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Procedure for Detection of Stator Inter-Turn Short Circuit in AC Machines Measuring the External Magnetic Field †

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Abstract: This paper presents a non-invasive procedure to detect inter-turn short circuit faults in the stator windings of AC electrical machines. It proposes the use of the stray external magnetic field measured in the vicinity of the machine to determine stator faults. The originality introduced by this procedure is the analysis method presented in the paper, which when compared to usual diagnosis methods, does not require any data on the healthy state of the machine. The procedure uses the magnetic unbalance created by the rotor poles and the load variation in faulty cases. The presented method can be applied to induction and synchronous machines used as a motor or generator. It is based on the variation of sensitive spectral lines obtained from the external magnetic field when the load changes. Analytical relationships are developed in the paper to justify the proposed method and to explain the physical phenomenon. To illustrate these theoretical considerations, practical experiments are also presented.

Keywords: AC machines; magnetic field; non-invasive fault diagnosis; spectral analysis

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1. Introduction

In recent decades the reliability and the operational safety of electrical machines become an essential issue, so many research studies are focused on their monitoring, which is a crucial phase to prevent severe unexpected failure [1]. For that, the development of acquisition, analysis, and decision techniques are necessary to ensure the detection and diagnosis of electrical machines. The success of these techniques requires a good knowledge of the machine and its behavior in the presence of an internal fault. Among all the diagnosis methods used for rotating electrical machines, one can find:

- methods of appreciation, including techniques that use artificial intelligence [2,3];
- methods for the identification and estimation of physical parameters of the machine [4];
- methods based on modeling of signals that analyze the time variation and the spectral content of different physical quantities. The work presented in this paper concerns that kind of analysis.

For detection of electrical and mechanical faults in electrical AC machines, different techniques have been tested as those based on spectral analysis of the machine's vibrations [5] or current signature analysis [6–10]. However, the interpretation of results requires an expertise level even more advanced than the method hereto described, making it difficult to ensure real democratization of those techniques. Therefore, monitoring systems are applied only to systems that require high operational safety (for example, in power generation plants). A reliable diagnosis technique which can detect a failure and avoid total damage of motors or generators with a simple and non-invasive monitoring system is of great importance. For this reason, the technology in this field is still in permanent evolution to develop advanced methods [11–16].

In the 1970s, a new technique using the analysis of external magnetic field was developed by Penman [17]. It is a non-invasive technique and easy to implement. The drawback of the latter is the modeling of the magnetic field which depends on the motor housings with an important shielding effect or on the stator yoke. The determination of the external magnetic field requires the modeling of the internal sources and the ferromagnetic influence and the machine conducting materials. The computation of such a problem can be made using finite element software. However, the accurate modeling requires a large computational effort [18,19], especially when 3D modeling is performed. Another approach consists of adapting analytical solutions existing for simple geometries [20] but these methods, based on simplified geometry and under particular hypotheses, can be hardly exploited for electrical machines. In [21], a method based on the definition of attenuation coefficients can be easily combined with an analytical model of the machine.

Fault detection methods using the external magnetic field analysis are based on the property that any fault changes the magnetic field in the near vicinity of the machine. Difficulties for modeling and in the interpretation of this variable lead to exploit only qualitative features of the spectrum, like the appearance of sensitive spectral lines [22]. More usually, studies on the exploitation of the external magnetic field for fault detection are generally limited to model internal consequences of the fault such as: changes in the m.m.f. distribution [23], interaction with the slotting effect [24], magnetic of electrical unbalance [25]. Other researchers prove that the axial field can provide additional information [26–28]. In [29], it is shown that the analysis of the stray flux after supply disconnection can be useful for diagnosis. Advanced exploitation has been developed to provide deeper information: In [30], a sophisticated inverse problem is used for fault detection. In [31], it is shown that the external magnetic field can give information concerning the location of the fault. To improve the diagnostic process, the use of two flux sensors is proposed in [32]. Furthermore, all the diagnosis methods usually require the knowledge of the healthy state of the machine regardless of the physical variable considered. The fault detection is then based on the comparison of the signature for a given state with that of the presumed healthy state by considering an indicator determined from a measurement that is known to be sensitive to a fault. On the other hand, the machine load can be a disturbing factor for diagnosis, because it induces several healthy states. A further difficulty lies in the fact that the healthy state is practically never known until the failure occurs because the user never records the healthy signature beforehand.

This paper proposes a new solution that exploits the information of the external magnetic field measured around the machine. Generally, the load is a disturbing factor for diagnosis methods. However, in the proposed solution, the load variation is used to improve the diagnosis with the advantage that it does not require the knowledge of the machine's healthy state. The detection of a stator fault is based on a comparison between no-load and load operating conditions. Initially, the analytical modeling of the stray flux analysis in the presence of the stator inter-turn short circuit is proposed. Then, the experimental validation for an induction machine (IM) working in a motor and generator case and a wound smooth rotor synchronous generator are presented. The reliability of the method has been tested in a self-excited induction generator (SEIG) which makes it possible to test an unbalanced load case with large frequency slip. The experimental safety measures that have to be taken to ensure the reliable diagnosis are also presented.