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Comparison of Conventional Salient-Pole Synchronous Generators and Permanent-Magnet-Assisted Salient-Pole Synchronous Generators based on Finite Element Analysis

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Abstract

This paper presents a novel salient pole synchronous generator i.e. permanent-magnet-assisted salient-pole synchronous generator (PMa-SGs). Due to saturation of conventional synchronous generators (SGs), permanent-magnet-assisted salient-pole synchronous generators (PMa-SGs) are presented. PMa-SGs are a new type of salient-pole synchronous machines with extra permanent magnets (PMs) between the adjacent pole shoes. Placing PMs between adjacent pole shoes leads to a reduction in flux saturation plus an increase in armature flux linkage. In other words, the generator can operate at higher capacity. In this paper, a comparative study is carried out between conventional SGs and PMa-SGs based on finite element analysis (FEA). This is done via simulation of a PMa-SG compared to a conventional SG. Simulation Results show superiority of PMa-SGs over SGs. In fact, in PMa-SG maximum flux density in stator core is increased and pole bodies are not saturated. Besides, PMa-SG has higher flux linkage compared to conventional SG. Therefore, higher voltage could be produced in the generator. In other words, the output performance of the PMa-SG is considerably better than that of a conventional SG.

Keywords: *Synchronous Generator (SG), Magnetic Saturation, Permanent Magnet-assisted salient-pole synchronous generators (PMa-SGs), Finite Element Analysis (FEA)*

1. Introduction

Permanent-magnet-assisted salient-pole synchronous generators (PMa-SGs) are a new type of electrical generators that compensate limitation of utilization for traditional synchronous generators (SGs). SGs are widely used in producing electricity such as hydro generators, wind generators, etc. However, these kind of generators are faced with a major problem; magnetic saturation of the cores. In most cases pole bodies are saturated which demands more excitation power. This is done through enlarging the cross-section area of field windings, but it is clear that this leads to an increase in the size of generator [1, 2].

Emergence of PMa-SGs opened a new horizon to the electricity industry. Placing additional permanent magnets (PMs) between two adjacent poles can reduce the magnetic saturation and as a consequence, performance of the generator would be improved [3]. Modeling and analysis of such generators are discussed in literatures [1-6].

The aim of this paper is to perform a comparison between conventional SGs and PMa-SGs based on finite element analysis (FEA). This is done via simulation of these two kinds of machines using Ansys Maxwell. Besides, the PM effects in decreasing the saturation of the cores are investigated in PMa-SGs. For this purpose at first, structure and features of PMa-SGs are discussed in section 2. After that a comparative study is done between the two mentioned generators based on the finite element analysis (FEA) in section 3. Finally paper is concluded in section 4.

2. PMa-SGs

Figure 1 shows scheme of a PMa-SG. As shown, in these generators there are PMs between two adjacent pole shoes. The PMs are located in the leakage flux paths, not in the main flux paths. So the PMs do not interfere with the main flux [6]. The PMs produce a flux in opposite to the one produced by field windings. As a consequence, saturation in pole bodies is reduced [1]. On the other hand by doing this, flux linkage of armature winding is increased and therefore armature voltage of generator is also increased. Hence, the output of the generator is increased without any increase in generator size or reduction in efficiency [4]. In other words, saturation curve of the generator is lifted up which means that generator can work at higher operating point.

The equivalent circuit of PMa-SG is shown in Figure 2. The impedance jA+B in the circuit denotes the saliency of the field poles in which A is composed of d- and q-axis reactance.

