Australian Journal of Basic and Applied Sciences, 8(2) February 2014, Pages: 124-131

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Coupled Magnetic Field and Thermal Analysis of Synchronous Generator

[1]Deepak Arumugam, [2]Dr. Premalatha Logamani

[1]Department of Electrical & Electronics Engineering, Jei Mathaajee College of Engineering, Kanchipuram, India.
[2]Department of Electrical & Electronics Engineering, Anand Institute of Higher Technology, Chennai, India

A R T I C L E I N F O

Article history:
Received 23 December 2013
Received in revised form 25 February 2014
Accepted 26 February 2014
Available online 15 March 2014

Keywords*:*
Finite Element Analysis (FEA),
Synchronous Generator,
Magnetic Field
Thermal Analysis

A B S T R A C T

Background: In general the synchronous generator by means of rectifier amalgamation is appropriate for extensive high promptness claims like excitation scheme of large electrically powered generators, Aircrafts, Shipboard and sub marine power system and high power DC supplies. Predetermined element analysis is a prevailing contrivance used for magnetic arena exploration and Thermal analysis of the electrical machines. **Objective:** To analyze, the magnetic field based values and temperature flow esoteric with the machine, it's easy to be associated using values acquired as of analytical intentions. **Results:** Comparatively this manuscript epitomizes the analytical and simulation analysis of 5KW, 28V at 8000rpm prominent pole synchronous generator. **Conclusion:** We have projected the analytical design by resounding out some compassionate standard mathematical expressions and simulation exertion to allocate on a view using the finite element software's'. To accomplish the inclusive counterfeit consequences related with systematic outcomes the compute enactment of the synchronous generator was impeccably implemented.

To Cite This Article: Deepak Arumugam and Dr. Premalatha Logamani., Coupled Magnetic Field and Thermal Analysis of Synchronous Generator. ***Aust. J. Basic & Appl. Sci.****, 8(2): 124-131, 2014*

INTRODUCTION

The energy is a big concern and vital in today's world and especially electrical machines plays an important role as one of the key component in energy generation (M.A. Arjona, 2011). Nearly all electrical power used throughout the world is generated by electrical machines. Synchronous machines are an AC rotating machine which generates AC power (Ivan Jadric, 2000). Michael Faraday and Hippolyte Pixii have proposed the concept of **alternator.** It improves power factor, reliability and generate high quality power. In synchronous machines under steady state condition, the speed is relative to the rate of recurrence of the current within its armature. Synchronous generator with rectifier system is suitable for many applications such as excitation system of large electric generators, Aircrafts, Shipboard and sub marine power system and high power DC supplies (Maarten Steinbuch, 1992; José Cidrás, 2000; Ivan Jadric, 1998; Nicolas Patin, 2008). The power for electrical system of recent vehicles produces from alternator. In preceding days, dc generators or dynamos be worn for this motivation but subsequent to progress of alternator, the dc dynamos are replaced by means of supplementary strapping and light weight alternator. Even though the electrical scheme of motor vehicles commonly requires all the way through contemporary but at a standstill an alternator by the side of with diode rectifier as a replacement for a dc generator is better preference as the complicated commutation is absent at this juncture. This unique type of generator which is exploiting in vehicle is acknowledged as automotive alternator. In Aircrafts power supplied to the loads through batter in early days but nowadays power supplied to this loads through Multi stage generator system and shaft coupled generator system (Antonio Griffo, 2013; Charanjiv Gupta, 2009). An additional **use of alternator** is within Diesel electric locomotive. In fact the engine of this locomotive is nonentity but we proclaim an alternator firm by diesel engine. The alternating current created by this generator is converted to DC by means of integrated silicon diode rectifiers to endorse all the dc traction motors. And these dc traction motors drive the wheel of the locomotive. This machine is also dilapidated in marine related to Diesel electric locomotive. The synchronous generator used in marine is specially designed with apt adaptations to the salt-water environment. The typical output level of marine alternator is about 12 or 24 volt. In huge marine, more than one units are used to provide large power. In this marine system the power produced by alternator is first rectified then used for charging the engine starter batteries and auxiliary supply batteries of marine. Computer based simulation is preferred because of Finite element analysis (FEA) was introduced initially in the year of 1960 by R.W.Clough. FEA is applied in system with complicated design and

Corresponding Author: Deepak Arumugam, Department of Electrical & Electronics Engineering, Anna University, Chennai, Tamil Nadu, 600025, India.

