International Journal of Scientific & Engineering Research, Volume 5, Issue 4, April-2014
ISSN 2229-5518

Electromagnetic and Thermal Analysis Of An Synchronous generator

Olivia Ramya Chitranjan, V.Gowrisree

Abstract— — The basis of any reliable and diagnostic method of all electrical machines is an understanding of the electric, magnetic and thermal characteristics of the machine under a healthy condition and a fault condition. The processes are intrinsically coupled and the study of interdependency of electromagnetic and thermal behavior of a machine is unavoidable. In this paper the magnetic field and thermal distributions provided by Finite Element Method (FEM) simulations using ANSOFT2D, along with analytical calculation essential in foreseeing the changes in the performance of the stator and rotor of a low 7KVA, 4 pole, 30 slot Synchronous Generator is done and studied. The main aim of the project is to analyse and suggest an optimal design with best Electromagnetic and thermal performance

Index Terms— electromagnetic analysis, thermal analysis, Synchronous Generator

1 INTRODUCTION

A Synchronous generator is an electromechanical device that converts mechanical energy to alternating current electrical energy. Synchronous Generators generate electricity by the same principle as DC generators, namely, when the magnetic field around a conductor changes, a current is induced in the conductor. This specific low KVA Synchronous Generator has a stationary field and a rotating armature. The rotating magnet called the rotor consists of a set of conductors wound in coils on an iron core and the stator consists of field windings wound around stationary poles. The conductors cuts across the field, generating an electrical current, as the mechanical input causes the rotor to turn.Synchronous Generators have the great advantage over direct-current generators of not using a commutator, which makes them simpler, lighter, less costly, and more rugged than a DC generator. Synchronous Generators use a set of rectifiers (diode bridge) to convert AC to DC. To provide direct current with low ripple Synchronous Generators have a three-phase winding.

Since some electrical machines are subject to different environmental conditions (such as moisture intrusion in most offshore activities), it is important to have an idea about the dependence of the failure rate on the environment. This section presents a comprehensive description of the most common faults to be found in Synchronous Generators. For each fault, the possible causes and mechanisms of failure are briefly outlined. According to Nandi and Toliyat (1998), the major faults arising in electrical machines may generally be classified as:

- Stator faults resulting in the shorting of the winding,
- turn to ground faults,
- Abnormal connection of the rotor windings,
- Static and/or dynamic air-gap irregularities,
- A bent shaft resulting s in rub between the stator and rotor causing serious damage to the stator core and windings
- Shorted rotor field winding,
- Demagnetization of permanent magnets,
- Bearing and gearbox faults.

2 MODELLING AND ANALYSIS OF THE MACHINE

2.1 Analysis of a Synchronous Generator

The thermal and electromagnetic field can be analysed using

a) Finite Difference Method
b) Finite Element Method

By comparing these two methods, usage of finite element method is nore common because it is used to solve complex structures.

Electromagnetic field analysis – FEA is particularly valuable in optimizing the design of electromagnetic devices such as motors, generators, solenoids, and so on.

Thermal Analysis – The behavior of heat flow is of great interest to the electrical power, and nuclear industries. FEA provides the most accurate numerical method for predicting temperature distributions and heat fluxes in heating, cooling, and energy conserving devices.

.

2.2 *Specifications and dimensions of the Synchronous Generator*

The Synchronous Generator that has been chosen for this project has the following specifications:

- *Olivia ramya Chitranjan is currently pursuing Ph.d program in renewable energy in VIT University, India, PH-9444240202. E-mail - olivia-ramya@gmail.com*
- *V.Gowrisree is currently working as an Associate professor in High Voltage engineering in Anna University, India ,PH-9965434002. E-mail: vg_sree@annauniv.edu*

International Journal of Scientific & Engineering Research Volume 5, Issue 4, April-2014
ISSN 2229-5518

i) Rating	-7.5 KVA
ii) Voltage	- 415 V
iii) Max current	-10.4 A
iv) Excitation voltage	-185 V
v) Field excitation	-2.5 A
vi) Speed	-1500rpm
vii) Rotor slots	-30
viii) Stator poles	- 4
ix) Outer diameter of stator core	- 27cm
x) Inner diameter of stator core	- 23cm
xi) Height of pole body	- 5cm
xii) Length of pole	- 15cm
xiii) Outer diameter of rotor	-18.5cm
xiv) Inner diameter of rotor	- 4cm
xv) Height of teeth	- 5.5cm
xvi) Breadth of teeth	- 1.5cm
xvii) Diameter of shaft	- 4cm
xviii) Axial length of machine	- 40cm
xix) Air gap under the pole	- 0.5cm

