Thermal Analysis for a Permanent Magnet Synchronous Generator

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Abstract – *This paper presents a thermal analysis for a permanent magnet synchronous generator using JMAG software. The generator has NdFeB permanent magnets glued to the surface of the rotor ring. The nominal power is 3kW. The aim of this analysis is to determine if the NdFeB permanent magnets, but also other components, are subject to overheating during normal operation of the electrical machine.*

Keywords – *Thermal Analysis – finite element analysis- permanent magnet machines – magnetic analysis – heat dissipation*

1. INTRODUCTION

Currently, the design of the machines is made considering a higher efficiency and thus, lower temperature dissipation is achieved. Nevertheless, a thermal analysis should be made in order to find if the permanent magnets (the most sensitive component to demagnetization) will not be affected by temperature generated during normal operation. It is advantageous to calculate the losses in a magnetic field analysis simulation using the finite element method and then using the result of losses distribution, to make a thermal analysis. Studies regarding thermal analysis using JMAG where made by S. Nategh in his PhD thesis [1] and by G. Zhang et al. in [2].

The electromagnetic (EM) and thermal models are directly linked because of the temperature – dependent properties of the machine materials: copper, lamination steel, permanent magnets etc.

This paper presents the results of the magnetic and thermal analysis which were realized on a radial flux permanent magnet synchronous generator (PMSG), for wind applications.

Through this study, the results considering the evolution of average temperature of each component of the machine will help to determinate if the turbine, by its conception, the dimensions and materials, could work without damages to the active materials, under normal operation.

Three cases are considered in this study: in the first one the rotor speed is 250 rpm with the mechanical power at 260W, the second with an average speed of 360 rpm with the mechanical power at 940W, and the last one with a speed of 500 rpm and working at the mechanical power of around 2600W.

2. STUDY CHARACTERISTICS

A. Magnetic study

The purpose of the magnetic study is to determine the losses in each element of the machine in order to correctly estimate the generated temperature.

For this, it is important to set the parameters of the study before running the analysis. Another important aspect is to adjust the mesh of the designed structure.

The main losses in the generator are the Joule losses in the coils. Also, iron losses could reach import values especially when working at higher frequencies. In the case of PMSG most of the losses are present in the stator, usually in the rotor are less significant.

The generator which is considered in the study is composed the elements presented in Table 1.

Table 1: characteristics of the generator.

Part	Material	Volume (mm^3)	Density (Kg/m^3)	Thickness (mm)
Screws	S10C	6930	7780	4
Rotor	S10C	13320	7780	4
Coil	Copper	42400	8960	4
Stator	50JN270	38650	7600	4
Yoke	50JN270	45000	7600	4
Magnet	NEOREC45F	13600	7500	4

In order to save time during 3D simulations, the generator has been designed in JMAG with the above parameters, whereas in reality, the turbine has the axial dimension multiplied by five (4 mm instead of 20 mm axial thickness).

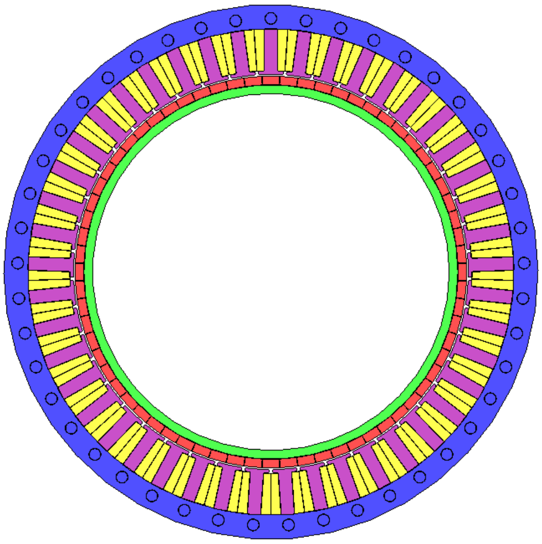

Fig 1: Model of the generator.