highly non linearity problem due to magnetic material. FEA is applicable in linear and non linear system, static stress and dynamic stress analysis, fluid flow, heat transfer, electric, electrostatic and magnetic field analysis (Fang Deng, 1998). Finite element method (FEM) used to apply design and analysis stage of electrical machines. FEA analysis of electrical machines was first carried out by P.Silvester in 1970's. Advantages of FEM is produce accurate results, high reliability, minimize power loss, maximize power and torque density and low product development cost. The FEA analysis applied in synchronous generators to evaluate magnetic field distribution, Thermal characteristics, Losses present in the machine, Faults present in the machine (Julio-César Urresty, 2010; Arjona, L., 1999; Zlatko Kolondzovski, 2005; Chang Eob Kim, 2002; H. Yaghobi, 2001; Sami Ruoho, 2007; Jagadeesh Chandra Prasad, 2011; Martin Ranlof, 2010). In this paper the theoretical and simulation analysis of the synchronous generator is carried out and finally the overall simulation results compared with theoretically calculated values. In section II the fundamental theory, design equations and overall design data is discussed. In section III simulation analysis and results are discussed by using finite element analysis software's. In section IV both analytical results and simulation results listed.

Overview of synchronous generator:

In Synchronous Generator, armature is the stationary part and field is the rotating part of the machine. Two types of synchronous generator are used in general. They are salient pole synchronous generator and cylindrical pole synchronous generator. Generally salient pole type generator is used for low and medium speed applications and cylindrical pole synchronous generator is used for high speed applications. In this paper 5KW/28V, 24 stator slots, 4 field pole sand 8000rpm synchronous generator has been presented. The actual structure of the machine is shown in the following Fig.1.

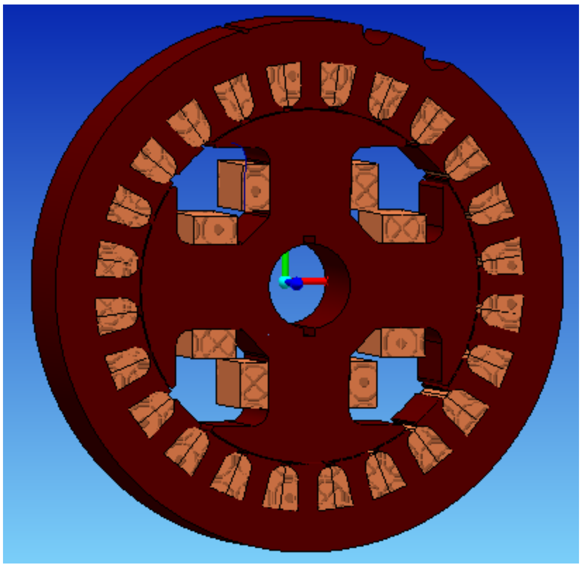

Fig. 1: General Structure of Synchronous Generator.

The rms value of generated emf equation of the synchronous generator is

$$E_{ph} = 4\ K_f\, K_d\, K_c\ Tf\phi \text{ in volts} \tag{1}$$

Where
K_f = Form factor
K_c = Coil Span
K_d = distribution factor
T = Number of turns
f = Frequency in Hz
ϕ = Flux in Webbers

When the machine electrical equations are transformed from abc to dq reference frame model, we get following equations.
In armature section voltage equation is

$$e_d = \frac{d\Psi_d}{dt} - \Psi_q\,\omega - R_a\, i_d \quad (2)$$

$$e_q = \frac{d\Psi_q}{dt} + \Psi_d\,\omega - R_a\, i_q \quad (3)$$

In field section voltage equation is

$$e_{fd} = \frac{d\Psi_{fd}}{dt} + R_{fd}\, i_{fd} \quad (4)$$

$$0 = \frac{d\Psi_{1d}}{dt} + R_{1d}\, i_{1d} \quad (5)$$

$$0 = \frac{d\Psi_{1q}}{dt} + R_{1q}\, i_{1q} \quad (6)$$

In armature section flux linkage equation is

$$\Psi_d = -(L_{ad} + L_l)i_d + L_{ad}i_{fd} + L_{ad}i_{1d} \quad (7)$$

$$\Psi_q = -(L_{aq} + L_l)i_q + L_{aq}i_{1q} \quad (8)$$

In field section flux linkage equation is

$$\Psi_{fd} = (L_{ad} + L_{fd})i_{fd} - L_{ad}i_d + L_{ad}i_{1d} \quad (9)$$

$$\Psi_{1d} = (L_{ad} + L_{1d})i_{1d} - L_{ad}i_d + L_{ad}i_{fd} \quad (10)$$

$$\Psi_{1q} = (L_{aq} + L_{1q})i_{1q} - L_{aq}i_q \quad (11)$$

Air gap torque

$$T_e = \Psi_{ad}i_q - \Psi_{aq}i_d \quad (12)$$

Stator Mean
Diameter
(MD) = (Slot root dia+ Slot tip dia)/2 (13)