2.3 *Model of Synchronous Generator*

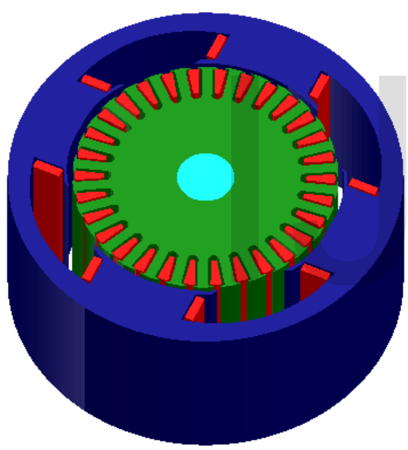

Fig1. Cross sectional view of the synchronous generator

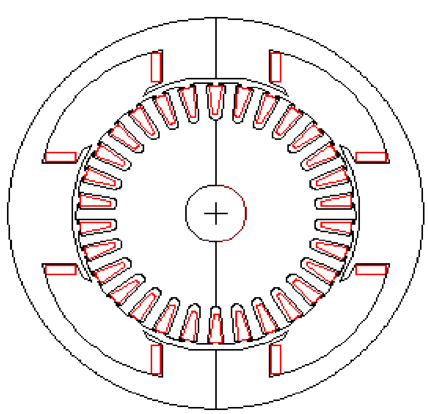

Fig 2. FEM Model of Synchronous Generator

2.4 Electromagnetic Analysis

Materials used

i)	Stator core	– steel
ii)	Rotor core	-- steel
iii)	Field windings	– copper
iv)	Armature windings	– copper
v)	Shaft	– cast iron
vi)	Background	– air

The following assumptions have been made for the simplification in the solution procedure to determine magnetic field distribution:

i) The rotor windings are symmetrical and have a perfect distribution along the air gap.
ii) The permeance of the magnetic paths on the rotor is independent of the rotor positions.
iii) The leakage on the outer surface of the stator and the inner surface of the rotor is neglected.
iv) Saturation and hysteresis effect are inexistent
v) The 2-D domain is considered, and the magnetic vector potential and the current density have only the z-axial component.

Bo*undary conditions.*

The choice of boundary conditions not only influences the final solution, but also can further reduce the domain under study. Hence the boundary condition chosen is the Dirichlet's condition. This condition corresponds to assign the value of the magnetic vector potential A_z on the given part of the boundary. Generally, the value assigned is constant, so that the boundary lines assumes the same value of the magnetic vector potential A_z .It follows the flux lines are tangential to the boundary itself, and no flux line crosses that boundary.

In Fig. 2 it is common to assign the homogeneous Dirichlet's condition, fixing the magnetic vector potential A_z =0 along all part of the boundary. Such a condition is equivalent to considering an external material with null magnetic permeability, which is a magnetic insulating material just outside the domain.

Dirichlet's boundary condition is assigned to the external circumference of the stator, forcing the flux lines remain confined within the stator yoke

3 THERMAL FIELD ANALYSIS

Thermal analysis here focuses on the stator core, windings, rotor core and rotor windings. Without any cooling system inside the Synchronous Generator, the density of axial heat flow is assumed to be zero. In this circumstance, 3D thermal field can be simplified to 2D. Fig.2 shows the 3D view of the Synchronous Generator. The whole region was selected as 2D

International Journal of Scientific & Engineering Research Volume 5, Issue 4, April-2014
ISSN 2229-5518

calculation model.

Some assumptions and hypothetical conditions are made to simplify process.

i) No heat transmission between shaft and flux barrier.

ii) Losses of rotor are concentrated in skin depth on the surface.

$$k\frac{\partial^2 T}{\partial x^2}+k\frac{\partial^2 T}{\partial y^2}=-q_v \quad (1)$$

$$k\frac{\partial T}{\partial n}=-h_e(T-T_f) \quad (2)$$

Where T is the temperature, qv is the heat generation density Tf is the ambient temperature.

