Aspects regarding the permanent magnets for wind power plants

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1. Introduction

Because worldwide the need for PM (permanent magnet) in various fields is growing exponentially, a study is required on the types of PM used at synchronous generator with permanent magnets (SGPM) for the wind turbines of wind power plants [1].

For the wind turbines, current development is conducted towards SGPM. Synchronous generators have a PM instead of the classic excitation winding. Synchronous generators have a fixed part - stator and a mobile one called a rotor [2]. The rotor presents a great constructive diversity, from which we can distinguish the variants that interest us, i.e. those with permanent magnet:

a) Axial or radial flux rotor;
b) Longitudinal or transverse flux rotor;
c) Inner or outer rotor;
d) Disc type rotor [3].

Among the advantages of using permanent magnets, the following are mentioned:

- Increased efficiency;
- Higher torque and / or output power per volume;
- Better dynamic performances;
- Simplification of construction and maintenance;
- Low cost price for some types of SGPM, if PM are made of ferrite [4].

Starting from these advantages we have the current situation, in which the construction of SGPM with PM predominates, especially in the field of wind turbines.

SGPMs that are provided with PM also have some disadvantages:

- Extreme temperature changes, heat is the factor that has the greatest effect on PM;
- Improper storage;
- Age;
- Impacts, some PM may withstand falling several times, but will lose properties after repeated blows with a heavy object [5].

2. Permanent magnets

Permanent magnets (PM) or strong magnetic materials have a high resistance to demagnetization after they have been magnetized. The essential quality of a PM is its property of storing magnetic energy.

Permanent magnets (PM) can be natural or artificial. We are only interested in artificial PM [6].

There are three major classes of artificial permanent magnets:

- ferrite (ceramics);
- rare earths: - Samarium Cobalt (SmCo);
  - Neodymium (NdFeB) [7].

a) Ceramics magnets (Ferrite)

- produced from barium or strontium ferrite powders;
- good choice for low cost requirement Br - up to 4.2 MOe;
- corrosion resistant;
- ideal for use in electrical insulators;
- withstands environments with high temperatures - until to 300 °C.

Ceramic magnets or ferrite magnets are PM with light, moderate energy, low energy, capable to withstand operating temperatures of up to 250 °C. They are corrosion resistant and function well in high volume applications. These characteristics make them a preferred choice in production and consumer applications, respectively they can be designed to be small enough to be functional in micro applications.

The most popular ceramic magnets are ferrite 5 and ferrite 8. They are anisotropic, which is the strongest. Anisotropic magnets undergo magnetization only in the direction formed during pressing operation, concluding a magnet with a total output of the magnetic flux.

b) Samarium Cobalt magnets (SmCo)

- it is a rare earth magnet;
- extremely strong - currently go to 32 MOe;
- less sensitive to oxidation, and more fragile than neodymium;
- withstands environments with high temperatures - up to 300 °C;
- are more expensive than Neodymium.

Samarium Cobalt magnets are made from rare earth magnets that give high maximum energy products and may operate in high temperature environments. They are very strong.

Samarium Cobalt magnets own three advantages:

- function at a wide range of temperatures;
- have higher temperature coefficients;
- support high corrosion resistance, therefore require surface treatment.

They may have a high resistance to external demagnetization fields, because to their high intrinsic coercive force (Hci).

Samarium Cobalt magnets are the most used magnets for high temperature applications. It retains most of its energy up to 302 °C. Samarium Cobalt magnets are recognized for excellent temperature stability:

- maximum operating temperatures are between 121 - 288 °C;
- Curie temperatures vary between 372 - 427 °C, so they are ideal for applications where thermic stability is required.

c) Neodymium magnets (NdFeB)

- rare earth magnet;
- offers the highest residual induction Br and intrisic coercive field Hci (magnetic coercivity) values;
- is the strongest magnet available - up to 52 MOe;
- susceptible to oxidation, because of high iron content;
- may be used in environments up to 200 °C.

Neodymium magnets are rare earth magnets and are the most widely used rare earth permanent magnets in the world. They are made usually of neodymium (Nd), iron (Fe) and boron (B) and have the highest maximum energy product of any PM material. However, these magnets are vulnerable to corrosion if exposed to elements. For protect the magnet from corrosion, the magnet is usually covered with nickel [8].

Of all the rare earth magnets, neodymium magnets have a highest resistance to demagnetization. They don`t lose their magnetization if they are thrown or exposed to other magnets. Neodymium magnets are the most advantageous for standard temperature and high temperature applications.

These high-strength magnets achieve maximum performance while maintaining minimum dimensions.

The most used are: Neodymium-N52, N52M, N38EHT, N38UHT, N42SHT [8].

