Levitating Bearings Using Superconductor Technology Under Smart Systems Scope

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Abstract. This paper presents a study about the cooling and leakage aspects of superconductor magnetic bearings towards their integration on a smart systems scope to keep the stability of the cooling system. The use of superconductor magnetic bearings in electric power generation, namely in wind power has been increased due to their weight, friction less, and volume reduction advantages. The novelty of this paper is the use of Zero-Field Cooling instead of the common Field Cooling technique. On the other hand, this new kind of bearings needs a constant flow of liquid nitrogen to keep the superconductivity properties. A prototype was modelled, simulated and implemented for experimental validation.

Keywords: Superconductor magnetic bearing, superconductors, Smart Grids, Magnetic levitation, Zero field cooling

1 Introduction

Technological Innovation for Smart Systems is essential for smart grids. Wind power systems manifest variations in the output power due to the variations wind speeds, thus introducing a new factor of uncertainty and risk on the electrical grid posing challenges in terms of power system security, power system stability, power quality and malfunctions. The significant breakthroughs in science and technology allow the opportunity to link cyber space and physical components, using technological Innovation for Smart Systems. This bridge leads to Cyber-Physical Systems [1].

Large wind power generators with superconductors bearings are in constant development due to their advantages such as weight, friction less, volume reduction and the increased efficiency when compared with conventional bearings technologies [2,3]. The use of Superconductor Magnetic Bearings (SMB) requires their constant cooling with liquid nitrogen. Smart grids allow the optimization of the available resources, namely in keeping and monitoring the liquid nitrogen critical levels.

Classical rotating bearings are a frequent component of rotational systems. They are widely used in wind energy production, hydraulic power plants and thermo power plants. The SMBs studied in this work will likely replace the existing classical bearings in a near future. Despite the SMB increased efficiency and life time as well as the frictionless advantages, they have other drawbacks. Actually they need a cryogenic system to maintain the working low temperatures that are needed (by now) to keep the superconductivity properties.

Advanced researches have been carried out to build SMBs. Prototypes have been developed for many applications like the construction of large-scale flywheels [4] or for bearings in the textile industries [5], or for wind energy conversion systems [6].

The main contribution of this paper is the use of the zero field cooling (ZFC) technique instead of the classical field cooling (FC) technique. The approach in this work uses has shown to be more efficient, presenting less Joule losses [7,8]. Moreover the Nitrogen consumption is analyzed as it is an important feature of SMB, regarding the economic impacts of its use.

2 Relationship to Smart Systems

A smart grid is a new type of power grid which highly integrates modern advanced information techniques, communication techniques, computer science and techniques with physical grids [9]. One of the objectives of smart grid is the optimization of resources allocation.

Cyber Physical Systems (CPS) is an important issue for smart grids and smart sensors. The coordination and interaction of cyber layers and physical components of wind systems require handling a number of challenges for essential feasibility and competiveness of future. Successfully integrating wind power into the existing electric power grid is a complex challenge that relies on distributed, interconnected cyber-physical systems, which are proliferating within the engineering industry [1].

One of the objectives of smart grid is the optimization of resources allocation. The use of SMBs require a critical allocation of smart systems, namely smart sensors to support the continuous availability of liquid nitrogen or to measure guidance and levitation forces, inside the SMB. These smart sensors can transfer information to a cloud architecture system, benefiting of existing Internet Cloud Services [2].

3 SMB Cooling Prototype

An SMB based on NdFeB permanent magnets and YBCO superconductor bulks, also referred to as high temperature superconductors was designed. The SMB viability was made in [10,11] and the conception and experimental evaluation the SMB was achieved in [3], as shown in Fig. 1.

In [10] the magnetic fields as well as the levitation and guidance forces were simulated in a finite element analysis tool.

The levitation forces, as shown in [10] are given by:

$$|F_{Lev}| = \frac{A}{\mu}\frac{|B_t|^2}{2} \qquad \textbf{(1)}$$

where A is the surface parallel to the xy plan, B_t is the magnetic flux density tangential component and μ is the magnetic permeability of the YBCO superconductor bulks.

The SMB was simulated in a finite element analysis tool, as shown in Fig 1. The arrows show the levitation forces F_{Lev} which were shown to be able to sustain the rotor weight [10].

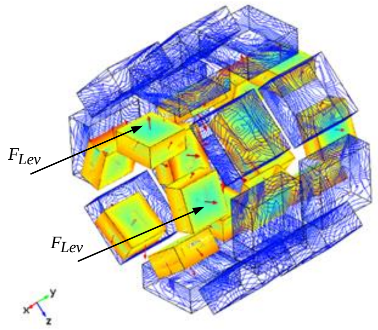

Fig. 1. SMB simulation of magnetization directions and contours.