Pole Mean
Diameter
(PMD) = (Pole Tip Dia+Pole RootDia)/2 (14)

Self Inductance

$$L_g = \frac{\mu_0 \Pi L_{stk} r_1 T_p^2}{2P_p^2 g'} \quad (15)$$

Where $g' = C_g\, g$

Based on above equations & some of other standard design equations the overall analytical design of the machine is carried out. Some of the machine design specifications listed in the following Table I.

Simulation Results:

The finite element analysis is the best way to analyze the magnetic field and heat flow of the machine. In this section the analytically designed synchronous generator was implemented in the finite element software's. Here we used FEA software's MagNet and ThermNet. MagNet software is used for magnetic field analysis and Therm Net is used to analyze heat flow and total heat produced in the machine.

Magnetic field analysis:

Generally the magnetic field analysis uses to analyze the magnetic flux produced, emf induced and current flow in the machine. Initially the analytically designed values are implemented in MagNet software. Once the solid model of the machine is obtained, then the material is applied. Here Armature & Field cores are made up of hyperco and both Armature & Field windings are made up of copper. After the application of all materials, static and transient 2D analyses are performed on the machine without load condition. The magnetic field waveforms are obtained after the analyses.

From the Magnet software, we obtained flux density waveform which shows in the Fig.2.(a). and Fig.2.(b). From these figures, the maximum flux density is approximately equal to 2.733Web/m^2 which is equal to the analytically designed value. Also Fig. 2. Shows that the maximum flux value is obtained near the aligned poles and the flux lines pass inside the core section.

TABLE I
DESIGN PARAMETERS

S.No.	Parameters	Values
1.	Rated Power, (W)	5000
2.	Rated DC Voltage, V_{dc} (V)	28
3.	Rated current, (A)	180
4.	Stator Outer Diameter, ods (mm)	138.5
5.	Rotor Outer Diameter, odr (mm)	91.86
6.	Length of the Air gap, L_g (mm)	0.37
7.	Speed, N (rpm)	8900
8.	Number of Slots, S	24
9.	Number of Poles, P	4
10.	Power Factor	0.88
11.	Frequency, (Hz)	292
12.	Flux/Pole, (kMm)	107.2
13.	Total Losses, (W)	758.9
14.	Efficiency, (%)	84.8

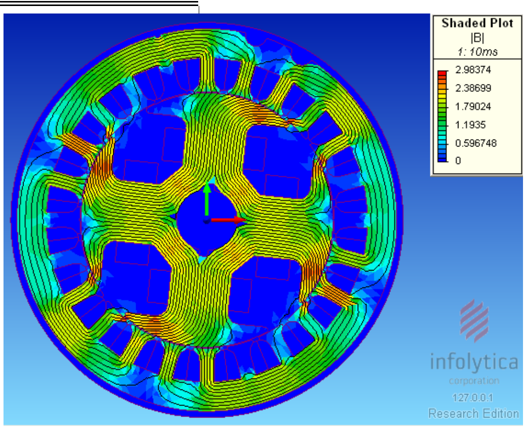

Fig. 2(a): Flux Density plot.

Australian Journal of Basic and Applied Sciences, 8(2) February 2014, Pages: 124-131

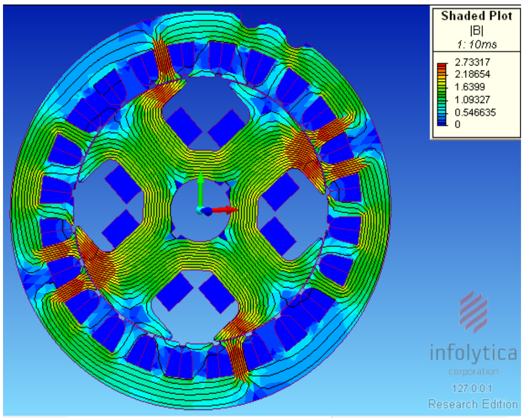

Fig. 2(b): Flux Density plot in another rotor position.

