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Evaluation of electrical insulation in three-phase induction motors and classification of failures using neural networks

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ABSTRACT

This paper presents a study for the evaluation of the electrical insulation of the stator of three-phase induction motors (IM) and the classification of the failure mechanism using an approach based on computational intelligence tools (CIT). A brief review showing the main parameters for the evaluation of insulation condition and testing of IMs is presented, as well as the promising use of CITs for fault diagnosis of industrial equipment, including motors. This paper proposes a new methodology for evaluation and classification of insulation conditions with the aid of K-means clustering and of a classifier based on ANNs (artificial neural networks).

1. Introduction

The use of electric drives based on induction motors increased sharply in industry, mainly due to their higher reliability and flexibility of operation compared to other electric machines [1]. Due to the construction robustness and the low maintenance requirements, currently, IMs are used in most critical processes in industrial plants, replacing drives previously based on gas or steam turbines [1].

Despite the high mean time between failure (MTBF) of induction machines, factors related with the coupling between the motor and the load, as well as environmental, operational and power quality problems, can lead to their premature failure. The predictive detection of failures in IMs have been analyzed in several studies and various techniques have been developed in order to allow maintenance of these machines without production interruption. In this context, insulation failure, responsible for about 40% of the stops of IMs, is an important issue to be investigated from the predictive point of view allowing the recognition and monitoring of this kind of failure [2].

A failure in the motor insulation leads to its immediate unavailability, causing production stops, undesirable financial losses and, in some cases, high maintenance costs. To identify low insulation resistance in the stator of low and medium voltage (LV, MV) IMs, preventive tools have been applied only during scheduled shutdowns of the machine [3]. During a schedule shutdown, resistance to ground (RTG), polarization index (PI) and the absorption index (AI) are measured, without any analysis or inference of the degradation state of the insulation. For this reason test results are restricted to condition "approved" or "not approved", without any information on the degradation status of the insulation.

Currently, many industries are adopting predictive tools for monitoring and evaluation of the insulation status of motors with the use of predictive analyzers [4]. The utilization of these devices along with a maintenance plan is considered success factors for identifying causes of insulation degradation in the planned maintenance of motors.

In the context of detection and evaluation of failures in industrial equipment, the use of CITs is becoming more popular. Techniques using ANNs and data clustering have been successfully implemented in applications such as robotics and industrial systems [5,6], partial discharge analysis [7] and current electrical signature analysis in motors [8–12], diagnosis of dissolved gases in transformer oil [13], vibration analysis in steam turbine [14], bearing fault detection [15], etc.

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Table 1
Guidelines for direct voltages to be applied during insulation resistance test.

Winding rated voltage (V)	Insulation resistance test direct voltage (V)
<1000	500
1000–2500	500–1000
2501–5000	1000–2500
5001–1200	2500–5000
>12,001	5000–10,000

The capability of generalization and learning of ANN has motivated its use in various areas of knowledge (engineering, medicine, economics, biology, etc.). Applications of ANNs in the classification, pattern recognition, control, prediction, diagnosis and fault detection have been successfully implemented [16,17].

This work presents a literature review of the main parameters for evaluation of insulation and some techniques for diagnostics of failure in industrial equipment and IMs. The purpose was to study mechanisms of degradation and failure of stator insulation system, presented a new methodology for evaluation and classification of insulation conditions with the aid of K-means clustering and of a classifier based on ANN.

In the proposed methodology, the classifier based on ANN will have a fundamental function, enabling the technical personal to make a rapid decision on the operating condition or the best procedure for maintenance of the motor, discarding the analysis of a specialist. The classifier also assists the identification of the root causes of premature failure of the insulation.

2. Techniques for evaluation of stator insulation

References indicate that 60–70% of failures in IMs are due to mechanical problems, especially bearing failure caused by inadequate lubrication [2]. The second largest cause of faults, 30–40%, in IMs is of electrical origin, highlighting the insulation failures in the stator covering 80–90%. In medium voltage the insulation failures represents a percentage of 60–70% of the overall causes of electrical failures [2].