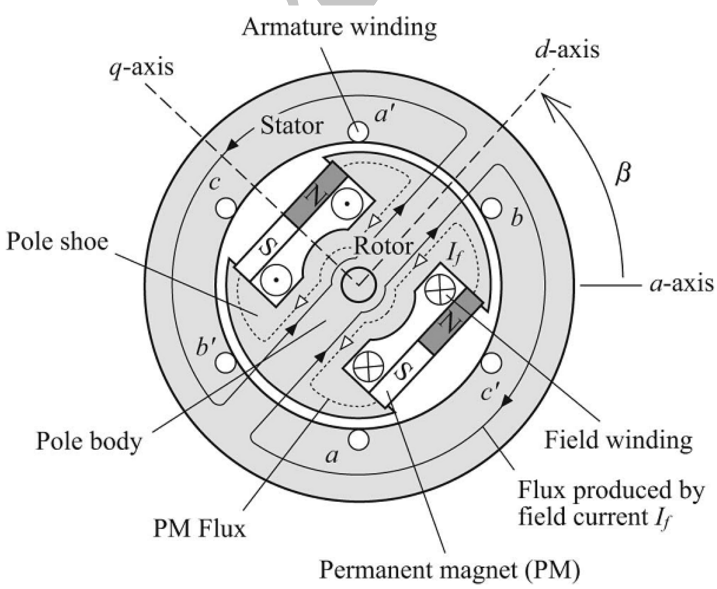
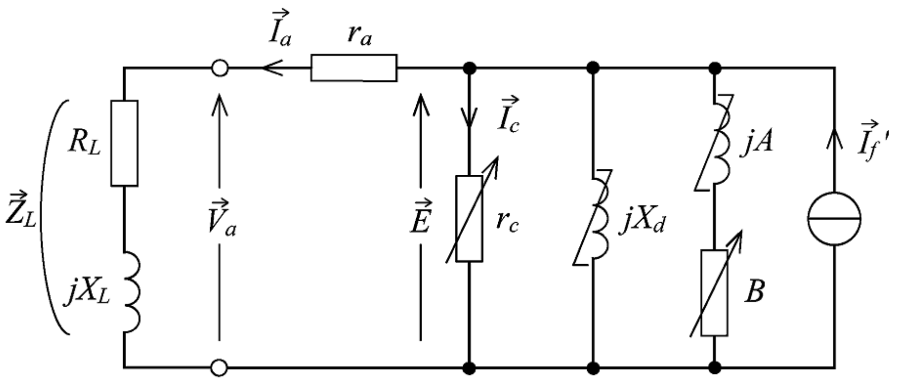


Figure 1. Schematic view of PMa-SG [1]



$$A = \frac{X_d X_q}{X_d - X_q}\ , \quad B = A\tan\beta_0\ , \quad \vec{I}_f\,' = K_n I_f(\cos\beta_0 + j\sin\beta_0)$$

Figure 2. Equivalent circuit of PMa-SG [1]

3. Comparison of SG and PMa-SG using FEA

The Finite element analysis (FEA) is used here to show the differences between SGs and PMa-SGs. Ansys Maxwell which is based on FEA is one of the most important and efficient tools for this purpose. In this section, Ansys Maxwell is used to investigate the effects of permanent magnets in reducing the saturation in cores of PMa-SGs. For this purpose, an SG and PMa-SG are simulated and compared with identical ratings.

3.1 A brief description about the FEA

The finite element analysis is an efficient tool in engineering systems. The use of this method in analyzing the problems of electrical engineering began almost 30 years ago. This method has long offered the tantalizing promise of providing us with a designed tool that gives detailed information about the electromagnetic conditions within the heart of a motor. The advantage of numerical methods like the finite element analysis is that arbitrary shapes, arbitrary boundary conditions and complicated or distributed sources, can be used with essentially no extra effort. Therefore, complicated systems and devices can be simulated by using this method.

Ansys Maxwell (formerly known as Ansoft Maxwell) is a well-known software in analyzing electrical machines problems. It gives accurate and reliable results. In fact, performance characteristics of machines can be accessible without building a real machine. This is done through simulation.

In this software which is a user-friendly program, desirable output quantities can be extracted by doing below steps:

- Drawing the machine
- Assigning materials and boundary
- Performing mesh operation
- Setting up an analysis to solve
- Extracting output data and plots.

3.2 Initializing the simulation

The two generators are selected with the same identical ratings. For these generators, stator and rotor core are composed of steel 1008. Magnetization curve of the core is depicted in Figure 3. The added permanent magnets in PMa-SGs are Neodymium-Ferrite-Boron (NdFeB) with: B_r=1.23 T and H_c= 890 kA/m.