The geometric placement of the permanent magnets and high temperature superconductors is carefully performed to keep symmetry along the main axis and to minimize the air gap of the prototype between the rotating part (rotor) and the static part (stator). Moreover, studies made during the development of this work involve changes in these geometric placements, either in the rotor as in the stator. Additionally, more finite element modelling was designed for simulation and viability study of the bearing, calculating the estimated levitation and guidance forces involved. The designed prototype model is shown in Fig. 2. Experimental validation was achieved by building a structure in conformity with the previously simulated geometry and comparing the simulation results with the ones obtained by measuring the existing forces in the real prototype. The results allowed the conclusion that it is possible to build a superconductor magnetic bearing using the zero field cooling technique, providing an important insight on how the system behaves.

To keep the YBCO superconductor bulks cooled, channels were created inside the stator for Liquid nitrogen cooling, as shown in Fig. 3.

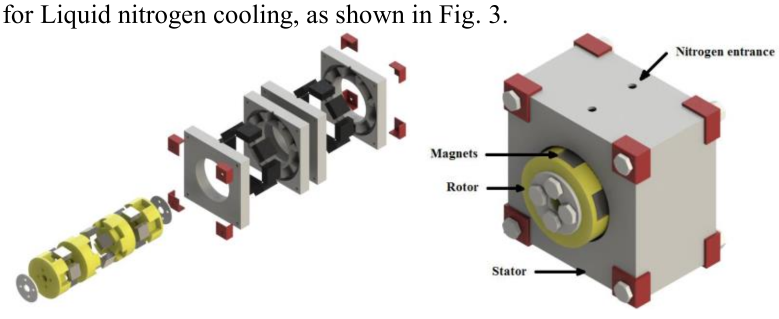

Fig. 2. Prototype model.

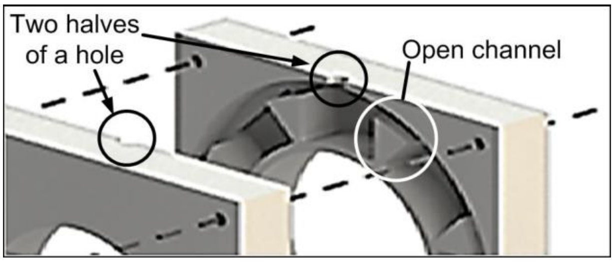

Fig. 3. Prototype model: channels for LN_2 cooling.

As the results were conclusive, a real prototype was implemented. Polyethylene and PLA were the materials used for the stator and rotor. To confirm the choice of the materials, namely the stator and the fasteners parts, an experience was developed to study the behavior of the structure at working conditions. These conditions are characterized by working at low temperatures, in the order of 77 K (liquid nitrogen temperature) and under clamping forces that close the stator slices together. With the intention of not harming all the structure, only half of the stator part was used in these first tests. Hence, the half of the stator part was totally submerged in liquid nitrogen, without any HTS bulks inside, until the system achieved a state of stability. For this purpose, some cables were attached to the structure so that it could be pulled. An example of this process is shown in Fig. 4.

Fig. 4. Totally submerged stator in LN_2.

- Submerged tests

In this first test, the used materials presented a good resistance within the working temperature range during the first experiences, without breaking or exhibiting any type of weakness.

- Leak tests

To ensure the structure, namely the stator, would enclose the liquid nitrogen in an efficient way, some leak tests were elaborated. These tests were made in a first phase with water, until the stator was successfully insulated.

In the first attempt, the stator was clamped only by the four holes in each corner. After pouring some water into the stator through the nitrogen entrance channel, it was observed that the water would come out through breaches between the slices of the stator. In order to correct this issue, a rubber based insulation tape was applied between each slice of the stator in order to insulate the structure. This insulation tape was cut accordingly to the profile of the inner part of the stator slices, so that it was applied only where the slices make contact. It was observed that some water still fell between the breaches, although in much less quantity. Subsequently it was decided to provide a better distributed and more uniform clamping to the structure, closer to the inner part of the stator. In a first phase, this was achieved by using clamps with PVC plaques to distribute the load. An example of how the structure was clamped is shown in Fig. 5.

Fig. 5. Clamps with PVC plaques.

As this solution proved to solve the tightness problem, it led to a change in the design of the structure explained, where as a way to avoid the clamps, 8 holes of 6.5 mm were designed closer to the inner part of the stator to distribute the loads uniformly.

- Nitrogen pouring

Liquid nitrogen is unstable when exposed to room temperature. Since its boiling point is at 77 K, it immediately evaporates. For this reason, when it is poured into the stator it often starts to boil, spilling if not handled with caution. Hence, the pouring of nitrogen is executed slowly in short movements, periodically switching channels of nitrogen entrances. This process usually takes about 10 min to 15 min, until the structure is full of stabilized liquid nitrogen. At this point we know that the temperature within the stator bulks is 77 K.

To complete the leak test, liquid nitrogen was poured inside the stator and the results were satisfactory, as the stator remained well insulated without any nitrogen spills.