In case of mechanical failure, predictive maintenance programs based on vibration analysis are well disseminated, bringing significant reductions of maintenance costs as well as reducing undesirable shutdowns [18].

For electrical insulation failures in the stator of IMs, the most widespread preventive and predictive techniques are:

1. RTG measurement, PI [3,19] and AI calculating [20];
2. Partial discharge analysis (PDA) [7,21–23];
3. Dissipation factor (DF) or power factor (PF) insulation measurement and power factor tip-up (PFTU) or dissipation factor tip-up (DFTU) test [19,21,24–28];
4. Capacitance to ground measurement (CTG) and capacitance tip-up (CTU) test [21,24,29];
5. AC Hipot [30], DC Hipot [31] and Surge test [32].

2.1. RTG test, PI and AI calculation

The RTG test is performed with direct voltage for 10 min, with a magnitude that depends on the winding rated voltage as shown in Table 1 [3].

The total current I_T that circulates in the insulation during the test can be decomposed into three components, as shown in Fig. 1 [3].

- conductive current I_G: current portion constant during the test responsible for the dielectric losses in the insulating material;
- absorption current I_A: current portion responsible for the polarization of the dielectric material. It has exponential decay and typically becomes constant after 10 min;
- capacitive current I_C: current portion occurring due to the capacitive nature of the isolation system. It has fast exponential decay and approaches zero after a few minutes.

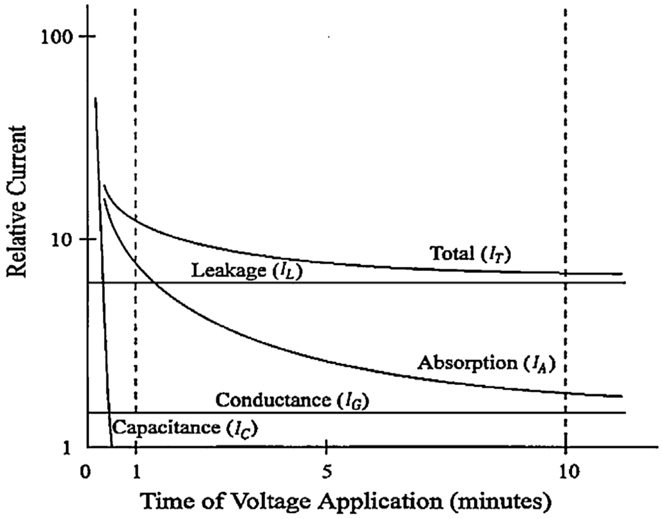

Fig. 1. Decomposition of current I_G in the RTG test [3].

Table 2
Minimum RTG values recommended at 40 °C.

Motor test	RTG_{MIN} (MΩ)
Motors manufactured before 1970 and others not listed below.	kV[a] + 1
Motors manufactured after 1970 with windings form coils.	100
For motors with random windings in the stator, motors with windings form coils rated below 1 kV and dc armatures.	5

[a] Nominal voltage motor or winding.

The minimum RTG values recommended by the IEEE Std-43 are seen in Table 2. The RTG value is measured 1 min after the start of the test. Its value is corrected to 40 °C to allow the comparison between present RTG value and historic ones obtained along the motor lifecycle.

The PI and AI values are defined as:

$$PI = \frac{RTG_{10\,\text{min}}}{RTG_{1\,\text{min}}} \tag{1}$$

$$AI = \frac{RTG_{60\,\text{s}}}{RTG_{30\,\text{s}}} \tag{2}$$

The minimum recommended PI values according to IEEE Std-43 and AI according to NFPA (National Fire Protection Association) are seen Table 3.

Some manufacturers recommend the evaluation of PI and AI within ranges that may indicate the insulation degradation condition. Table 4 shows values of PI, AI and the estimated insulation state [29,33].

Table 3
Minimum recommended PI and AI values.

PI (IEEE)		AI (NFPA)
Thermal class rating A	>1.5	>1.5
Thermal class rating B, F and H	>2.0	