The constitution of the model is done as below:

- the rotor's yoke (rotor) is in green;
- the magnets are in red;
- the stator poles are in purple;
- the coils are in yellow;
- the stator's yoke (yoke) and the screws are in blue.

JMAG, through this analysis must calculate the Joule and iron losses which appear in the generator during operation and then use these losses to calculate the heat generation in the different parts of the machine.

The Joule losses for the 500 rpm study are presented in Fig. 2. It should be noted that these losses include the rotor losses due to eddy currents.

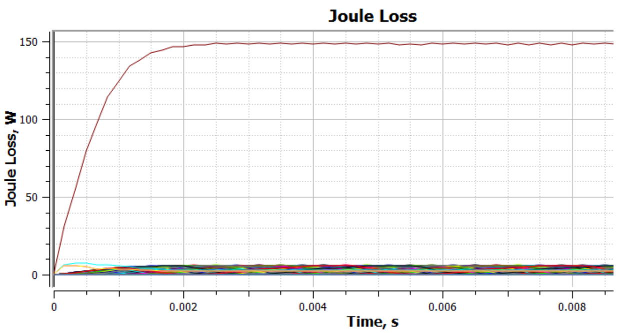

Fig. 2. Joule losses - 500 rpm

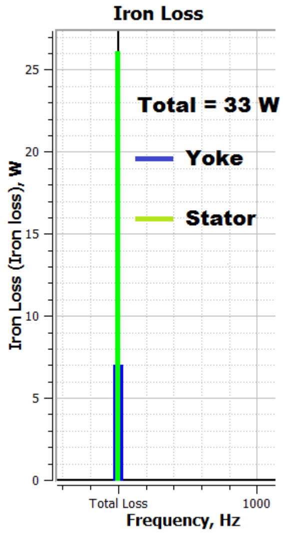

Fig 3: Iron losses - 500 rpm

The Joule losses are distributed in the rotor's yoke (2.8W), in the permanent magnets (4.7 W) and in the coils (140W). In Fig. 3 are presented the iron losses in the stator, these losses are totalizing 33W. Thus, at nominal speed and power, the most important losses are the stator Joule losses.

For 250 rpm analysis, there rotor losses are 4W (rotor yoke and magnets), the iron losses in the stator are 13W and Joule losses in the coils are 5W. Thus at low speed and power, the iron losses are the most important ones.

For 360 rpm analysis, the losses in the rotor are around 6W (rotor yoke and magnets), iron losses of 21.5W in the stator and Joule losses of about 30 W in the coils. At this speed, the Joule losses in coils are balanced with the other losses.