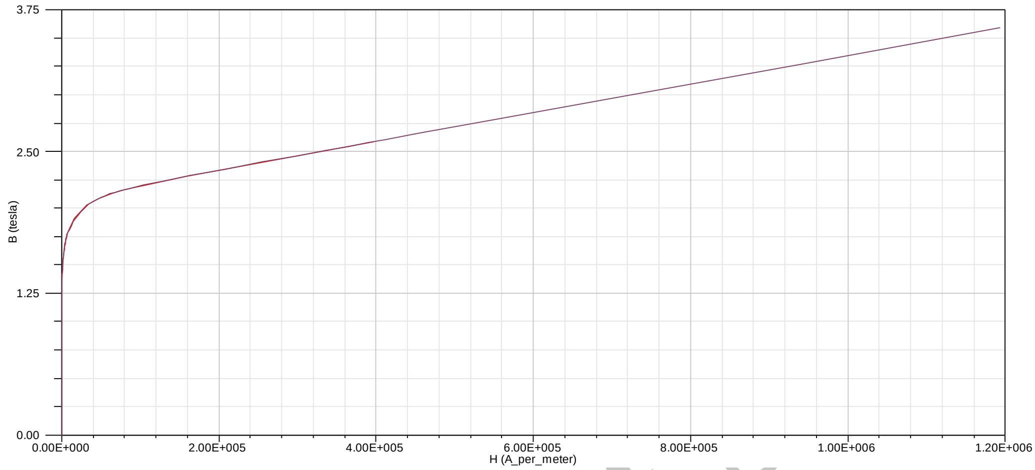
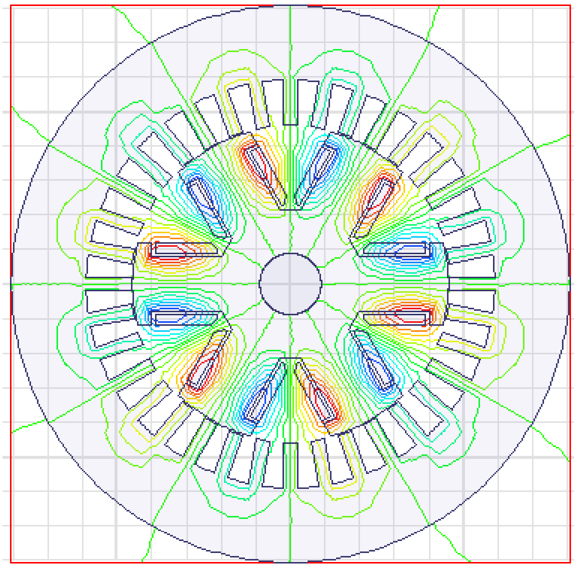


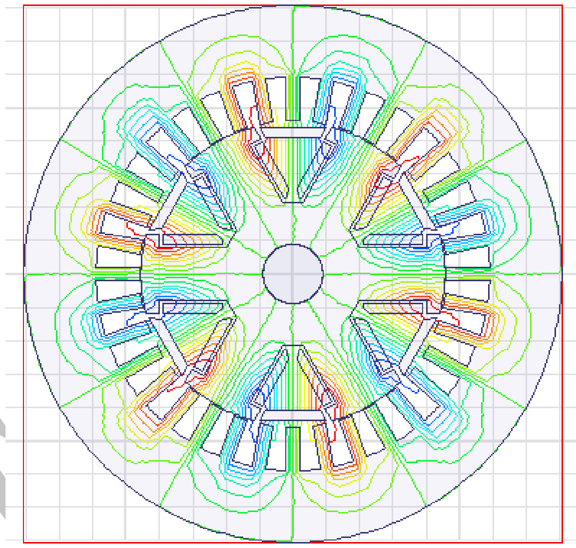
Figure 3. Magnetization curve of core

3.3 Results of Comparison

Running the software gives required output operating curves. In this section, we focus on some determining output diagrams that would efficienctly illustrate the superiority of PMa-SGs over conventional SGs. Figure 4 shows flux lines distribution in a SG and PMa-SG. By comparing Figure 4.a which is the flux lines of a SG with Figure 4.b which is flux lines of a PMa-SG, it is obvious that there is a more uniform and smoother flux lines distribution in PMa-SG compared to SG. The more uniform distribution of flux lines would help the generator to operate much better. Besides, flux density diagram of both generators are shown in Figure 5. As shown, in PMa-SG maximum flux density in stator core is increased and pole bodies are not saturated. In fact, maximum flux density in SG (Figure 5.a) is about 0.47 T that is increased to 0.79 T in PMa-SG (Figure 5.b). This increase of flux density and lack of saturation of pole bodies can be noticeable in high-power applications where saturation of pole bodies is very critical and important. Flux linkage of the two generators is also shown in Figure 6. As shown in Figure 6, PMa-SG has higher flux linkage compared to conventional SG. Flux linkage of SG (Figure 6.a) is about 0.033 Wb while flux linkage of PMa-SG (Figure 6.b) is about 0.047 Wb which is considerably higher than that of a SG. This increase of the flux linkage is because of the added permanent magnets in PMa-SG. Therefore, higher voltage could be produced in the permanent magnet added synchronous generator. In other words, output performance of the PMa-SG is considerably better than a conventional SG. Table 1 summarizes the abovementioned differences between these two generators. As given in Table 1, capacity of flux density has increased about 68 % in a PMa-SG. It is also expressed that value of flux linkage has also increased about 42 % in a PMa-SG.

