Unloading Performance Analysis of Main Generator in Aeronautic AC Power Supply Based on Ansoft

Gong Feng
Department of Computer Science and Technology
Binzhou University
Shandong, China
gong_feng_2008@126.com

Ma Zhen
Department of Computer Science and Technology
Binzhou University
Shandong, China

Li Jianlei
Department of Computer Science and Technology
Binzhou University
Shandong, China

Zhang Xianjiang
Department of Computer Science and Technology
Binzhou University
Shandong, China

***Abstract*—Equivalent magnet circuit method is adopted in investigating main generator in three-level synchronous generator system of aeronautic AC power supply. With RMxprt software of Ansoft corporation, it establishes geometrical model and computes primary electrical parameters. Furthermore, with Maxwell 2D software, it attains two-dimensional transient model and simulates magnetic spacial distributing, electromagnetic and circuit parameters under unloading. With contrast to actual measure values, it verifies the correctness of the model. It has been proved available for element encapsulation in further study for other types of aeronautic power supply computational auxiliary design and optimization.**

***Keywords*—Aeronautic AC Power Supply, three-level synchronous generator system, main generator, two dimensional transient field, RMxprt, Maxwell 2D**

I. Introduction

Airplane generator fault will seriously influence flight security, therefore, monitor generator's operation online or truly predict its operation is so important that it can escape fault extension and take action to protect the whole system. Thus a fault transient process simulation model is needed to substitute actual fault operations those are unallowed of. Currently there are three common aeronautic power supply system, variable speed and constant frequency (VSCF), constant speed and constant frequency (CSCF) and high voltage direct current (HVDC) systems [1]. Moreover, brushless synchronous generator with rectifier rotating is the core component of CSCF, VSCF and HVDC system. It adopts the brushless excitation and cancels the slip touching parts, so it has the advantage of convenient maintenance, high reliability, long continuous operation time, fit for the vocation of self-management and has an extensive application foreground. B707, B737 airplane adopt two-level brushless AC generator system, and B747, B757, B767, MD-82, A320 adopt three-level one, French battleplane of phantom-2000 adopts three-phase electromagnetic CSCF system, and American battleplane of F-16 adopts three-phase mechanical and hydraulic CSCF system[2]. Therefore it is important to investigate its transient characteristics.

Ansoft is an American software package especially designed for airplane, aeronautic and astronautic, electric power, electric drive and control system which includes not only simulated, digital mixed signal electric circuitry, but also mechanic structure, electro-mechanical apparatus, hydraulic and other multi physical field system. RMxprt is used for professional motors structure and primary electrical parameters design, Maxwell 2D is used for electromagnetic computation and Simplorer is used for mixed circuit system simulation. Altogether, this software package has the advantage of system modeling and simulation and thus be an indispensable package for new-style multi electrical or overall electrical airplane simulation.

This article takes on a concrete instance to state the design principle with RMxprt, two-dimensional transient modeling with Maxwell 2D and post process analysis of main generator among a certain three-level brushless synchronous generator in aeronautic AC power supply. Under unloading condition, transient circuit and magnetic performance of important parameters are simulated to prove the practicability of the model.

The corresponding parameters of main generator are presented here. There are 81 slots in stator, and the number of rotor pairs of poles is 3, each of which has 5 damper winding. The rated output voltage is 120V, the rated output current is 83.4A, synchronous speed is 8000rad/min, frequency is 400HZ and power factor is 0.75 lagging behind. Through simulation, such electromagnetic values as magnetic flux, magnetic intensity, flux linkage, terminal voltage and current can be all computed and transient change trend curves can be therefor plotted.

II. Main Generator Structure Design Based on RMxprt

Phasor diagram analysis has been used for main generator structure design as figure 1 shown.