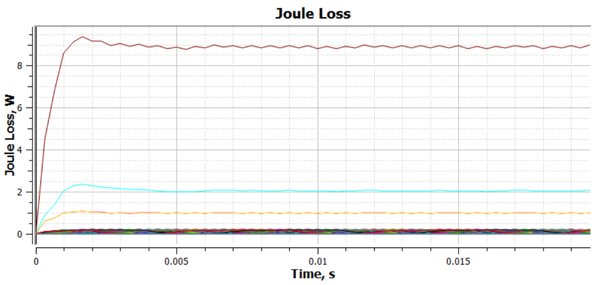

Fig. 4. Joule losses - 250 rpm

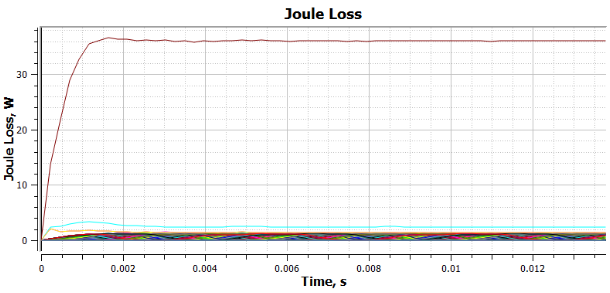

Fig. 5: Joule losses - 360 rpm

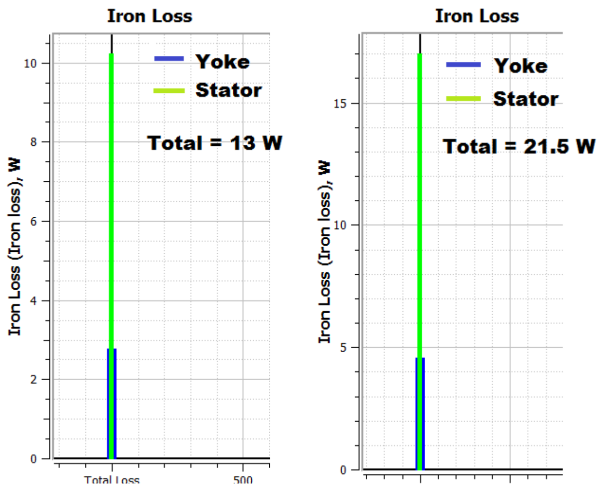

Fig. 6. Iron loss - 250 rpm and 360 rpm.

B. Thermal Analysis

Once the magnetic study is done and the losses are determined, it is then possible to start the thermal analysis.

In the beginning, all parts of the model have to be included in a thermal circuit. For this, it is needed to set this circuit in JMAG. The role of this circuit is to model the heat transfer by convection between machine elements and between the machine and its environment. Moreover, the circuit is also used to take into consideration the existence of parts which are not modeled in the geometry of the turbine (bearings, cover, etc.). Finally, the circuit is used to implement the air dissipation created by the rotation of the rotor.

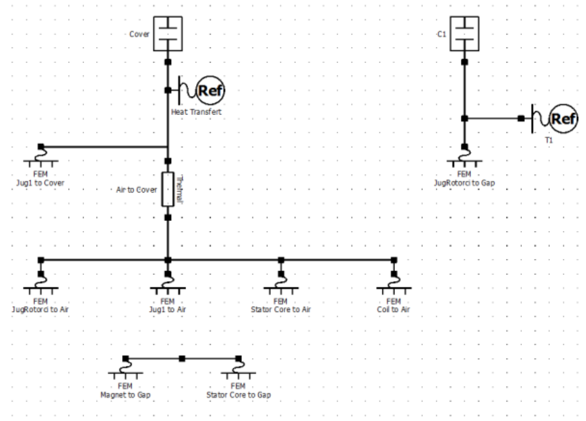

Fig. 5. Thermal circuit.

a. Heat Transfer Boundary

To start the study, the “Heat Transfer Boundary” has to be set. This condition makes the link with the thermal circuit. It is used to set the contact faces between each parts of the generator and the airgap or cover. For this condition, it is needed to insert a coefficient which represents the transfer by convection, however these coefficient has to be calculated in different ways for each type of transfer.

To calculate the heat transfer from a component to airgap, equation [1] is used.

$$h = \frac{6.6\ vr^{0.67}}{10^5\ lg^{0.33}} \times 10^4\ (\text{W/m/K}) \qquad [1]$$

With vr the rotation speed in cm/s and lg the radius of the part in cm.

To calculate the heat transfer from a component to cover, equation [2] is used.

$$h = \frac{\lambda}{d}\ (\text{W/m/K}) \qquad [2]$$

λ is the thermal conductivity of the air expressed in (W/m/K) and d the distance between the component and the cover (m).

To set the contact face between each part and the air, the value of the coefficient is always 10 W/m/K.

The values used in the study are presented in Fig. 3, and expressed in W/m/K.

Table 2. Heat transfer coefficients.

Link rotor – air gap	104
Link stator – air gap	61.2
Link yoke – cover	27
Link magnets – air gap	57.6

b. Contact Thermal Resistance

The “Contact Thermal Resistance” is used to set the transfer by convection between each component facet of the machine. The use of this condition needs coefficients of thermal conductivity linked with the materials used to build the machine.

The values of thermal conductivities were not provided by suppliers of materials, that is why the datasheets given by the material library of JMAG were useful.