The coefficient of heat conduction is constant for isotropic material. According to assumption (i), the second type condition is adopted to the boundary of the rotor inner circle. There is heat convection on the surface of the solid stator and rotor, so the third type hypothetical condition is applied to the boundary of the rotor and stator outer circle [5]. The function of 2D steady state thermal field could be expressed

4 EXPERIMENTAL WORK AND ANALYTICAL CALCULATIONS

4.1 RL Measurement

The resistance and inductance values of rotor coil which is measured using LCR meter in static conditions are given below,

TABLE I

R&L measurements

Excited phases	Inductance 100mH	Resistance 100Ω
a	15	4.2
b	12.4	5.3
c	14.4	4.8
a & b	27.3	42.3
a & c	30.6	41.4
b & c	27.2	42.2

4.2 Temperature Measurement

The temperature at various parts of the Synchronous Generator is measured using temperature gun for a duration of around 2 hours.

The voltage applied during that test was 225V and a load current of 4A. .Fig.3 given below is the temperature gun

Measured Values

i) Room temperature = 32°C
ii) Stator core Temp $_{min}$ = 33.2°C
iii) Stator core Temp $_{max}$ = 46°C
iv) Field winding Temp $_{min}$ = 32.8°C
v) Field winding Temp $_{max}$ = 42°C
vi) Rotor core Temp $_{min}$ =32.6°C
vii) Rotor core Temp $_{max}$ =54.6°C
viii) Rotor winding Temp $_{min}$ =33.2°C
ix) Rotor winding Temp $_{max}$ =52°C
x) Shaft Temp $_{min}$ =33.4°C
xi) Shaft Temp $_{max}$ =57°C
xii) Slip ring and brushes $_{min}$ =34°C
xiii) Slip ring and brushes $_{max}$ =60°C
xiv) Poles Temp $_{min}$ =33°C
xv) Poles Temp $_{max}$ = 44°C

Fig 3. Temperture gun

4.3 Analytical Calculation

1. Armature winding calculations

Armature slots	- 30
Coil span	- 7 sots
Slot angle	- 24°
Pole pitch	- 60°, 7.5 slots
Coils per phase	- 10
Number of groups/phase	- 4
Coils/group	- 2.5
Phase sequence	- abc
ωt	- 90°
Phase grouping	- a(3,2) : c(2,3) : b(3,2)
S/P	- 15/2

2. Three phase current calculations

Ia = Im sin(ωt) = 10.4 A
Ib = Im sin(ωt – 2π/3) = -Im/2 = -5.2 A
Ic = Im sin(ωt – 4π/3) = -Im/2 = -5.2 A
Id = Idm × sin(vr)
Iq = -Iqm × cos(vr)
If = 2.5 A

International Journal of Scientific & Engineering Research Volume 5, Issue 4, April-2014
ISSN 2229-5518

3. Inductance calculations

Only 'a' phase is excited and the inductance values are calculated as

i) Inductance La = $N \frac{\partial \phi}{\partial I}$ *hendries* (3)

ii) Where $\phi = \frac{IN\mu oA}{l} wb/m$ (4)

where Ns = 300 turns , A = 3.9cm2 , l = 9.8 cm.
therefore La = 14.7 mH.
,Similarly the inductance values for other phases are calculated. Which is almost equal to the values measured in Table.1.Inductance depends on the number of turns in coil and geometry of core.

4. Thermal source calculations

Heat source in stator & rotor = copper loss/area

i) Copper loss in rotor = 3I2R
= 3×10.42 ×4.2
= 1.362KW
ii) Area of rotor = п r2
= 3.14×4.42
= 60.2 cm2
iii) Heat Source of rotor = 1362/60.2
= 22.39 W/cm2
iv) copper loss in field = I2R
= 2.52×150
=937.5W
v) Area of stator field = п r2
= 3.14×42
=50.2cm2
vi) Heat source of stator = 18.6 W/ cm2