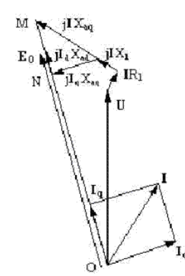

Figure 1. Phasor diagram of main generator

In figure1, Phase OM denotes inductive potential each phase,

$$\overline{OM} = U + I\left(R_1 + j\chi_1 + j\chi_{aq}\right) \quad (1)$$

R_1 denotes resistance of stator armature winding and χ_1 denotes leakage reactance of stator armature winding. χ_{ad} denotes d-axis armature reactance and χ_{aq} denotes q-axis armature reactance. Angle between U and I is called power factor angle φ, while angle between E_0 and U is called power angle θ. Therefore angle between E_0 and I is called ψ, $\psi = \varphi + \theta$. In d-q coordinate, current will be decomposed into,

$$\begin{cases} I_d = I \cdot \sin\psi \\ I_q = I \cdot \cos\psi \end{cases} \quad (2)$$

In (2), phase ON denotes back electrical potential caused by d-axis flux linkage. E_0, χ_{ad} and excitation current I_f can be confirmed by unloading characteristic curve and $k_{ad}F_{ad}$.

With motors design tool RMxprt of Ansoft, main generator of a certain type of aeronautic AC power supply is established, including stator figuration, material, coil rolling mode, parallel branches, rotor pole shape, material, excitation winding rolling mode, damper slot outline, material and outline. Figure 2 shows lamination and slot shape for stator and rotor of main generator.

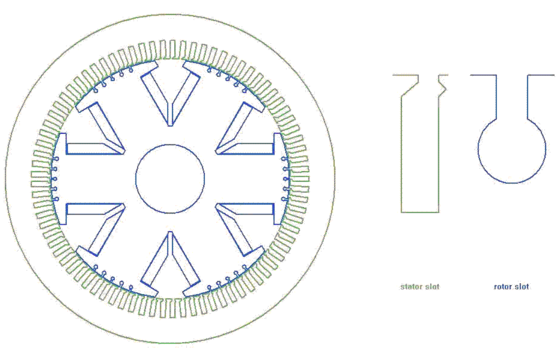

Figure 2. Lamination and slot figuration of stator and rotor of main generator

Whatever salient or non-salient generator, Schwarz-Christoffel transformation can be used to solve air gap distribution. Considering short pitch winding, winding distribution, skewed slot, connection way, load influence and other factors, it is necessary to analyze coil and winding waves. Figure 3 is the quantitative analysis under unloading condition with RMxprt. Seen from figure 3, linear area is when unloading excitation current is below 5A, while non-linear area is when unloading excitation current is higher than 6.5A.

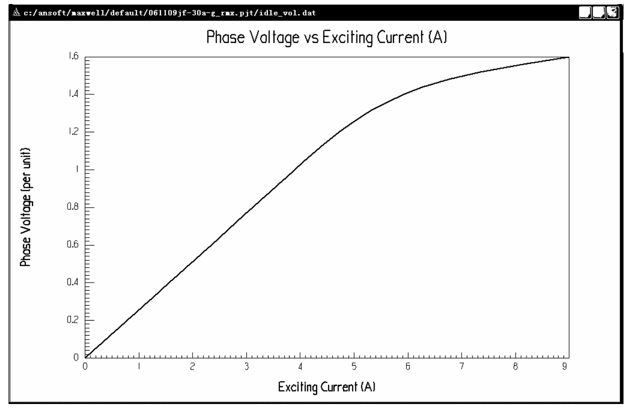

Figure 3. Unloading voltage simulation curve with RMxprt of main generator

III. FINITE ELEMENT MODELING WITH MAXWELL 2D FOR MAIN GENERATOR

Finite Element Method (FEM) is a common numerical method, which divides the whole area into many small units, makes each unit computation simple by choosing proper figure function. With the summation of all these simple computations of the whole units, it gets the solution of the whole area with entire matrixes. According to transient characteristic simulation research of three-level synchronous generator system, the ideal condition is to establish electromagnetic finite element model of single generator, choose static filed, transient filed or other solver to analyze static, stable, transient, normal and fault operational performance. Maxwell 2D has adaptive grid subdivision technology. User can define material library, high performance matrixes solver, multi CPU process ability and prompt solution speed. Because main generator has symmetry structure of axis orientation, transient field solver can be adopted for finite element analysis with Maxwell 2D. Modeling process will be introduced in detail in this chapter.