- Nitrogen usage

In order to estimate the rate at which the liquid nitrogen would evaporate from inside the stator, a graph of time vs. weight was elaborated. This was achieved by pouring liquid nitrogen inside the stator until the structure was full. To read the weight values a weighting scale was used. With the structure standing on the weighing-scale, the time was measured until the weight stopped falling. With the purpose of not doing any damage to the weighing scale with the liquid nitrogen, a box of Styrofoam was used to protect the scale. The proper tare of this box was made to allow the precise reading of the structure weight. The set-up established to read the weigh values is shown in Fig. 6.

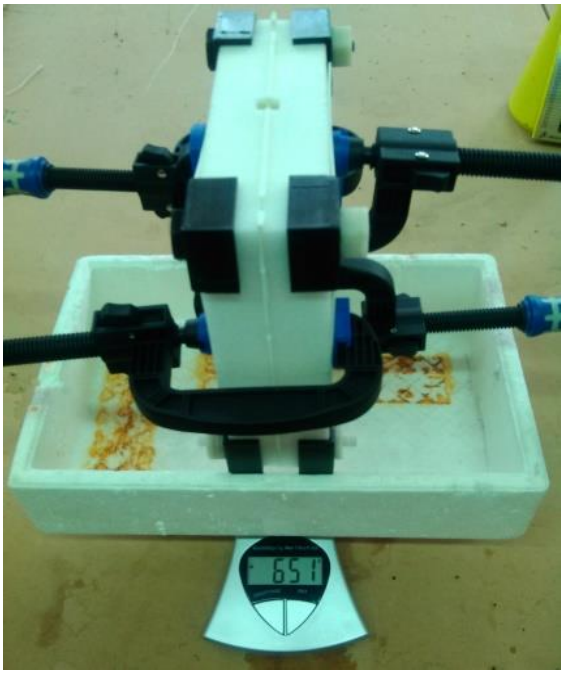

Fig. 6. Set-up used for the nitrogen usage information.

The curve of weight vs. time is shown in Fig. 7. It is easy to see that the rate at which the liquid nitrogen evaporates in the first 600 seconds can be considered linear, and therefore possible to calculate. In the calculation of the nitrogen usage rate, the first value considered was the weight measured after one minute, because after pouring the liquid nitrogen in the stator, it takes some seconds to stabilize. The evaporation rate in *g/min* of the liquid nitrogen in the stator was calculated and is given by:

$$LN_{er}=(814-727)/(600-60)=0.161 \text{ g/s} =9.67\ g/min$$

Knowing that the density value of LN_2 is 0.807 *g/mL*, the evaporation rate in *mL/min* is given by:

$$LN_{er} =0.161/0.807=0.200\ mL/s =11.979\ mL/min$$

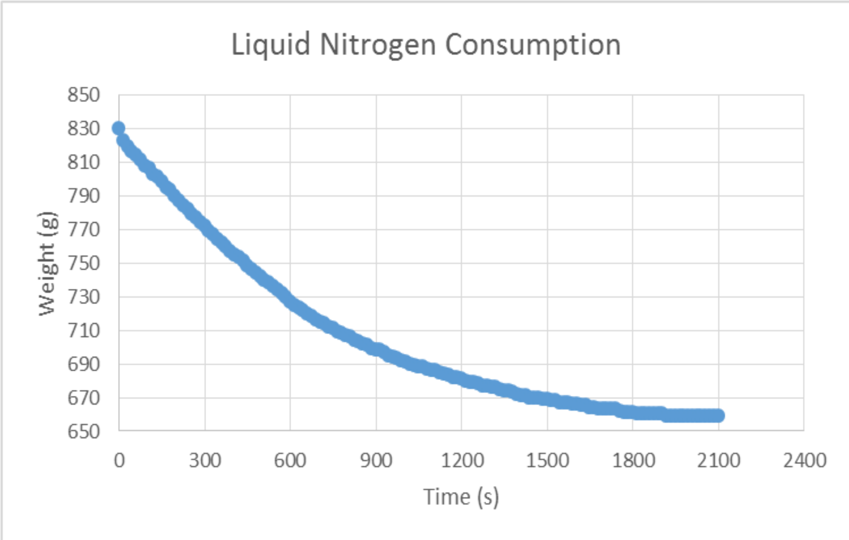

Fig. 7. Superconductor bearing consumption of LN2.

4 Conclusions

One of the objectives of smart grid is the optimization of resources allocation. As shown in this paper, the Superconductor Magnetic Bearings usage requires a critical allocation of smart systems, namely smart sensors to support the continuous availability of liquid nitrogen. The SMB viability was shown, a prototype was build and the LN2 consumption was measured. This data is important for smart grid management, and requires a comprehensive smart system to support the continuous availability of liquid nitrogen or to measure and guidance and levitation forces inside the Superconductor Magnetic Bearing.

Further work will deal with the integration of this data into smart systems, in an embedded architecture which embodies advanced automation systems to provide control and monitoring over the continuous availability of liquid nitrogen or to measure and guidance and levitation forces inside the Superconductor Magnetic Bearing.

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