5 SIMULATION RESULTS

5.1 Flux Plot

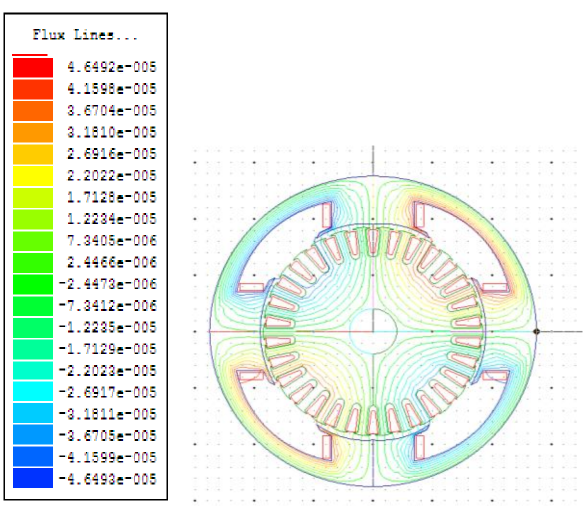

Fig.4. flux plot of entire machine

5.2. B vector plot

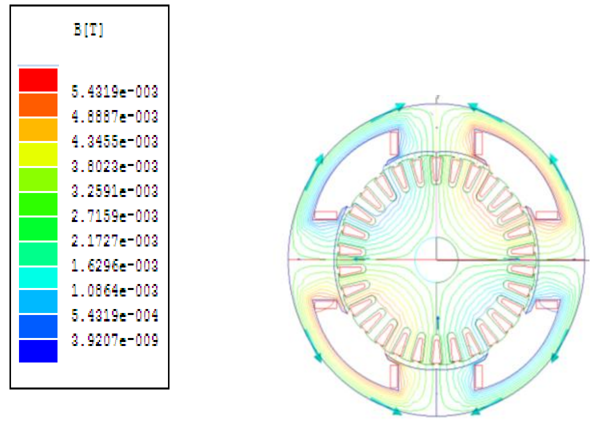

Fig5. B vector plot of entire machine

5.3. Flux plot with both d-axis and q-axis current

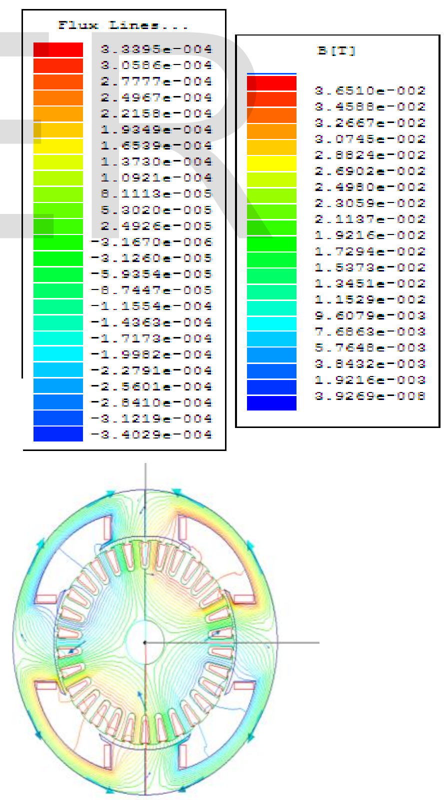

Fig 6. flux plot with both d-axis and q-axis current

5.4 Plot of quarter geometry

Due to symmetry and periodicity only a quarter portion of the machine is analysed.

International Journal of Scientific & Engineering Research Volume 5, Issue 4, April-2014
ISSN 2229-5518

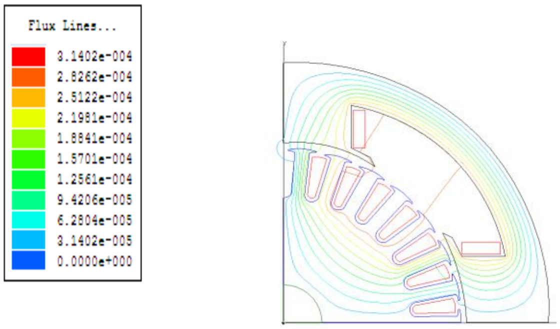

Fig 7. Flux plot of quarter portion of machine.