A. *Transient Solver Choice and XY Coordinate*

According to the actual structure of main generator, transient solver will be chosen to finish two-dimensional finite element modeling process. The above RMxprt model will be used to imported into Maxwell 2D by RMxprt link.

B. *Material Property Confirmation*

Stator armature lamination adopts DW310-35 silicon steel sheet with distance of 0.35mm, rotor pole lamination adopts DT3 pure iron slice with distance of 0.5mm. Damper winding adopts purple copper and each pole has 5 damper windings, which is generated with connection of pole to pole. DC magnetization characteristic data of the above can be checked from “usual material manual of motors”.

C. *Boundary Condition and Excitation Definition*

There are three boundary conditions currently, Dirichlet boundary condition, Neumanm boundary condition and the combination of the two above.

The expression of Dirichlet boundary condition is,

$$A|_{\Gamma_1} = g(\Gamma_1) \quad (3)$$

In (3), Γ_1 presents Dirichlet boundary and $g(\Gamma_1)$ presents common position function. In special conditions, $g(\Gamma_1)$ can be constant or zero. Dirichlet boundary condition states the magnetic force in a certain boundary is fixed. In this case, some distance away from main generator can be defined zero magnetic force.

The expression of Neumanm boundary condition is,

$$\left.\frac{\partial A}{\partial n}\right|_{\Gamma_2} + \sigma(\Gamma_2)\cdot A\big|_{\Gamma_2} = h(\Gamma_2) \qquad (4)$$

In (4), Γ_2 presents Neumanm boundary, n is the outside normal vector boundary, $\sigma(\Gamma_2)$ and $h(\Gamma_2)$ present common function. In special conditions, $\sigma(\Gamma_2)$ and $h(\Gamma_2)$ can be set constant or zero. Neumanm boundary condition usually expresses the symmetry of geometry size and excitation. In this case, rotor of main generator has three pairs of poles. To decrease the computation time, one third structure of magnetic force can be computed accordingly, while the others can be attained by symmetry.

If common function in both Dirichlet boundary condition and Neumanm boundary condition are zero, the boundary can be simplified to homogeneous Dirichlet boundary condition or homogeneous Neumanm boundary condition expressed as (5).

$$\begin{cases} A\big|_{\Gamma_1} = 0 \\ \left.\dfrac{\partial A}{\partial n}\right|_{\Gamma_2} = 0 \end{cases} \qquad (5)$$

In (5), the first condition states the magnetic force function in a certain boundary is zero. Because 1.5~2 times radius distances can be set the zero magnetic force and zero electrical force position, homogeneous Dirichlet boundary condition is fit for this kind of boundary. While the second condition of (5) states magnetic force function rate of change in a certain boundary normal orientation is zero. In this case, main generator has three pairs of poles, therefore magnetic force and electrical force in any pair of poles can be computed and thus get the whole electromagnetic distribution by symmetry.

Since the phenomenon is not so evident in outer magnetic leakage, homogeneous Dirichlet boundary condition is adopted. The magnetic force outer radius distance out of main generator equals to zero, i.e. $A\big|_{\Gamma_1} = 0$, $\Gamma_1 = \odot\, R_{outer}$. Because one third structure of main generator has been drawn with RMxprt, homogeneous Neumanm boundary condition is adopted in any interface between two poles. Moreover, the mirror is thus set to 3.