Fig.3 shows the direction of flux travelling in the machine which has 4 closed paths which is equal to the number of poles present in the rotor and this figure shows clearly that the maximum flux concentrated near the aligned poles.

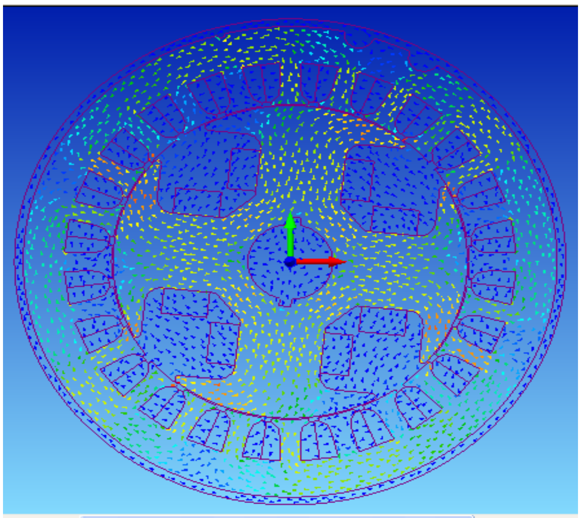

Fig. 3: Flux flow plot.

Fig.4 and Fig.5 shows that the voltage induced in the armature winding is 14V and the current flowing through the armature winding is 180A. From the figures we conclude that the induced voltage and current are sinusoidal in all the three phases.

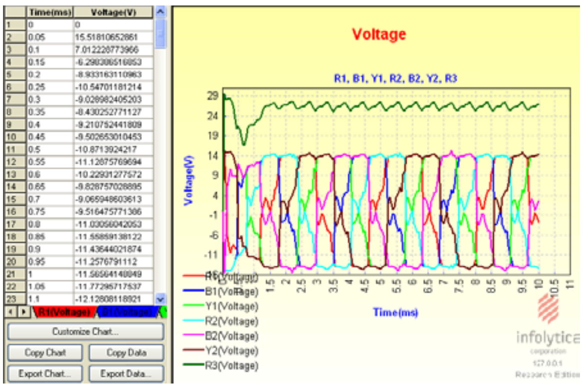

Fig. 4: Induced voltage at Armature winding.

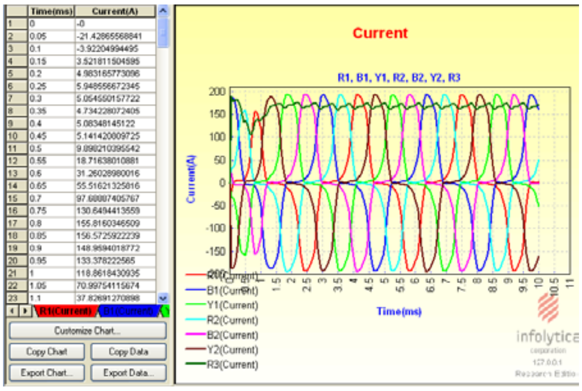

Fig. 5: Flowing current at Armature winding.

Initially, the machine analyzed at the unloaded condition. Then the synchronous generator connected to the resistive load at a value of 0.15Ω through diode rectifier. This synchronous generator with diode combined system is suitable for many applications like Aircrafts and Marine power system. Then this system applied in the transient 2D analysis to get DC voltage and DC current of the load. Fig.6 and Fig.7 show the voltage across the load is 28V and current flowing through the load is 180A which is equal to the analytically designed values already mentioned in the design table.

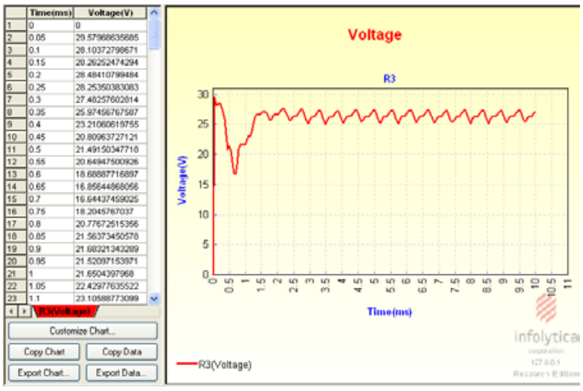

Fig. 6: Dc voltage across load.