A contact between two materials involves two thermal conductivities, consequently the higher value was chosen as thermal conductivity. The values are presented in Table 4.

Table 3. Thermal conductivity (W/m/K).

Contact yoke - holes	55.7
Contact coil - stator	400
Contact coil - yoke	400
Contact yoke - cover	55.7

c. Heat Source

The "Heat Source" is used to indicate which part of the turbine is concerned by such type of loss. This condition allows the establishment of the link between magnetic and thermal analysis.

d. Other useful parameters

For a thermal transient analysis, it is also relevant to establish an initial temperature.

In some cases, the thermal datasheets of materials are not complete and it could present drawbacks during the simulation, as a consequence it could be necessary to create a new material with the missing coefficients.

3. RESULTS OF THE THERMAL ANALYSIS

The results for the thermal analysis without air dissipation in the rotor are presented in Figs 6-8 for the three cases: 250 rpm, 360 rpm and 500 rpm.

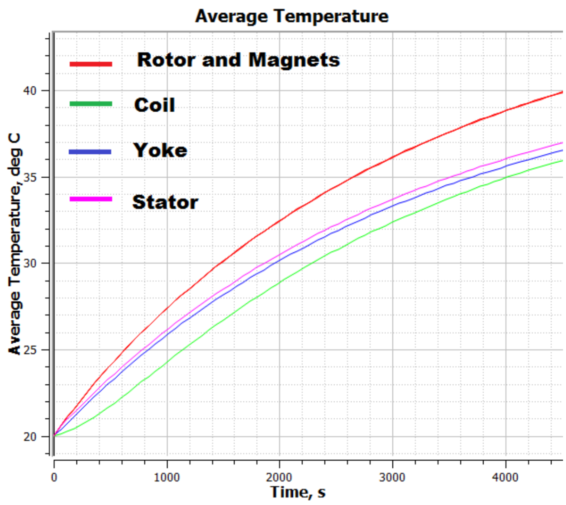

Fig. 4. Thermal study - 250 rpm.

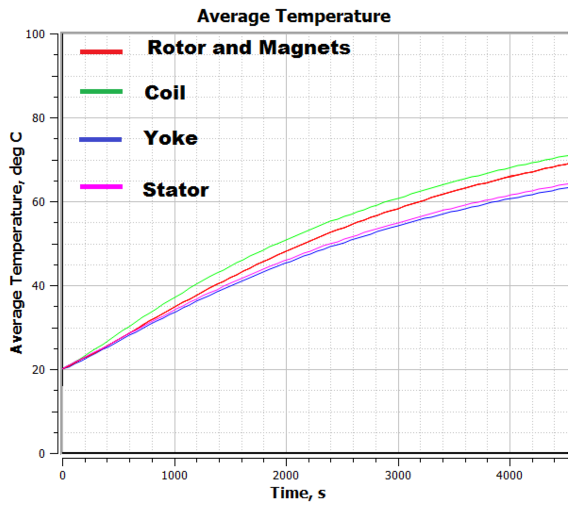

Fig. 5. Thermal study - 360 rpm.

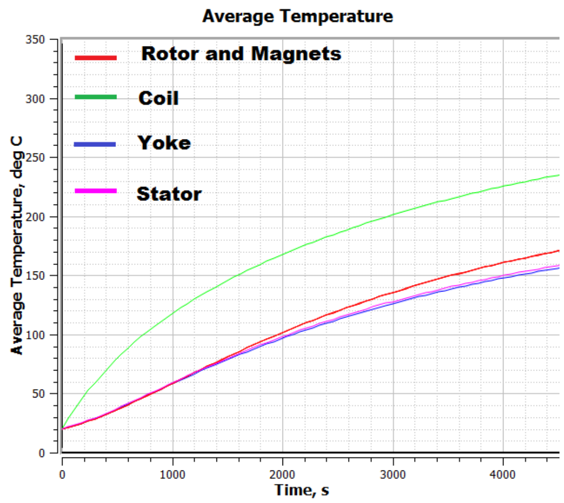

Fig. 6. Thermal study - 500 rpm.