D. *Finite Element Adaptive Grid Subdivision Set*

Maxwell 2D has adaptive subdivision technology which can improve grid precision in partial large curvature and small air gap areas. The number of grids directly influences the precision of computation. The larger number it has, the more space and internal memory it should offer, thus the less convergence and the longer time it has. Some area may occur with the incorrect results caused by too many grids and non-convergence arithmetic. On the contrary, the smaller number it has, the less variable range sensitivity in large radian area it has and the less solved correctness it has. Generally speaking, it is primary for modeling to choose grid subdivision units reasonably. Figure 4 shows the basic grid subdivision by choosing area subdivision number 6.

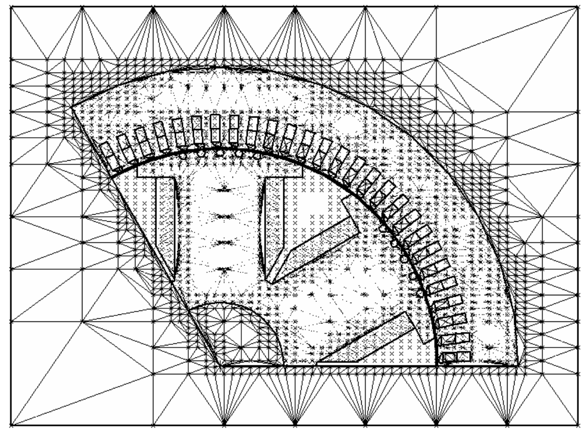

Figure 4. Finite element grid subdivision choosing area subdivision number 6 of main generator

Seen from figure 4, the grid subdivision choice near pole shoe, armature tooth, inside slot, inside magnetic pole, inside excitation winding of rotor and inside stator armature areas are all unsuitable, therefore partial refinement is finished as figure 5 shown.

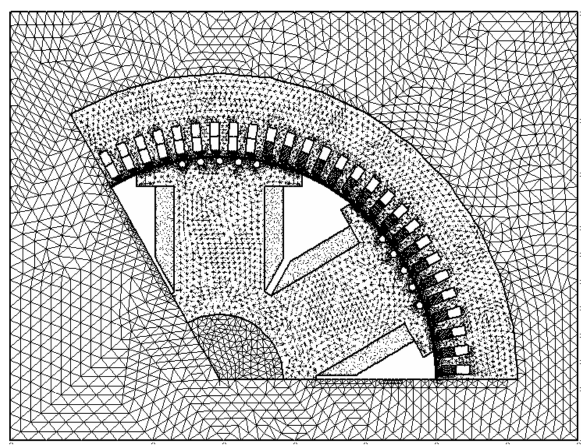

Figure 5. Grid subdivision refinement of main generator

E. *Primary Conditions and Solution Criterion Definition*

There are several details in primary condition definition, including motion band partition, mechanical definition, simulation time span, step, error requirement, solver arithmetic, mirror and etc.

Previous overall subdivision methods in the air gap area are unfit for this instance. On one hand, re-subdivision is needed in each simulation step, thus the computing period is largely increased. On the other hand, partial convergence will be changed since grids change in air gap area during rotation, which will lead to error increasing. Air gap boundary layered method has been introduced in this article. The process is to draw two completely coincide arcs in the middle of air gap which can divide the air gap into two parts. One belongs to stator and the other belongs to rotor. Stator air gap is fixed in stator coordinate, while rotor air gap is synchronously rotating with rotor. In each simulation step, grids among stator air gap are stead while those among rotor air gap are adjusted. Such method can effectively decrease overall subdivision in every step and increase simulation efficiency.

Synchronous speed is set to 8000rad/min, simulation time span is [0-0.5]s. Because each 360 electrical degrees rotation cost 2.5ms, the simulation step is set to 0.3125ms and field preservation period is 0.625ms considering periodic influence of tooth and slot of main generator. The error tolerance requirement for linear area is 0.001 and that for nonlinear area is 0.005. The number of pairs pf poles is 3, thus the mirror is set to 3. And axial length is 87mm.