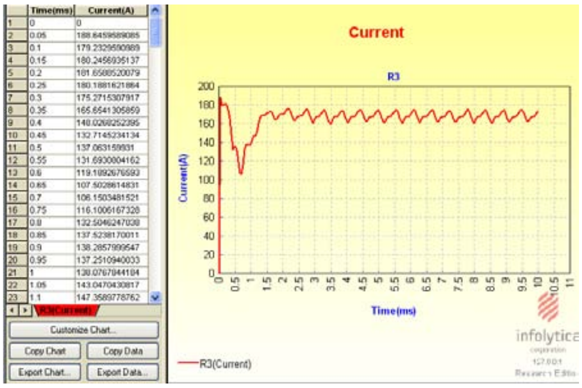

Fig. 7: Dc current through the load.

Thermal analysis:

Generally thermal analysis of the machine helps to find total temperature produced in the machine and heat flow direction of the machine. In this paper we present coupled magnetic field and thermal analysis of the synchronous generator. That is analytically designed values implemented in the MagNet software and after magnetic field analysis is carried out that same circuit directly implemented in the ThermNet software. This process is called the coupled magnetic field and thermal analysis. After the implementation of circuit in the ThermNet software, 2D transient analysis is taken. From this analysis we obtained heat flow of the machine and total heat produced in the machine this is shown in the Fig.8 and Fig.9. From Fig.8, we get total heat flow direction in the machine. Fig.9 shows that the total produced in the machine is 25◦C and shows that the maximum heat produced at the coil section.

Comparison Between Analytical And Simulation Analysis:

In this section the overall results obtained from both analytical and simulation analysis are compared and listed in the following table.

Table II: Comparison Between Analytical And Simulation Results.

S.No	Parameter	Analytical Value	Simulated value
1	Output voltage	28V	28V
2	Output current	180A	180A
3	Flux/Pole,	107.2 k_{Max}	138.2 k_{Max}
4	Temperature	20◦C	25.8◦C

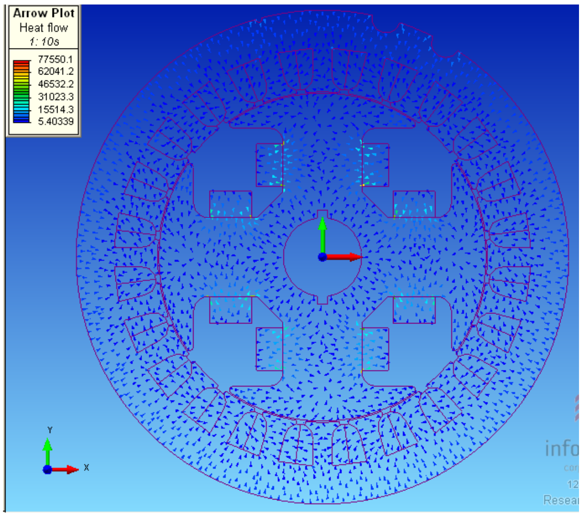

Fig. 8: Heat flow in the machine.

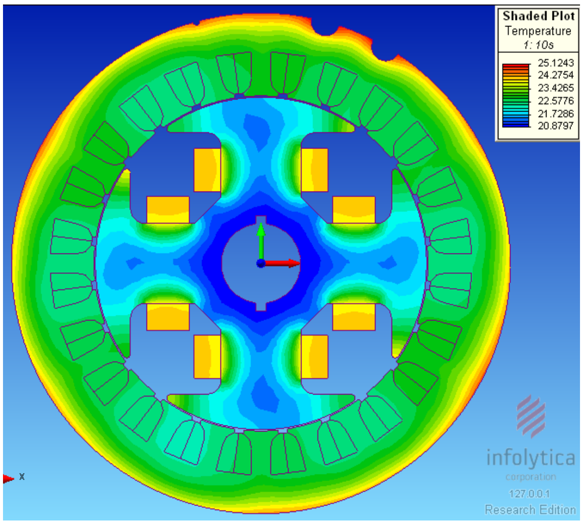

Fig. 9: Temperature in the Machine.

Conclusion:

Electrical energy is generated through induction generator, Synchronous generator and Permanent magnet synchronous generator. Out of all generators, the synchronous generator has a benefit that the output frequency of the generator is able to be further effortlessly synchronized to remain at a constant value. The Synchronous generators are more resourceful than asynchronous generators. Synchronous generators can simply accommodate load power factor variations and it is capable of in progress by means of supplying the rotor field excitation from a battery. So it is apt for many high speed applications where AC and DC power supply is required. This paper compares the overall simulated results with the analytical values through magnetic field analysis and thermal analysis of analytically designed synchronous generator with a rating of 5KW/28V at 8000rpm. By this comparison, the performance of analytically designed synchronous generator is fine so that this generator is well suitable for many high speed applications.

