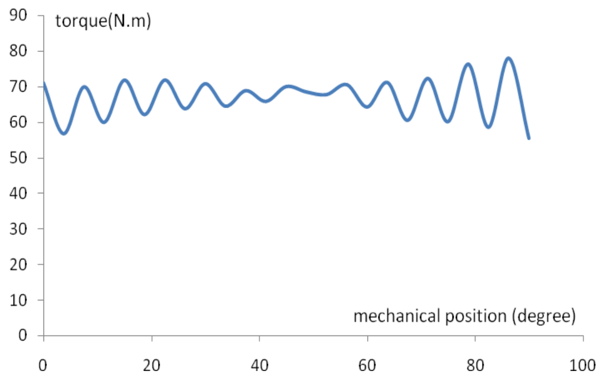

Fig. 5. Output torque

Referring to Fig. 5, one can clearly deduce that the electrical angle has an impact on the machine output torque. The maximum of the output torque is reached when the electrical angle is equal to 90°. The maximum output torque is near to 78 Nm.

It is so clear that there is a ripple in the torque curve. This is due to the so called ripple torque of a machine.

The no load air gap flux density is illustrated in the following Fig. 6.

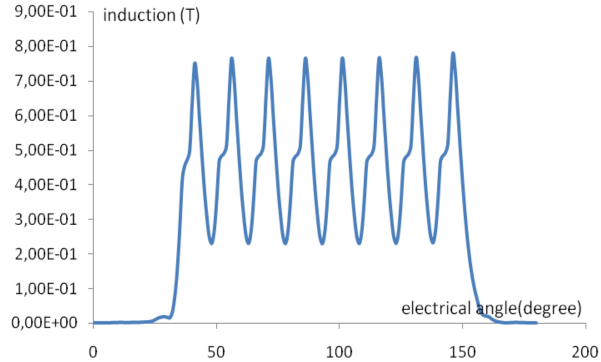

Fig. 6. No-loads air gap flux density versus electrical angle.

Fig. 6 shows the wave form of the flux density created by the magnets in the half stator air gap middle. It is obvious that there is a ripple marked in the air gap flux wave form. This is due to the effect of the slotting.

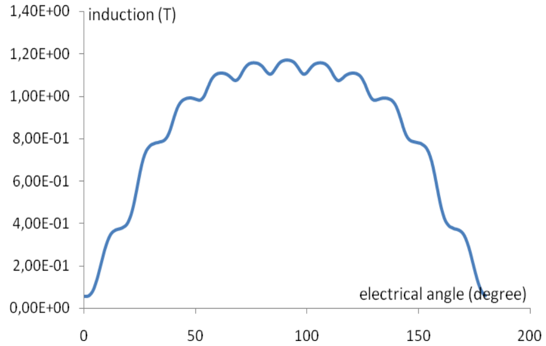

Fig. 7. Air gap flux density due only to the armature current versus electrical angle.

As presented in Fig. 7, the air gap flux density produced only by the stator current turns to be sinusoidal with a maximum near to 1.2 T. This is because of the sinusoidal waveform of the current supply.

The air gap flux density in the middle of the half stator under load conditions is evaluated. The obtained results are illustrated in fig. 8.

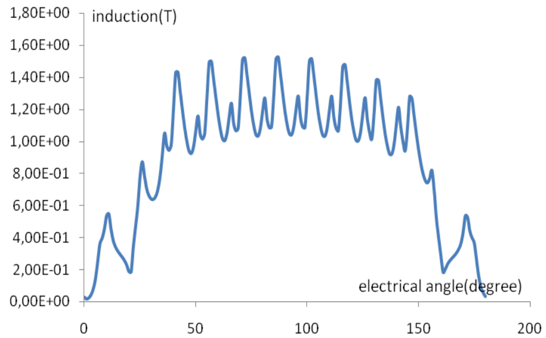

Fig. 8. Air gap flux density under load conditions.

Fig. 8 shows that the air gap flux density waveform under load conditions presents a ripple.

The flux distribution over the study domain for two rotor positions are illustrated in Fig. 9 and fig. 10.