IV. SOLUTION HARDWARE CONFIGURATION AND SIMULATION WAVES ANAYLSIS

Hardware configuration is: Intel(R) Xeon(TM) CPU 3.06GHZ, 2.00GB memory. In the above primary condition, simulation costs 12 hours and 42 minutes.

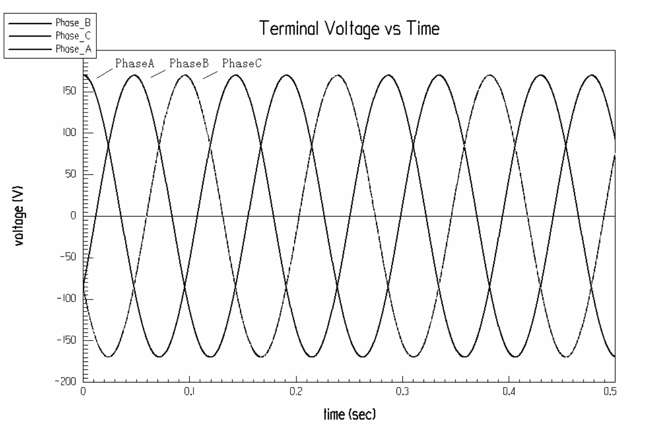

Figure 6. Three unloading terminal voltages in [0-0.5]s of main generator

Seen from figure 6, the simulation unloading effective terminal voltage is 135V, and the actual experimental value is 122V. Thus the error is 10.7%. The computed value from two-dimensional transient finite element model has a good accordance with actual experimental value. Therefore it verifies the practicability of the established model.

Moreover, several contrasts with field distribution at the moment of 0.0625s and 0.21625s have shown as follows which include magnetic lines of force and flux density variation characteristics.