REFERENCES

Antonio Griffo, Rafal Wrobel, Phil H. Mellor and Jason M. Yon, 2013. Design And Characterization of A Three-Phase Brushless Exciter For Aircraft Starter/Generator, IEEE Transactions On Industry Applications, 49(5): 2106-2115.

Arjona, M.A., L.D.C. Macdonald, 1999. A New Lumped Steady-State Synchronous Machine Model Derived From Finite Element Analysis, IEEE Transactions On Energy Conversion, 14(1): 1-7.

Arjona, M.A., M. Cisneros-González, C. Hernández, 2011. Parameter Estimation Of A Synchronous Generator Using A Sine Cardinal Perturbation and Mixed Stochastic–Deterministic Algorithms IEEE Transactions On Industrial Electronics, 58(2): 486-493.

Chang Eob Kim, J.K. Sykulski, 2002. Harmonic Analysis Of Output Voltage In Synchronous Generator Using Finite-Element Method Taking Account of the Movement, Ieee Transactions On Magnetics, 38(2): 1249-1252.

Charanjiv Gupta, Sanjay Marwaha, 2009. Manpreet singh Manna, Finite Element is an aid to Machine Design: A Computational Tool, COMSOL Conference, Bangalore, pp: 1-6.

Fang Deng, Nabeel A. Damerdash, 1998. Comprehensive Salient-Pole Synchronous Machine Parametric Design Analysis Using Time-Step Finite Element-State Space Modeling Techniques, IEEE Transactions On Energy Conversion, 13(3): 221-229.

Ivan Jadric, 1998. Modeling and Control of a Synchronous Generator with Electronic Load Finite element analysis of synchronous machine, Master of Science, Dept. Elect. Eng., Virginia Polytechnic Institute and State University.

Ivan Jadric, Dusan borojevic, Martin Jadric, 2000. Modeling and control of a synchronous generator with an Actice DC load, IEEE Transactions on Power Electronics, 15: 303-311.

Jagadeesh, B., Chandra Prasad, Dr. B.V. Sakker Ram, 2011. Evolution of synchronous Generator Reactance using Finite Element Metthod, Journal Of Theoretical and Information Technology, 27(2): 68-76.

José Cidrás, Camilo Carrillo, 2000. Regulation of Synchronous Generators By Means Of Hydrostatic Transmissions, IEEE Transactions On Power Systems, 15(2): 771-778.

Julio-César Urresty, Jordi-Roger Riba, Luís Romeral, Antonio Garcia, 2010. A Simple 2-D Finite-Element Geometry for Analyzing Surface-MountedSynchronous Machines With Skewed Rotor Magnets, Ieee Transactions On Magnetics, 46(11): 3948-3954.

Maarten Steinbuch, Okko H. Bosgra, 1992. Dynamic modelling of a Generator/Rectifier system, IEEE Transactions on Power Electronics, 7: 212-223.

Martin Ranlof, 2010. Electromagnetic Analysis of hydro Electric Generators, Ph.D. dissertation, Faculty of science and Technology, Uppsala Univ, Sweden.

Nicolas Patin, Lionel Vido, Eric Manmossan, Jean Paul Louis, Mohamed Gabsi, Michel Lecrivain, 2008. Control of a Hybrid Excitation Synchronous Generator for Aircraft Applications, Ieee Transactions On Industrial Electronics, 55(10): 3772-3783.

Sami Ruoho, Emad Dlala, Antero Arkkio, 2007. Comparison Of Demagnetization Models For Finite-Element Analysis Of Permanent-Magnet Synchronous Machines, IEEE Transactions On Magnetics, 43(11): 3964-3968.

Yaghobi, H., K. Ansari, H. Rajabi Mashhadi, 2011. Analysis Of Magnetic Flux Linkage Distribution In Salient pole Synchronous Generator With Different Kinds Of Inter turn Winding Faults, Iranian Journal Of Electrical & Electronic Engineering, 7(4): 260-272.

Zlatko Kolondzovski, Lidija Petkovska, 2005. Determination Of A Synchronous Generator Characteristics Via Finite Element Analysis, Serbian Journal Of Electrical Engineering, 2(2): 157-162.