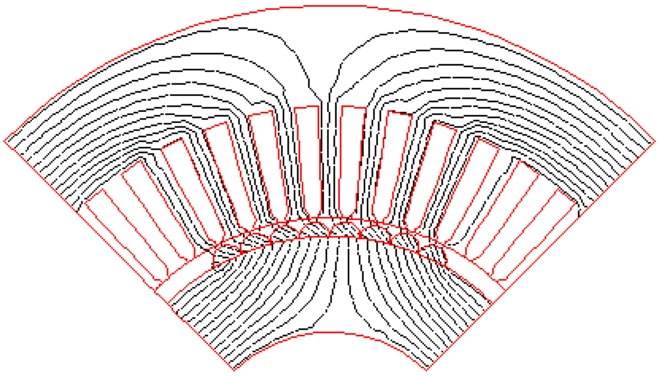

Fig. 9. Flux distribution over the study domain, θ_m=0°.

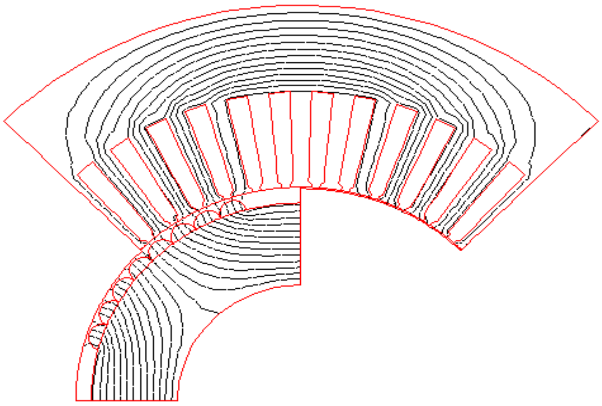

Fig. 10. Flux distribution over the study domain, θ_m=45°.

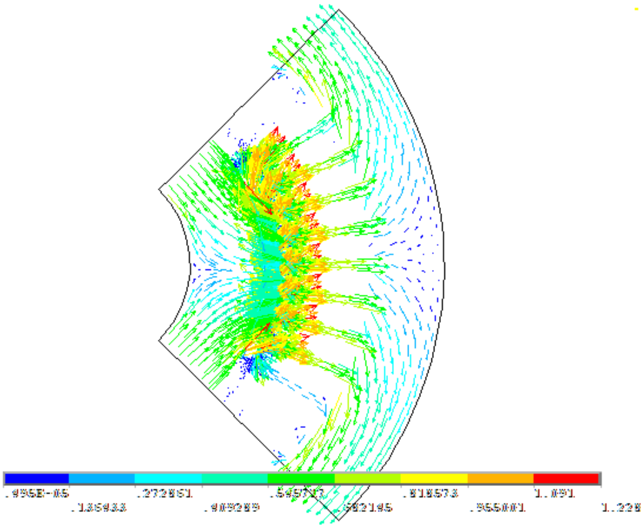

Fig. 11. Magnetic field distribution: no-load conditions.

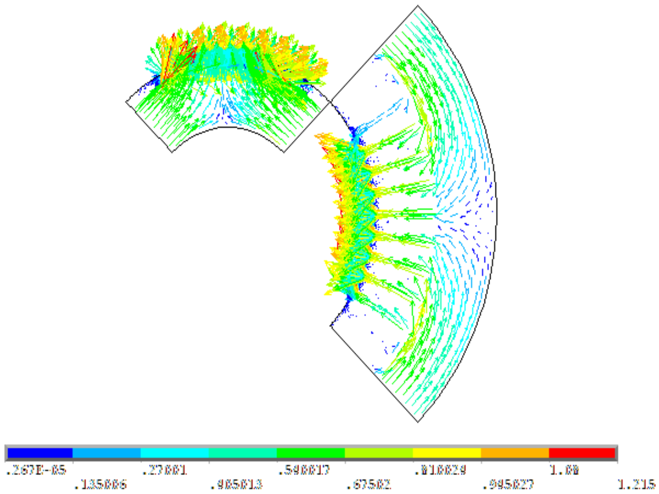

Fig. 12. Magnetic field distribution: no-load conditions.

