Thermal Imaging System for Hydroelectric Generator Stator Based on Distributed Optical Sensors

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Abstract: This paper presents a thermal imaging system for stators of hydroelectric generators using distributed sensors. The main advantage of this approach over conventional sensors is the possibility to identify temperature variations over the stator structure.
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1. Introduction

One of the most relevant parameters in the degradation of hydroelectric generators is the stator temperature. The stator temperature must be constantly monitored, since temperatures above 100 °C may accelerate the aging of the insulating materials present in windings, leading to premature failure [1][2]. As a consequence, short circuits in the machine may lead to a reduction in the lifetime of the generator [2]. Commonly, stator temperature measurements are performed through conventional localized sensors such as RTD´s. These sensors are suitable to monitor temperature changes during standard operation given that the temperature distribution is considered to be rather uniform [3]. However, they are not able to identify hot spots that may arise in the stator coils as a result of insulation breakdown [3][4]. Given the difficulties presented, the technology of optical fiber sensors has characteristics with great potential for the instrumentation of the generator, which can solve most problems found in conventional sensors [4]. Two important features are the high galvanic isolation and electromagnetic immunity, which can solve measurements problems in environments with high electrical potential [5]. Another advantage is the possibility of distributed sensing, which facilitates the installation over the whole structure of the stator [3][4][5].This work presents a system for monitor the temperature of generator stator through the thermal imaging of the structure. The imaging system is based on a distributed temperature sensor (DTS) using Raman scattering. The thermal image is generated by combining information of temperature and spatial position of the sensor with a 3D model of the structure. The distributed monitoring can help to identify regions with high temperature and prevent possible failures in the structure insulation. An overview of the proposed system is presented in Section 2. Section 3 presents experimental results performed on a 200 MW hydroelectric generator.

2. Methodology

The imaging system was tested on a 200 MW hydroelectric generator of Salto Osório power plant, located in São Jorge D´Oeste in the state of Paraná, Brazil. Fig. 1 shows an overview of the methodology used in the experimental tests with the thermal imaging system. The instrumentation of the stator is performed by accessing the generator cabin. An optical fiber used as the distributed sensor is fixed in the internal surface of the stator using commercially available epoxy- based glues. The DTS equipment provides temperature information along the entire optical fiber with a spatial resolution of 1 m [5]. The information is processed by a software developed to generate thermal images of the stator. The software is based on a 3D model of the stator, and the spatial position of the sensor was fixed to the structure. The operating principle of the software is summarized in the block diagram shown in Fig. 2. First, the DTS equipment provides the information of distance and temperature along the optical fiber. The temperature values are converted into colors based on a preset color ramp. A 3D model with real dimensions of the stator is associated with the distance information to provide the spatial position of the sensor fixed on the stator. From the 3D model also we obtain the vertex matrix, which is used to calculate the temperature distribution by a color interpolation algorithm. The algorithm calculates the temperature of each vertex based on the spatial coordinates of the measuring points. As a result, a new texture is formed as a function of the temperature measured in the stator structure. The combination of calculated texture to the stator 3D model generates a thermal image of the structure. The thermal image is updated for every acquisition sensor, providing a real-time monitoring of the stator temperature, with advanced features such as enlargement, reduction and 360º rotation, which facilitate the identification of hot spots at any part of the structure. Section 3 presents results of experimental testing with a 200 MW hydroelectric generator.

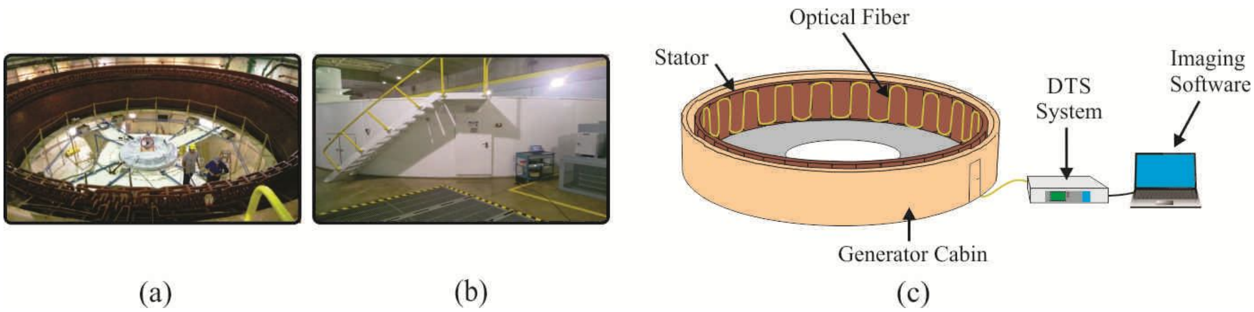

Fig. 1. Overview of the methodology used in the experimental tests with the thermal imaging system. (a) Picture of generator stator. (b) Picture of generator cabin and imaging system. (c) Schematic with components involved.

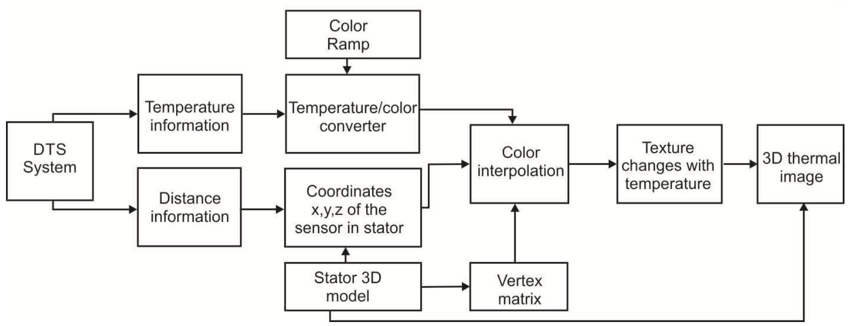

Fig. 2. Block diagram of the thermal imaging of generator stator using DTS system.

