Synchronous Generator Fault Investigation by Experimental and Finite Element Procedures

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Finite Element calculations and experimental measurements are employed in this work to detect faults in synchronous generators. A special benchmark constructed to this study allows to impose several controlled defects as short-circuits in the rotor filed winding, short-circuited stator turns, rotor eccentricities as well as short-circuits on the stator core iron sheets. The air-gap magnetic field can be detected by means of sensors inside de machine and is also calculated by the FEM.

***Index Terms*— Electric machines, Finite Element Method, Magnetic Sensors, Electromagnetic Modeling**

I. Introduction

THE USE of the magnetic field for fault detection in synchronous generators appeared in the 1970's. To what one can ascertain, the first works in this area were developed by D. R. Albright ([1]) from General Electric in USA. In 1986 J. Wood and R. Hindmarch presented a paper dealing with rotor short-circuited windings [2]. In these works, authors seek solutions to problems arising with the installation of generators with increasing powers, which invariably suffered from overheating caused by short circuits. The detection of such defects was mainly made by means of the magnetic fields in the air-gaps. More recently, several works continued to use this same methodology [3]-[5]. In the case of reference [5], two air-gap sensors were used and the resulting waveform obtained by the sum of the acquired signals was used to detect the faults in a four-pole generator.

In this work, numerical and experimental studies are made in order to detect faults in a two pole synchronous machine, rarely investigated in the literature with this kind of study. As known, the mechanical and electrical fundamental frequencies are the same for this generator, requiring a more careful analysis. Because this investigation is quite peculiar, the FEM numerical tools have an important role for comparison and for providing good results, reliability and confidence. The numerical techniques necessary to obtain consistent results will be explained in the full paper.

II. The Studied Cylindrical Rotor Generator

The 10 kVA two-pole generator has a 380 Volts three-phase wye connected stator and is able to operate at 50 and 60 Hz primary moved by means of a DC motor. As the commercial frequency in Brazil is 60 Hz, the 50 Hz operation was chosen to segregate phenomena produced by the generator operation and those from the surrounding stray fields noise. Figure 1 shows the 2D machine calculation domain with the flux distribution at no-load during healthy operation.

Several faults can be imposed to the generator. For instance, shorted turns in the rotor field winding can be experimentally imposed by applying the DC voltage to only a part of the whole field as indicated in the scheme shown in Fig. 2(a). For measuring the magnetic flux a sensor is winded on a stator tooth as shown in Fig. 2(b). In simulation, the voltage induced in this sensor is calculated and compared to experimental results.

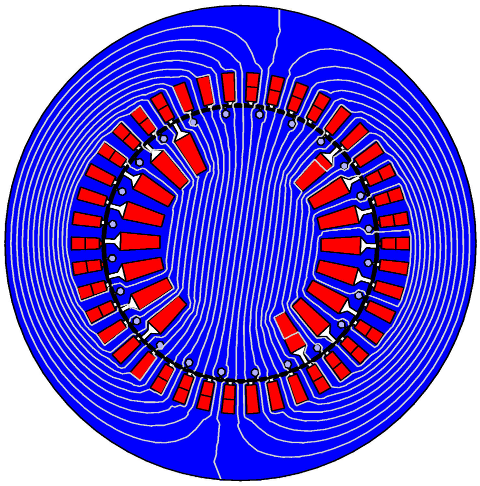
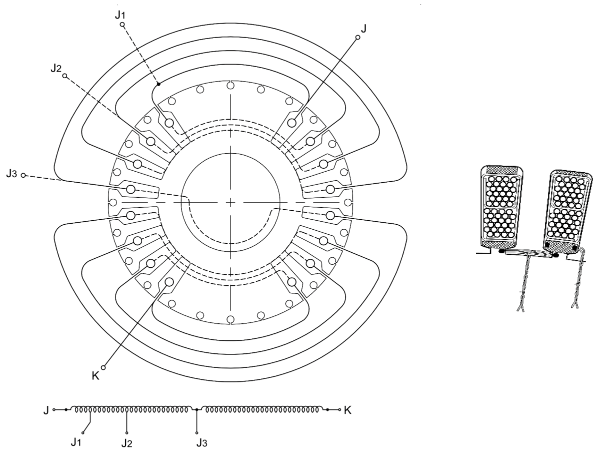


Fig. 1. Two pole generator no-load field distribution (healthy operation).



(a) (b)

Fig. 2. (a) Field winding scheme allowing imposing short-circuited parts. (b) Tooth winded sensor.

III. Results

Figure 3 shows the calculated sensor voltages for the health and faulty operation of the generator at no-load. The differences between the curves are indicated by arrows.

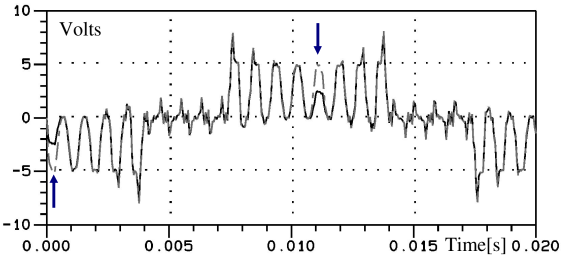


Fig. 3. Calculated sensor voltages: dotted line healthy rotor and continuous line faulty field winding.

