Design and Application of 2-Dimensional Equivalent Model for a Novel Hybrid Excitation Brushless Claw-Pole Alternator

Changqing Zhu[1], Xiuhe Wang[2], Yubo Yang[3] and Xu Tang[4]

[1]School of Electrical Engineering, Shandong University, Jinan 250061, China, zhucq@sdu.edu.cn
[2]School of Electrical Engineering, Shandong University, Jinan 250061, China, wangxh@sdu.edu.cn
[3]School of Electrical Engineering, Shandong University, Jinan 250061, China, ybyang@sdu.edu.cn
[4]School of Automation Engineering, Qingdao Technological University, Qingdao 266520, China, tangxu_qtech@163.com

A 2-dimensional equivalent model is presented for a novel hybrid excitation brushless claw-pole alternator in this paper. Based on 3D geometry and 3D magnetic field distribution, 2D equivalent model is constructed and 2D FEA is performed. The model is far more applicable for its easy build and fast in computation. Simulation accuracy is verified by the results comparison obtained from 3D FEA and prototype tests measurement.

***Index Terms*— 2D equivalent model, 2D FEA, claw-pole alternator, hybrid excitation.**

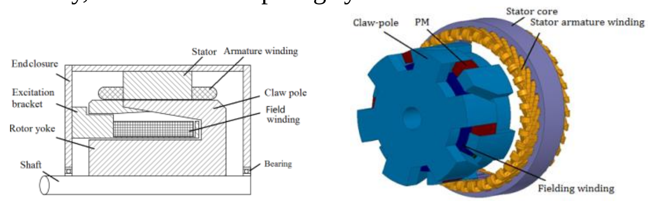
I. Introduction

THE CLAW-POLE type synchronous alternator is the heart of virtually all automotive electric power generation and storage system. However, poor output, low efficiency as well as big noise make improvement and optimization of conventional claw-pole alternators structure necessary. A novel brushless hybrid excitation claw-pole alternator is introduced in this paper. It has the advantages of high efficiency, good low-speed characteristics, adjustable field excitation, high flux densities and so on. But, due to the complexity and irregularity of alternator's structure and typical 3-dimensional magnetic field characteristics, conventional 2-D analysis methods cannot be directly used for this type alternator. Thus 3D FEA (Finite Element Analysis) and MEC (Magnetic Equivalent Circuit) are the common methods used to accurately predict the electrical and mechanical behavior of the machine. Therefore, 3D FEA requires much computation time and 3D model is very hard to build for most engineers who are not familiar with related software[1]. Another approach－MEC, requires huge matrix of potential, permeance, and source, which are truly 3D networks when considering rotor rotating and armature reaction [2].

The method using 2D equivalent model for claw-pole type machines was proposed and analysis results were verified by measurements[3-4]. However, they are designed for conventional field excitation claw-pole type machines. In this paper, 2D equivalent model for a novel hybrid excitation claw-pole alternator is developed. It could consider the saturation of the entire part of stator and rotor. The air gap flux density distribution and back EMFs could be obtained quickly by 2D FEA, whose results are well agreed to 3D FEA and measurements obtained from prototype tests.

II. Hybrid Excitation Claw-pole Alternator Model

Fig.1 (a) presents the axial structure view of the machine and Fig.1(b) shows the 3D model. Every pair of poles in the rotor is composed of two claws, welded together with magnetic impermeable material between the hypotenuse of the two poles. Permanent magnets tangentially magnetized are placed between the right-angle side of two poles. One claw is fixed on the shaft and the other one has a bore in the claw palm. The excitation bracket is fixed on the end closure, and the field winding wraps around the excitation bracket, then the winding and excitation bracket insert into the claw through the bore in the claw palm. Due to the field winding being stationary, there are not slip-ring systems at all.



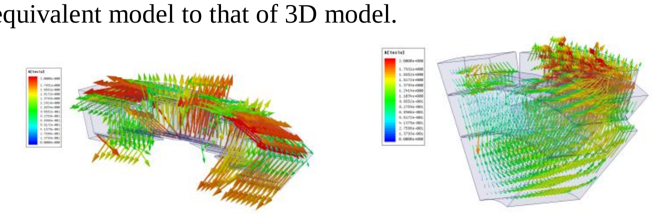
(a) Axial structure view (b) 3D model

Fig. 1 Hybrid excitation claw-pole alternator

III. 2D Equivalent Model

A. 3D magnetic field distribution of the machine

Fig.2 shows magnetic field distribution of the machine. It is clear that rotor structure is not symmetrical along rotor axis and flux distribution is 3D, thus the accuracy of 2D equivalent model focus on the similarity level of magnetic circuit of 2D equivalent model to that of 3D model.



(a) Stator (b) rotor

Fig.2 3D magnetic field distribution

B. Determination of structure parameters of 2D model

As a homo-polar type, claw-pole type alternator has the same MMF in all poles with one field winding. Taking account of the unique characteristic, a half of total MMF of field winding and PM are applied to both side of one rotor pole, respectively [4]. Moreover, the machine has additional air gap except the main air gap, magnetic circuits contributed by permanent magnet and field winding are parallel. Then a 2D equivalent model (1/6 model) is shown in Fig.3(θ=60°).