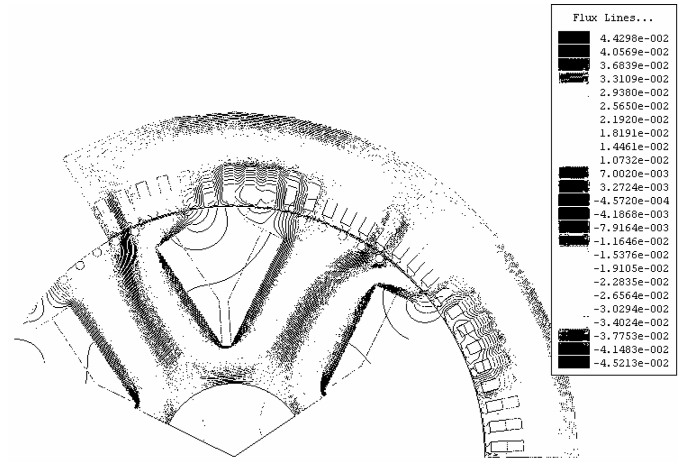

Figure 7. Unloading magnetic lines of force at 0.0625s of main generator

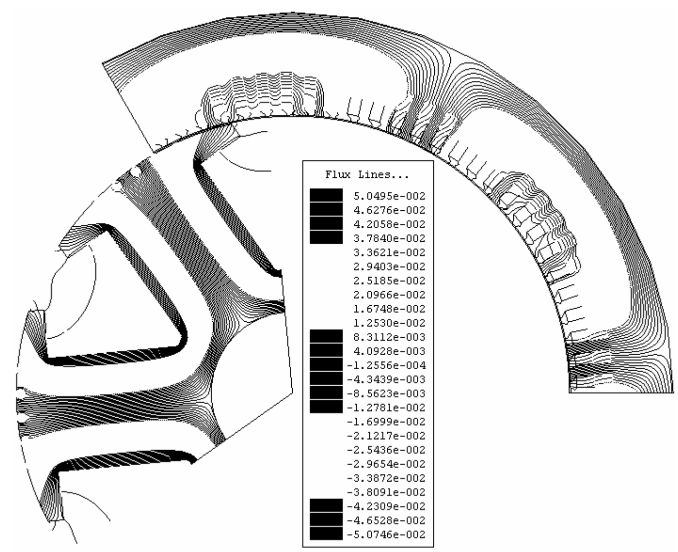

Figure 8. Unloading magnetic lines of force at 0.21625s of main generator

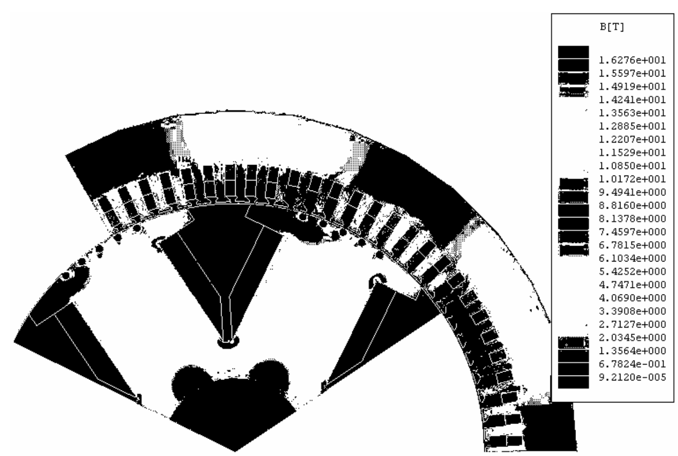

Figure 9. Unloading flux density magnititude at 0.0625s of main generator

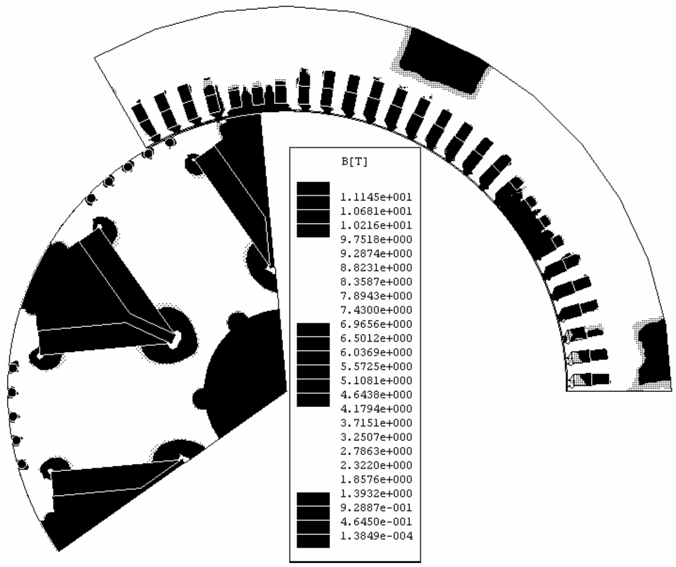

Figure 10. Unloading flux density magnititude at 0.21625s of main generator

Seen from figure 7~12, it can concluded that ignoring eddy current influence vector magnetic potential has only Z axis value and without armature reaction magnetic linkage caused by excitation winding will pose symmetrical special distribution during synchronous rotation. The maximum magnetic density value is 3.11T in [0-0.5]s and it occurs among stator yoke respect to rotor, stator armature winding respect to rotor pole center and the connection with rotor pole body to excitation touch, which is agree with theoretical analysis.

V. CONCLUSION

This article has established two-dimensional transient finite element model for main generator among three-level brushless AC synchronous generator system with RMxprt and Maxwell 2D, then analyzed circuit and field performances under unloading condition. By contrast with simulation and actual experimental values, the model can be proved correctness and practicability. Furthermore, transient magnetic vector computation and variation trends are analyzed quantitatively. The model has played an important role in corresponding generator transient performance analysis and will be extent to other types of motors, permanent generators and etc. Moreover, electromagnetic characteristic analysis under stable short-circuit, fault operations will be studied in future to improve fault prediction ability in aeronautic power supply system.

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