As one observes, the voltage waveform for the healthy generator has roughly a square shape. Moreover, the positive and the negative half cycles have the same format. For these reasons its FFT (Fast Fourier Transform) presents the fundamental and only odd harmonics, as shown in Fig. 4 [6].

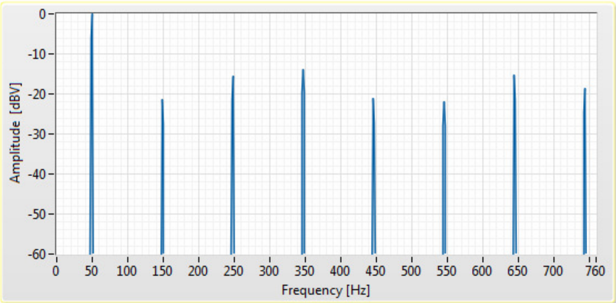


Fig. 4. Calculated sensor voltage frequency spectrum for the healthy rotor.

When the fault is simulated the positive and negative half cycles have different formats and due to this asymmetry other even order harmonics appear as shown in Fig. 5.

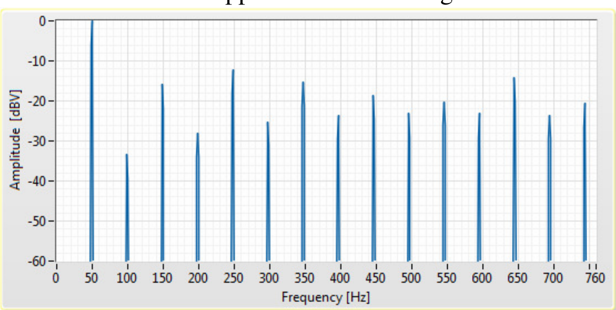


Fig. 5. Calculated sensor voltage frequency spectrum for the faulty rotor.

On the other hand, the real machine is not perfectly symmetric as the FEM model, presenting small geometric inaccuracies including eccentricities, not homogeneous windings and magnetic anisotropy in the core. Moreover, due to electromagnetic noises and small variations in its operating point during the signal acquisition period, the sensor voltage is not symmetric as it is for the modeled machine, even when no defect is imposed. If in the sensor voltage waveform (Fig. 6) such asymmetries are not easily detectable, its FFT presented in Fig. 7 shows odd and even harmonics, although the latter are considerably lower, as expected.

Finally, Fig. 8 presents the FFT of the sensor induced voltage for a faulty rotor. Corroborating with the simulation results spectrum presented in Fig. 5, the even harmonics now have higher amplitudes.

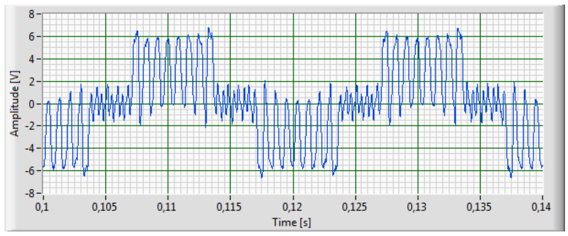


Fig. 6. Experimental sensor voltage for the healthy rotor.

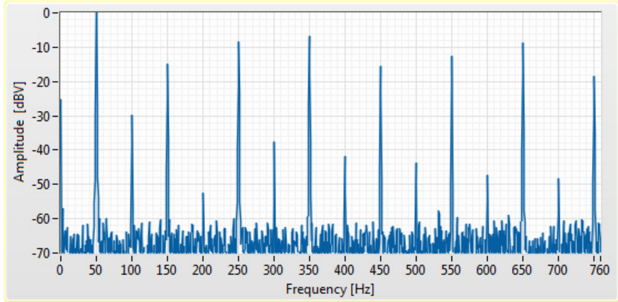


Fig. 7. Experimental sensor voltage frequency spectrum for the healthy rotor.

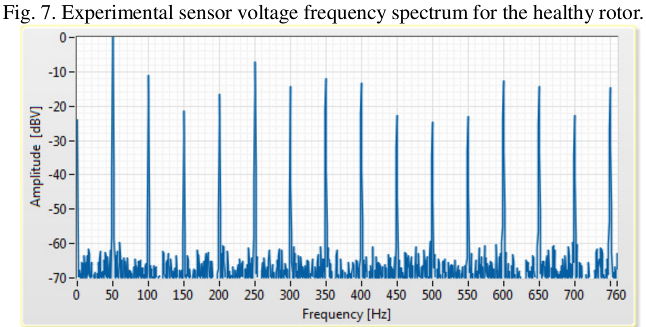


Fig. 8. Experimental sensor voltage frequency spectrum for the faulty rotor.

IV. Conclusions

Due to non-idealities of synchronous generators construction or operation (even when considered without defects), they present non ideal functioning conditions in real situations. Then, it is necessary to segregate, from the measured data, the information exclusively associated to the faults. For accomplishing it, this work proposes a complementary procedure able to analyze the results coming from experimental tests and FEM simulation models.

V. References

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