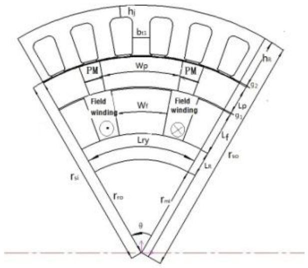


Fig.3 2D equivalent model (1/6 model)

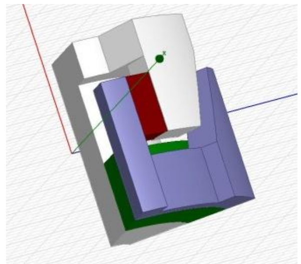


Fig.4 Pole shape in 3D model

The main structure parameters of the 2D equivalent model could be determined as following:

a. L_{ef} (Axial length)

Axial length contributing to output is determined by overlapped length of front and back pole.

b. W_p (Pole width) and L_p (Pole depth)

Pole shape facing stator side along axial direction is shown in Fig.4, where the shape is right trapezoid. W_p and L_p are determined as average values of pole width and pole depth, respectively.

c. W_f and L_f

The determination of W_f and L_f is based on the equivalent of reluctance in the 2D model to that of excitation bracket and pole palm in 3D model.

d. L_R (Rotor yoke thickness) and L_{ry} (Rotor yoke length)

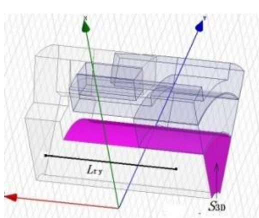
Fig.5 shows the relation of rotor yoke between 3D model and 2D equivalent model, then L_R is determined as following: [4]

$$\frac{L_{ry}}{S_{3D}\cdot\mu_{Fe}} = \frac{L_{ry}}{S_{2D}\cdot\mu_{Fe}} \tag{1}$$

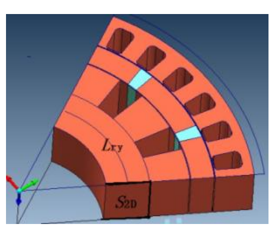
And

$$S_{2D} = L_R \cdot L_{ef} \tag{2}$$

Where μ_{Fe} is permeance of rotor yoke.



(a) Rotor yoke in 3D model



(b) Rotor yoke in 2D model

Fig.5 Comparison of rotor yoke parameters

e. h_j (Stator yoke height) and b_{t1}(Tooth width)

h_j and b_{t1} are determined as same as those in 3D model to guarantee the corresponding magnetic resistances equal.

f. g_1(additional air gap length) and g_2 (main air gap length)

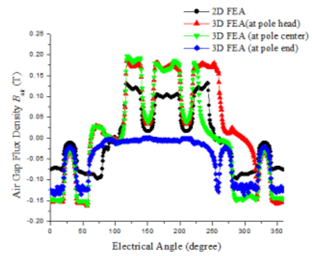
Make the value of g_1 and g_2 same to those in 3D model.

According to parameters above, r_{in} (rotor magnetically inert region radius), r_{ro}(rotor outside radius), r_{si}(stator inside radius) and r_{so}(stator outside radius) could be determined.

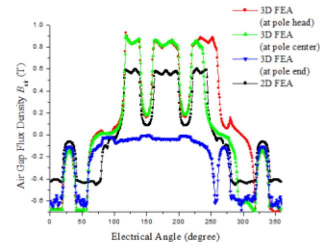
IV. Analysis and Verification

A. Air gap magnetic field distribution

Fig.6 is a comparison of magnetic field distribution in main air gap obtained from 2D equivalent model and 3D model at different pole location. It shows that 2D result could well reflect the “overall strength” of air gap flux density since actual air gap field distribution is not symmetrical along rotor axis.



(a) No field current

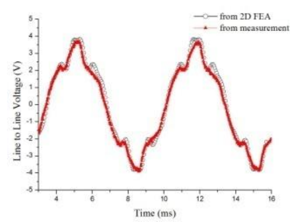


(b) Field current=1A

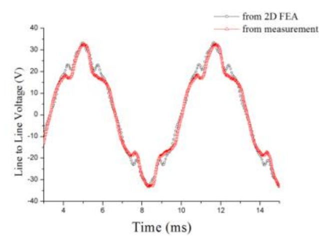
Fig.6 Comparison of air gap flux density distribution from 2D and 3D FEA

B. Back EMFs waveforms

Fig.7 gives the comparison of no-load EMFs obtained from 2D FEA and measurement results of prototype tests at rotor rotating speed 1500 r/min. Good agreement illustrates the practicability of the model in the analysis and design of the machine.



(a) No field current



(b) Field current 1A

Fig.7 Comparison of no-load EMFs

V.Conclusion

An equivalent analysis method is proposed for hybrid excitation claw-pole type alternator in the paper. It transforms 3D model to 2D model based on corresponding magnetic circuit equivalence. The simulation results are verified by 3D FEA and measurements. The advantages of easy to build and fast in computation make it be directly applied in the analysis and design of hybrid excitation claw-pole type alternator.

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