In table 2.1, the three classes are compared of magnets used in the construction of SGPM.

3. Physical properties of PM

The tests are performed in the laboratory under strictly controlled conditions. Sintered PM that have been selected from the types of PM available on the market are utilized as samples. PM are frequently used in rotor or stator of SGPM as a source of excitation for wind farms. According to their production technology, PM may be divided into groups such as: sintered magnets, cast magnets and bonded magnets (so-called dielectro-magnets or bonded magnets).

Sintered and bonded PM will be tested. The samples were made on sintered ceramic magnets of type F30, sintered magnets of Nd-Fe-B type N38, as well as SmCo5 type S18 and Sm2Co17 type S30. The magnetic, electrical and mechanical properties of the selected PM will be tested.

For the bound magnets, appropriate research on the impact of production technology on their physical properties has also been carried out. A part of the research focused on magnets bound from hard magnetic powder material, modified to improve their physical properties.

The aim of the analysis is to create a base knowledge of permanently bonded and sintered magnets, including information about the physical properties of various hard magnetic materials. The main purpose of the analysis is to get acquainted with designers of PM electrical motors with their various physical properties. Due to this fact, they will choose PM with optimal properties for a needed construction of SGPM [10].

Testing the physical properties of PM includes measuring the magnetical, mechanical and electrical properties of sintered ceramic magnets type F30, sintered Nd-Fe-B type N38, sintered SmCo5 type S18 and Sm2Co17 type S30. These types were measured.

The table 3.1 shows the values of the magnetic properties measurements for sintered magnets. Sintered ceramic magnets have weak magnetic properties, but permanent, magnets in this group are cheap. The most expensive are Nd-Fe-B magnets with the highest maximum value (BH).

Because of the fact that some types of SGPM have PM attached to the rotor and are subjected to centrifugal forces while also requiring a high mechanical strength, it is necessary to test the mechanic properties of PM. Because of the very varied dimensions and forms of sintered PMs, not all parameters could be determined.

Table 2.1. Classes of the most used permanent magnets [9].

Ferrite (ceramics)	SmCo (rare earths)	NdFeB (rare earths)
- appeared in 1950, those based on Strontium and Barium	- invented between 1960-1970	-created in 1982
- derivatives of iron or other metal oxides	- made from alloy with Sa, Co, Cu, Zr, Fe	- make part of PM family of rare earths: Nd, Fe, B
- breakable	- they are high energy magnets	- they are high energy magnets
- sintering	- sintering	- sintering
- great coercive field (265 [kA/m])	- large coercive field (700 [kA/m])	- high value of coercive field - (1000 [kA/m])
- low residual induction (0.39 [T])	- medium residual induction (1.05 [T])	- high residual induction (1.35 [T])
- low magnetic energy	- high maximum magnetic energy	- higher maximum magnetic energy
- corrosion resistance	- high corrosion resistance	- susceptible to corrosion
- high electrical resistance	- high thermal stability	- moderate thermal stability
- maximum working temperature 400°C	-	- maximum working temperature 150°C
- low cost price	- high cost price	- lower price cost than SmCo
- it is used for the construction of SGPM with lower performances	- it is used especially in applications where the thermic stability of SGPM is vital	- it is used in high performance SGPM applications

Table 3.1. Measurements of the magnetic properties of sintered PM.

Material	D [g/]	Br [T]	HcJ [kA/m]	HcB [kA/m]	(BH)max [kJ/]
Strontium ferrite	4.81	0.388	229.2	224.8	28.68
Nd-Fe-B	7.43	1.212	976.9	868.2	265.05
Sm-Co5	8.36	0.882	1598.1	584.9	128.37
Sm2-Co17	8.48	1.082	>1600	839.8	227.17

Table 3.2 presents the values of the measurements of mechanical properties.

Table 3.2. Measurements of mechanical properties of sintered PM.

Material	Ultimate tensile strength Rc [MPa]	Yield strength Rg [MPa]
Strontium ferrite	960	149
Nd-Fe-B	959	258
Sm-Co5	1855	64,6
Sm2-Co17	796	94

Electrical properties of sintered PM are represented by the measurement of resistivity. It has been found that increased resistivity reduces the Eddy current losses [10].

4. Application of pm for the excitation of a SGPM

The Nd-Fe-B class of PM has been selected for the application at the excitation circuit of a SGPM for a wind turbine of a wind plant, as presented in the figure 4.1.

Starting from the available power for the wind power plant, the sizes of the SGPM are calculated with both the law of the magnetic circuit and the law of the magnetic flow, applied for the magnetic circuit of the excitation. The demagnetizing characteristic of the neodymium PM is also necessary. This is the subject of the design of a SGPM for a power plant, which will be drafted in the next period, based on the data presented here.