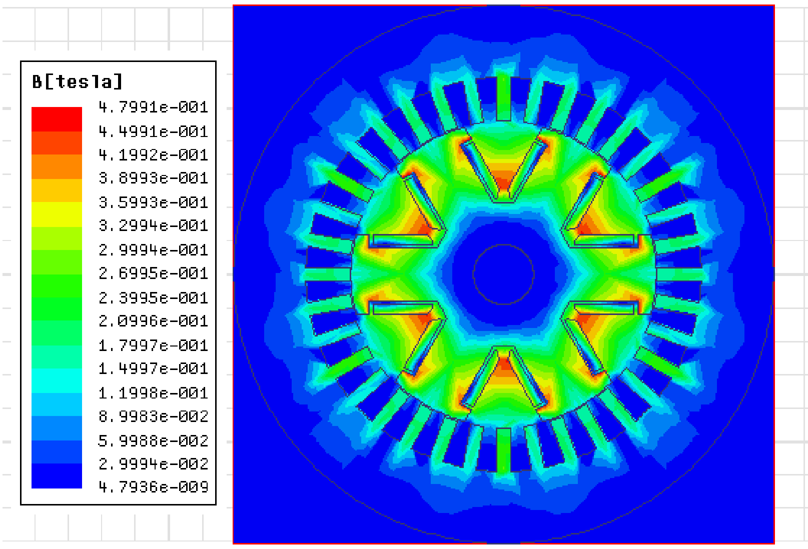


(a)

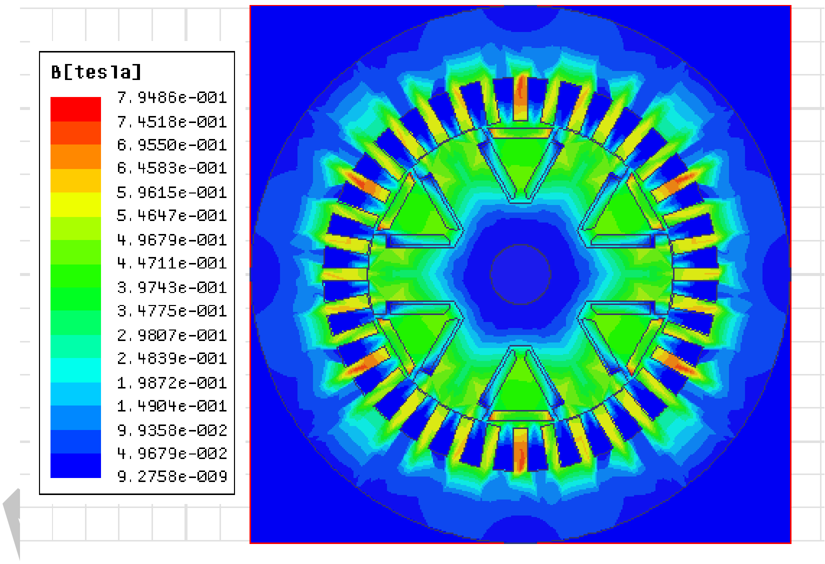


(b)

Figure 4. Flux lines distribution of a) SG and b) PMa-SG

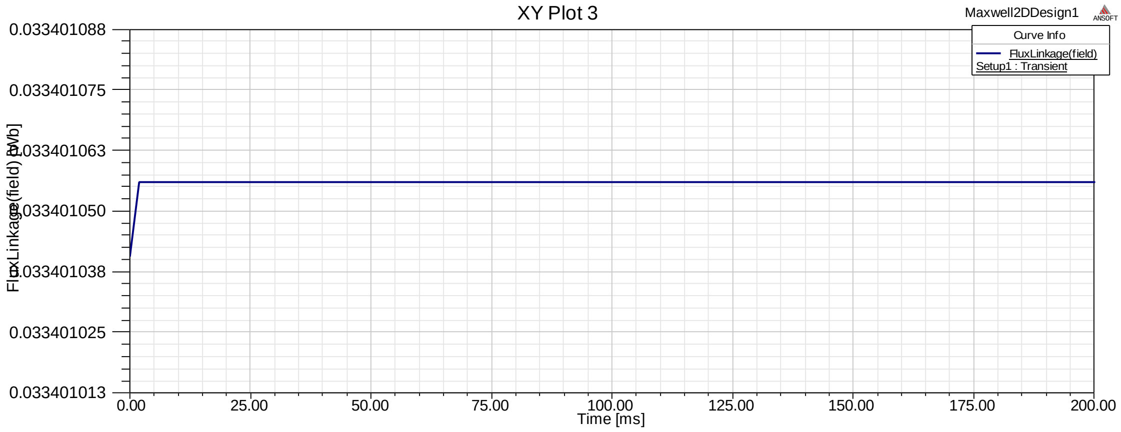


(a)