5.5. *Thermal plot*

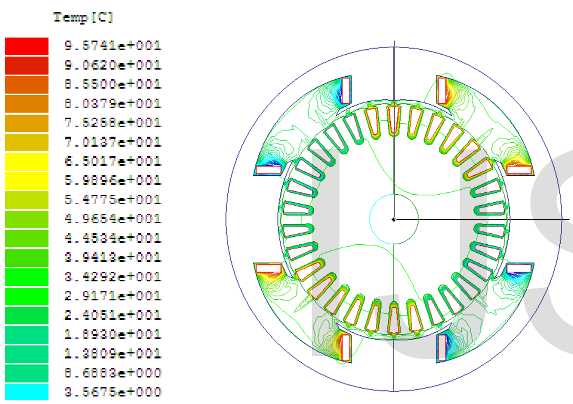

Fig 8. Temperature plot of the Synchronous Generator

6 Error Calculation

Inductance values

S.no	Measured	Analytical	Numerical	Error
1.	15mH	14.7mH	14.2mH	3.4%

The measured value is higher because it includes the edge effects and fringing effects but the analytical values are calculated under assumptions that they are neglected.

7 Conclusion

Thus it was proved that the FEM based analysis is an effective and inexpensive method for studying the behavior of electrical machines. Using Ansoft2D the stator and rotor of the Synchronous Generator under healthy static condition was analyzed electromagnetically and thermally, The concentration of flux lines show the regions of higher flux density and is used to identify the regions of intense saturation If a short circuit fault is generated in the windings of the rotor it will show higher stress at those areas and it is also expected that there will be a significant increase in the temperature, thus affecting the thermal performance of the Synchronous Generator.

Simulated values have an error of 20% compared to calculated values. Optimal design is to be suggested for temperature reduction around the rotor core and saturation of flux lines. Its been seen that the temperature around the stator core and slip ring brushes arrangement is high. Hence brushless arrangement is necessary to reduce the temperature rise and an optimal design suggested.

Acknowledgment

At the outset I wish to record my profound gratitude to my guide Dr.V.Gowrisree, Associate Professor, Division of High Voltage Engineering, Department of Electrical and Electronics Engineering for her dexterous guidance and co-operation during the course of the project.

I extend my munificent thanks to **Dr.S.USA**, Professor, Division of High Voltage Engineering, Department of Electrical and Electronics Engineering, for her valuable advice and guidance.

References

[1] [1] Chan T.F. Yan, L.T and Lai, L.L 'Analysis and performance of a three phase ac generator with inset NdFeB rotor'. Presented at Conf. on 'Advances in Power system Control, Operation and Management'(APSCOM-2000), Hong Kong,2000, pp 436-440.

[2] [2] Marian Dumitru Negrea (2006), "Electromagnetic flux monitoring for
[3] detecting faults in electrical machines", ISBN-10 951-22-8477-

[4] [3] Chan T.F. Yan, L.T and Lai, L.L 'Performance of a three phase ac generator with inset NdFeB rotor' Proc. IEEE Int. Electric Machines and drives Conf.(IEmDc2001),Cambridge, USA, June 17-20 2001, p.652-657.

[5] [4] A. K. Das Gupta, "Mathematical analysis of inductor Synchronous Generators "AIEE Trans. (Power Apparatus and Systems), vol. 79, pp. 684-689, October 1960.

[6] [5] R. **D.** Nathenson, J. Cherepko, and M. R. P a t e l , "Thermal S t r e s s Analysis and Design of the Stator of a 300 MVA Superconducting Generator", Vol.EC-1,No.3,September1986,pp.141-147.

[7] [6] Grec C.Ston, Edward A.Boulter, Ian Culbert, Hussein Dhirani,'Electrical insulation for rotating machines", *IEEE Press series on power engineering*, 2004.

[8] [7] Weili Li, Ying Xie, Jiafeng Shen and Yingli Luo, "Finite-Element Analysis of Field Distribution and Characteristic Performance of Squirrel-Cage Induction Motor with Broken Bars". *IEEE Transactions on Magnetics*, vol. 43, no. 4, 2007, pp. 1537-1540.

[9] [8] V. Hatziathanassiou, J. Xypteras, G. Archontoulakis, "Electrical-thermal coupled calculation of an asynchronous machine", *IEEE Transactions on Energy Conversion*, 1994, pp. 117-122.