5. Conclusions

The conclusions of the study presented, offer a base knowledge about the physical properties of the permanent magnets. An information database allows the correct selection of strong magnetic materials to be utilized in a new generation of electrical devices.

Magnetic materials from rare earths (eg, neodymium-iron-boron) are magnetized in the final phase of the manufacturing process. Instead, ferrite magnets, which have lower internal energies, can be magnetized in the beneficiary's installations. The complexity of the magnetization installation depends on the way of the magnetization and the number of pairs of poles [10].

Ceramic magnets are utilized in the construction of SGPM with low-performance permanent magnets. The utilization of SmCo magnets is recommended in applications where the thermic stability of SGPM is very important. For high performance it is advisable to use Neodymium magnets [9].

Choose the ceramic PM version of SGPM if we need generally lower performance, low cost price, low residual induction that requires ferrite geometries to achieve a concentration of magnetic flux leading to an induction in the air gap. Ceramic magnets are arranged radially and circularly, to increase the surface area of the magnet on the pole and achieve a better concentration of the inductive field. Ceramic magnets may be used if we want a cheaper and simpler version of a vertical wind turbine [12].

- Remaining magnetic induction (Br): 0.388 T;
- Coercive field (Hc): 229.2 kA / m;
- Quality index (BH) max: 28.68 kJ / m³;
- Maximum working temperature (Tmax): 250 °C [13].

After research conducted for PM based on Samarium and Cobalt (SmCo5 type S18 and Sm2Co17 type S30), it was concluded that, if PM are mounted inside or inserted in rotor, then PM are better protected against centrifugal and radial electromagnetic forces, and the values are high for:

- Remaining magnetic induction (Br): 0.882 - 1.082 T;
- Coercive field (Hc): 1598.1 - 1600 kA / m;
- Quality index (BH) max: 128.37 - 227.17 kJ / m³;
- Maximum working temperature (Tmax): ≤ 80 °C [13].

These attributes make the samarium cobalt PM provide excellent corrosion resistance and will not normally need surface treatment. Cobalt samarium magnets are prone to fracture and are very weak under loads that stretch or compress them. Cobalt samarium magnets have high resistance to external demagnetizing fields because to their high intrinsic coercive force (Hci). This resistance makes Samarium Cobalt magnets an excellent option for electro-mechanical applications. Of all the PM, they have excellent thermal stability, which is especially recommended for applications where thermic stability is vital, this is reflected in the high cost price.

After these researches, the permanent Nd-Fe-B magnets were selected as the most prefered to be used in the construction of SGPM for wind power plants because of their special properties:

- Remaining magnetic induction (Br): 1,212 T;
- Coercive field (Hc) consisting of:
  - Coercive force (bHc): 868.2 kA / m;
  - Intrinsic coercive force (iHc): ≥ 955 kA / m;
- Quality index (BH) max: 265.05 kJ / m³;
- Maximum working temperature (Tmax): ≤ 150 °C [13].

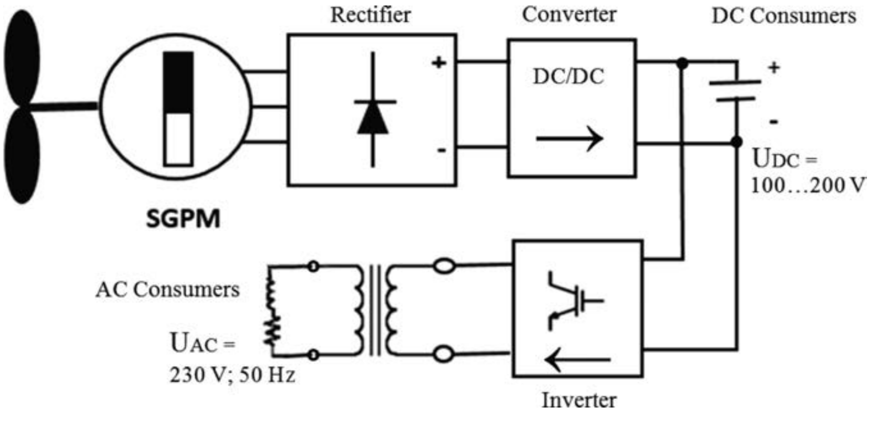

Figure 4.1. Block diagram of a wind turbine generator with variable speed, with SGPM [11].

The most ordinary type of SGPM on the market is Neodymium PM (Nd-Fe-B) SGPM with axial or radial field disc rotor. The most common model of wind farm is the one with a horizontal axis, as in the figure 4.1 [14].

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