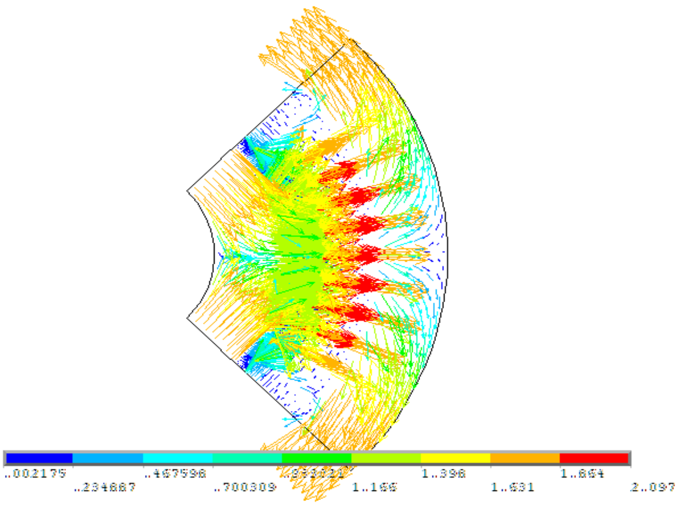

Fig. 13. Magnetic field distribution: under load conditions.

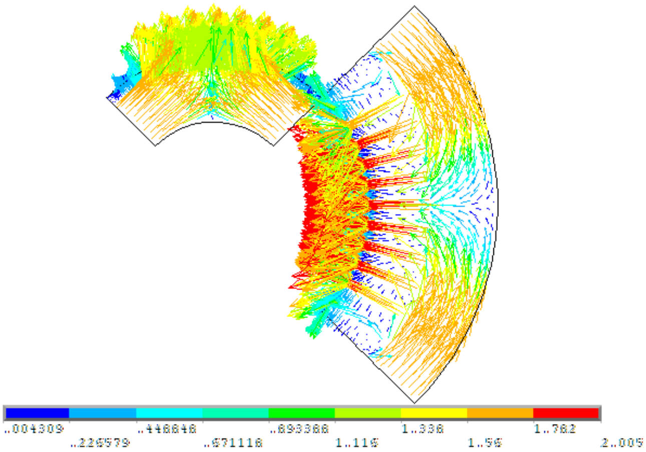

Fig. 14. Magnetic field distribution: under load conditions.

Fig. 11 and Fig. 12 show the distribution of the no-load magnetic field over the study domain for two rotor positions θ_m=0° and θ_m=90°. Referring to these figures, one can notice that the the saturation phenomenon is in the extremities of the stator teeth in the side of the air gap.

Fig. 13 and Fig. 14 illustrate the distribution of the magnetic field under load conditions over the study domain for two rotor positions θ_m=0° and θ_m=90°. Referring to these figures, one can notice that the saturation level is increased under load conditions.

IV. COMPARISION BETWEEN THE PROPOSED TOPOLOGIE AND THE STANDAR ONE

In order to show the influence of the magnets shape on the performance of a PMS motor a comparison between the proposed design and a standard one in term of torque production is established. The simulation results are illustrated in Fig. 15.

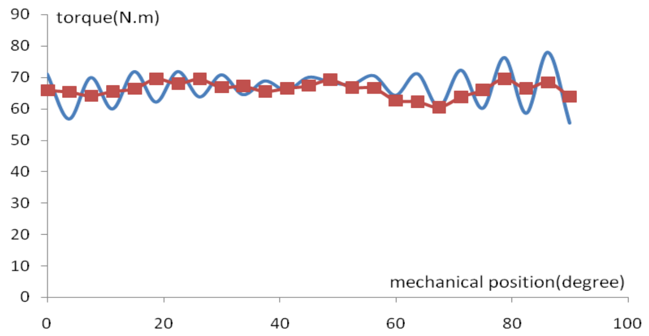

Fig. 15. Torque versus rotor position; the continued line stands for result from the proposed topology, the dashed line stands for result from the standard topology.

Fig. 15 shows the effect of the shape of magnets on the output torque. It's clear that the machine with circular magnets has the highest ripple torque, whereas the other one has the lowest ripple torque.