At 250 rpm, the wind turbine works at low speed. The temperature which presents a stabilization after 6000 seconds will not overpass 40 °C.

For instance, with a time of work of 20 minutes, the temperatures are: in the rotor 29°C, in the stator 26°C and in one of the permanent magnets reaches 28°C. As a result, due to the low temperatures, the dissipated heat will never cause damage to the generator.

The operation at 360 rpm is presented in Fig. 7. The temperature will not overpass 100°C for any component (as a reminder, the results are valid for a simulation without air dissipation). For example, for a period of operation of one hour, the temperatures in the magnets and the rotor should be about 63°C, for the same time the temperatures in the stator are about 59°C.

The material which has been chosen for the magnets is the NEOREC45F, this type of material can support a maximum temperature of 80°C, if the material overpasses this temperature, a demagnetization can occur. Consequently, for a long period of work at 360 rpm, the heat elevation will have probably no impact on the material.

In opposition to the two other cases, at 500 rpm, the turbine will work rarely. After a period of 25 minutes, the temperature of the magnets, the rotor, the stator and the yoke reach 80°C. Because of the materials which were chosen for the magnets, it is after this period of 25 minutes that temperatures begins to be dangerous for the permanent magnets and could create a permanent demagnetization for them. But, this case has very few chances to happen, in fact with the variation of the wind speed, the turbine does not work at this speed during a long time. Moreover, the heat dissipation of the rotor is not considered.

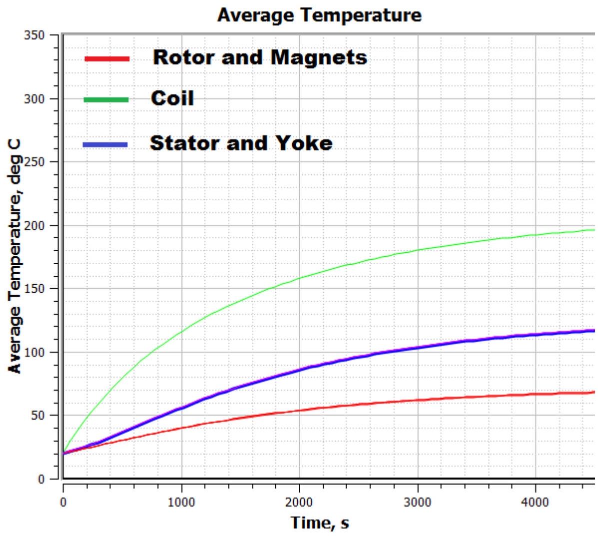

Fig. 7. Thermal analysis - 500 rpm with air dissipation.

If we take into account the air dissipation in the rotor, after 1 hour of operation, for the analysis at 500 rpm, the rotor temperature will not exceed 70°C. By considering the air dissipation, it is evident that the safety of the turbine will be assured for a longer time.

As a result, considering heat dissipation, the magnets will never exceed a temperature of 80°C regardless of the turbine speed.

4. DISCUSSION

Because of the time devoted to the study, some directions of research have not been developed enough. In order to improve the precision of the simulation, some settings could be more detailed.

Firstly, some parts of the generator are not represented in the geometry, for example the bearings or the cover, even though the lack of these parts are considered in the thermal circuit, it could modify the results of the simulation.

To have more precise results for the air dissipation, it could be interesting to export the project in a CFD (computational fluids dynamics) software. In fact, JMAG is only conceived to do some finite element analysis calculations.

The thermal conductivity coefficients, are given by JMAG's library were implemented in the simulation but it could bring a higher precision if search were done with suppliers of materials in order to have better coefficients.

5. CONCLUSION

This paper has presented a thermal analysis for a permanent magnet synchronous generator using JMAG software with the aim to determine if the NdFeB permanent magnets, but also other components, are subject to overheating during normal operation of the machine. Thanks to this study, it is acceptable to say that this PMSG should have no problems in operation.

ACKNOLEDGMENT

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