4. Results

The results were obtained during a 22-hour test, starting at 16:00 of the first day and ending at 14:00 of the following day. During this period, the generator was driven into compensation mode twice when it does not generate active power.. The optical fiber used as the sensor was fixed in the structure parallel to the stator bars. Fig. 3(a) shows the scheme used for installation. In this installation 31 m of optical fiber were used, which represents 31 measurements zones given a DTS spatial resolution of 1 m. The results of temperature measurements from 31 measurements zones during the test are presented in Fig. 3(b). As it can be seen, during normal operation the average temperature of the stator was approximately 54 °C. When the compensation mode is driven for the first time at 19:00, the generator operate without load for 1 hour, and the average temperature slowly drops to 45 ºC. At 20:00 the machine starts to generate active power again and the temperature rises up to 52 ºC, which is lower than the initial temperature and can account for the lower environment temperature as it is already 20:00 isn't midnight. The second maneuver is at approximately 00:00, and the average temperature drops to 41 °C after 7 hours and 30 minutes without load. An important observation is that differences of up to 3 ºC can be noticed between different parts of the structure. These differences may be associated with the distribution of stator bars, which are the main heat source due to the Joule effect [3]. Thus, considering several heat sources and the large size of the structure, relatively small temperature variations can occur.

The thermal image of the instrumented part of stator was generated during the 22-hour test. Fig. 4(a) shows the thermal image generated 18:00 where the generator was operating in the normal condition and the average temperature was 54 ºC. Fig. 4(b) shows the thermal image at 20:00 where after 1 hour of operation without load the temperature drops to 45 °C. Fig. 4(c) shows the thermal image at 7:00 the next day, where the generator operated without load for 7 and a half hours, and the average temperature drops to 41 °C. Although only part of the stator was instrumented, the results showed great performance for generating images according to the temperature distribution in the stator structure. The differences of only 3 °C between different measuring zones are not easily, and therefore the generated images had relatively uniform temperature distribution. However, insulation faults can result in regions with a high temperature, and these can be easily identified through thermal imaging.

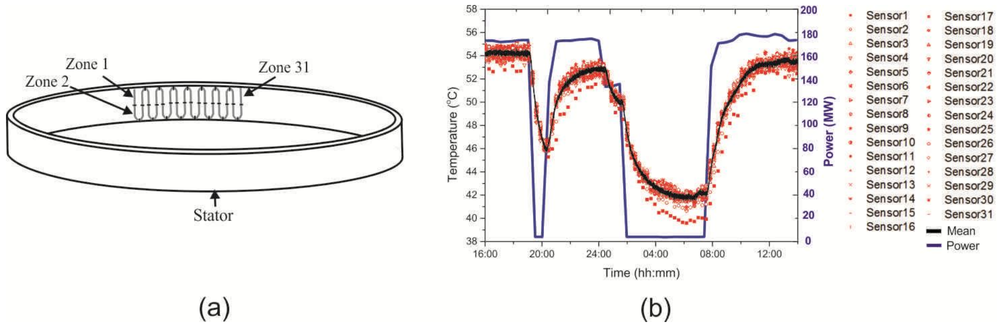

Fig. 3. (a) Scheme used for the installation of optical fiber in the vertical direction. (b) Stator temperature vs. power generation for vertical during 22-hour test.

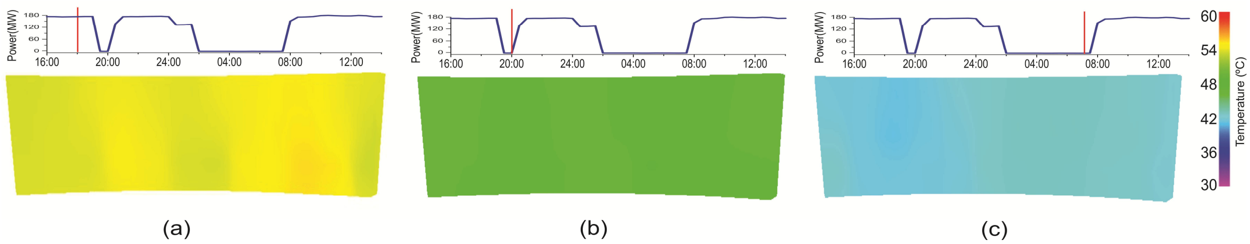

Fig. 4. (a) Thermal image during normal operation of the generator, where the average temperature is 54 °C. (b) Thermal image after 1 hour operating without load, where the average temperature is 45 °C. (c) Thermal image after 7 and a half hours operating without load, where the average temperature is 41 °C.

4. Conclusions

The presented thermal imaging system using distributed sensors can be a promising solution for prior identification of insulation faults in the stator. The faults are identified as hot regions on the structure, which can be viewed by maintenance engineers through the images provided by the software. The results of thermal images considering only part of the stator showed great performance to monitor the temperature distribution as function of generator power. In the near future a complete installation will be carried out, and new tests with a minimum duration of 60 days will be conducted. The constant monitoring of the entire stator structure can be a fundamental tool for predictive maintenance, ensure the performance and operational availability of the generator. Predictive maintenance can help identify wear isolation structure, reducing the risks of catastrophic failures, such as short circuits in the stator windings.

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6. References

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