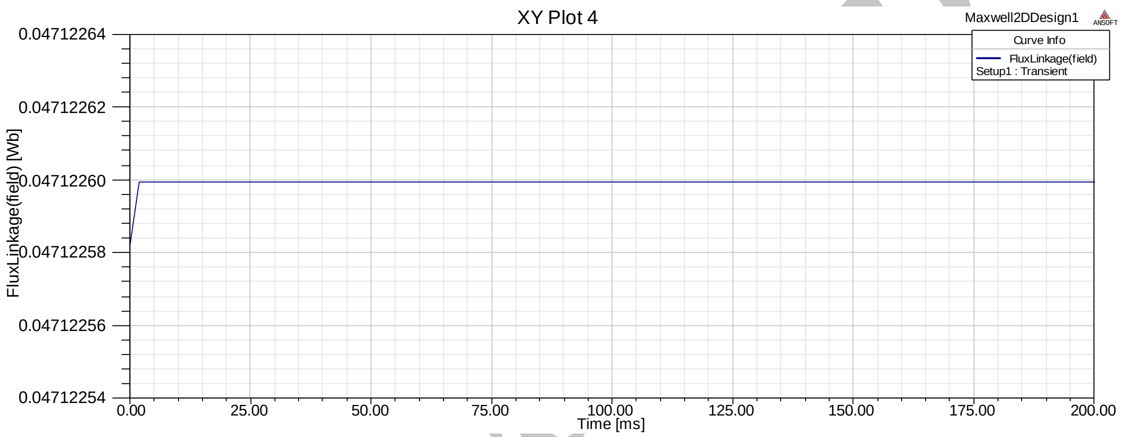


(b)

Figure 5. Flux density diagram of a)SG and b)PMa-SG



(a)



(b)

Figure 6. Flux linkage of a)SG and b)PMa-SG

Table 1. Comparison of SG and PMa-SG

Type of Generator	Maximum flux density (T)	Flux linkage (Wb)
SG	0.47	0.033
PMa-SG	0.79	0.047
Level of increase (%)	68.05	42.4

4. Conclusion

In this paper, a comparative study was performed between conventional SGs and PMa-SGs based on finite element analysis (FEA). Simulation Results show superior features of PMa-SGs over SGs. It was shown that in PMa-SGs maximum flux density in stator core is increased and pole bodies are not saturated. The percentage of flux density increase in PMa-SG is about 68 % compared to SG. Besides, PMa-SG has higher flux linkage compared to conventional SG by a percentage of 42 %. Hence, the armature voltage in PMa-SGs is increased. This leads to an increase in power output of the generator. Therefore, a PMa-SG with identical ratings of a conventional SG has a better and higher performance and would be a preferable choice in high-power applications.

References

[1] T. Fukami, T. Hayamizu, Y. Matsui, K. Shima, R. Hanaoka, and S. Takata, Steady-State Analysis of a Permanent-Magnet-Assisted Salient-Pole Synchronous Generator, IEEE Trans. Energy Conversion, vol. 25, no. 2, 2010.

[2] K. Yamazaki, S. Tamiya, K. Shima, T. Fukami, and K. Shirai, Modeling of Salient-Pole Synchronous Machines Assisted by Permanent Magnets, IEEE Trans. Magnetics, vol. 47, no. 10, 2011.

[3] K. Shima, N.Hirano, K.Iitomi, T.Tsuda, T.Fukami, R.Hanaoka, and S. Takata, Analysis of reduction effect on magnetic saturation in salient-pole synchronous machines by additional permanent magnets, in Proc. ISEF2007, Prague, Czech, Sep., pp. 1–4.

[4] K. Yamazaki, K. Nishioka, K. Shima, T. Fukami , and K. Shirai, Estimation of Assist Effects by Additional Permanent Magnets in Salient-Pole Synchronous Generators, , IEEE Trans. Industrial Electronics, vol. 59, no.6, 2012.

[5] T. Hosoi, K. Shima, and T. Fukami, Magnetic Circuit Analysis of Permanent-Magnet-Assisted Salient-Pole Synchronous Machines Under Steady States, IEEE Trans. Industry Applications, vol. 48, no. 3, 2012.

[6] Y.Matsui, T. Hayamizu, K. Shima, T. Fukami, R. Hanaoka, and S. Takata, A salient-pole synchronous generator with permanent magnets between the field poles, Electrical Engineering in Japan, vol. 174, no. 4, pp. 58–67, 2011.