Iron losses phenomenon is a severe problem encountered in PM machines as it impacts the performances of a machine. So that, the iron losses criteria should be taken into account during the design process of a machine.

In this perspective, many models estimating the iron losses are studied. Most of models inputs are the magnetic flux density and their outputs are the iron losses. For this purpose, the knowledge of the distribution of the magnetic flux density in the machine is subject of this work.

The prediction of iron losses will be subject to future works.

V. CONCLUSION

In this work, two-dimensional magnetic field problem is analyzed. At first, a particular technique is adopted to assure the rotor motion and to avoid the destruction of the mesh during the rotation of the rotor. This technique consists in constructing a sliding line in the middle of the air gap. Secondly, the studied PMSM has been subject of a deep investigation by FEA. A particular interest is paid to the air gap flux density and the provided output torque. Finally, a comparison between the proposed topology and a standard one in term of performance has been established to highlight the effect of magnets shape on machine performances. This work will be continued by implementing an accurate hysteresis model in order to estimate the iron losses.

REFERENCES

[1] J. Azzouzi , "Contribution à la modelisation et à l'optimisation des machines synchrones à aimants permanents à flux axial . Application au cas de l'aérogénérateur," Ph.D. thesis, the University of Havre, 2007.

[2] A. Mansouri, and H. Trabelsi, "Effect of the Magnet-Segments on the Output Torque and the Iron Losses of a SMPM ", In Con. On Signals Systemes Decision and Information Technologie (SSD' 2013) 18-21 Mars 2007, Hammamet,Tunisia.

[3] Z. Q. Zhu and D.Howe, "Electrical machines and drives for electric hybrid and fuell cell vehicules," In Proc. IEEE, vol. 95, no. 4, pp. 476 - 765, Apr. 2007.

[4] J. Wang, K. Attalah,Z.Q. Zhu and D.Howe, "Modular 3 phrase per-manent magnet brushless machines for in-wheel applications," IEEE Trans.Veh.Tchnol, vol. 57, no. 5, pp. 2714-2720, 2008.

[5] M. Ashabani,Y.Abdel-Rady,and I.Mohamed, "Multiopjective Shape Optimisation of Segmented Pole permanet-Magnet Synchronous Machines With improved Torque Characteristics," IEEE transaction on magnetics, vol. 47, no. 4, April 2011.

[6] B.Singh, and S.Dwivedi, "A State of Art on Different Configurations of Permanent magnet Bruchless Machines," Electrical Engineering, IIT Delhi, Hauz Khas, New Delhi ,Vol. 87, June 2006.

[7] A. Mansouri, H.Trabelssi, M. Gmiden, "Iron Losses Calculation of a Surface-mounted Permanent Magnet Motors in Transient Finite Element Analysis ," In CD-ROM Fourth IEEE In. Con. On Signals Systemes Decision and Information Technologie (SSD' 2007) 19-22 Mars 2007, Hammamet, Tunisia.

[8] H.Trabelssi,A.Mansouri,and M.H.Gmiden, "On the modelling of a SMPM and the Iron losses calculation in transient FEA ," Trans.on Systems Signals and Devices (TSSD) Issue on Power Electrical Systems, Vol. 3, No. 1, 2008.

[9] S. Meir, "Teoretical design of surface-mounted permanent magnet motors with field weakening capability, " Master Thesis, The University of Stockholm, Royal Instiute of Technology, Stockholm -Swiss, 2002.

[10] H. Msaddek, "Dévelopement par la MEF d'un modéle dynamique d'une MSAP avec prise en compte des pertes magnétiques," Master thesis, University of Gabes, Gabes Engennering School, Gabes-Tunisia, 2012.

[11] A. Mansouri, and H. Trabelsi, "Effect of the Magnet-Segments on the Output Torque and the Iron Losses of a SMPM ," In. Con. On Signals Systemes Decision and Information Technologie (SSD' 2013) 18-21 Mars 2007, Hammamet,Tunisia.

[12] A. Mansouri and H. Trabelsi, "Performances Evaluation and Iron Losses Modelling of an Inset Surface Mounted Permanent Magnet Motor," Trans.on Systems Signals and Devices(TSSD) Issue on Power Electrical Systems, 2013.