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Knowledge acquisition of vibrations in high-power transformers using statistical analyses and fuzzy approaches – A case study

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ABSTRACT

This paper presents the results of a knowledge acquisition of vibrations in high-power transformers in two substations of an Electrical Power System in the Amazon region, Brazil. Radial graph areas were obtained, to enable the analyses of the vibrations at four sites at different measurement points in the transformer bodies. In certain cases, variations in vibrations non-justified by corrective maintenance were observed. The repeated measure analysis showed that the largest mean vibration area occurred in the front of the transformer. With these results, measurements on a sequential processor were made and the vibration behavior due to commutations analyzed. Statistical analyses and the repeated measure analysis were used in the process of knowledge acquisition, establishing the basis for the construction of a fuzzy inference system. Compared to other predictive maintenance methods, vibrations are a physical phenomena that can be used in the construction of non-invasive, low-cost analyses techniques, so this approach may become an important and valuable tool for use in solving problems in environments of uncertainty, as in the programming process of vibration monitoring in high-power transformers, providing a means to diagnose the physical operational states of transformers by the generated inspection alerts.

1. Introduction

Power transformers are static equipments used in electric power systems (EPS). Failures in these devices can lead to defects and accidents, thus compromising electricity distribution [1]. The study of vibrations in transformer tanks, compared to other methods of predictive maintenance, may lead to low-cost monitoring solutions prevent future defects in these instruments. The vibrations are generated by different forces that exist in the core and windings of these equipments during transformer operations [2]. The use of vibrations in transformer tanks for fault diagnosis in the core or windings is not very common, but over the years research in this area has been intensifying.

Booth et al. [3] proposed vibration monitoring using a back propagation neural network that calculated the range of 100, 200 and 300 Hz of the vibration components, using as input variables the three main harmonics of the fundamental vibration, current and temperature at several points of the transformer. Mechefske [4] reported an experiment with vibration monitoring in the transformer tank of two identical processors, one with loose winding clamping, describing significant differences between the amplitudes of the harmonic vibrations, the time to reach a steady state, after a change of load, and the harmonic content of the high frequency bands, in both processors.

Aschwanden et al. [5] monitored the vibrations and analyzed 19 main harmonics through the Kohonen map. Bartoletti [6] used four parameters (total harmonic distortion in the range of low and high frequency, the sum of harmonic amplitudes and the main harmonic ratio) to classify transformers into new, used and defective.

Garcia et al. [7,8] proposed vibration monitoring in an online transformer tank, to complement the analyses conducted with the offline transformer. The author also reports that analyzing transformer vibration is a key test of predictive maintenance programs for rotating machinery and that this method is heavily used to detect faults in changing the keyswitch, by means of a noise analysis during this change.

Munir et al. [9] evaluated the following methods: Fast Fourier Transform (FFT), Hilbert Huang Transform (HHT) and Wavelet Packet Transform (WPT) in combination with HHT and determined that only the main frequency signal can be used as a reliable parameter, and that it is the “fingerprint” of transformer condition.

In this context, this study used statistical analyses, consisting of a repeated measure analysis, from the construction of the vibration

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area at four sites with different numbers of measurement points of 12 transformers in two substations, which enabled us to verify that in some cases variations in vibrations non-justified by corrective maintenance were present. The repeated measure analysis showed that the largest means of the vibration areas occurred in the front of the transformer. With these results it was possible to conduct sequential measurements on a transformer and study the vibration behavior due to the commutations. With the statistical analysis results, a perceptual mapping of the variable domains was conducted and a fuzzy approach proposed in order to obtain a diagnostic system of inspection alert for these equipments.

2. Materials and methods

2.1. Measurements

The vibration measurements of twelve 230 kV single-phase transformers at two different Electrical Substations (SE) located in Belém, Pará, Brazil were analyzed. Five measurements were conducted at both the first substation (SE1) and the second substation (SE2), from 2002 to 2007.

One transformer was selected in July 2006 and measurements were conducted at one point at the transformer front, during one week, using the monitoring system developed by the Eletrobrás Eletronorte do Brasil Center for Technology.

The transformer vibrations were measured by a Microlog-type accelerometer, model: CMSS2200, sensitivity: 98 mV/g, accuracy: ± 10% at 25° C, frequency range: 1–5000 Hz with ± 10% error and temperature range: −50 to +120° C. The Prism[4] [10] software was used to build the route, allowing for the selection of an adjusted collection sequence and a pre-defined set of 34 measurement points throughout the transformer body, distributed in four locations: 6 points in the transformer front, 6 on the right side, 16 on the bottom and 6 on the left side.

2.2. Statistical analyses and repeated measures statistics

In order to conduct the statistical analyses, radar charts were constructed regarding the four sites throughout the transformer body, regarding different numbers of measurement points on 12 transformers at the two substations. The respective vibration areas were calculated using the R program Maptools Package [11].

- The repeated measures analysis is a statistical technique used to denote measurements made in the same variable or in the same experimental unit on more than one occasion testing the significant differences between groups when there is the application of successive treatments in a same sample [12–14]. Some assumptions are necessary in order to use this technique [14].
- The Mauchly test of sphericity – that predicts equal variances and absence of correlation between the dependent variables – which, when breached, uses the Greehouse–Geisser or Huynh–Feldt corrections of degrees of freedom.
- The Lambda multivariate Wilks test.
- The univariate tests for within-subject effects.

This technique was chosen due to the fact that repeated vibration measurements in 34 pre-selected points in the transformer bodies, separated by location throughout the transformer body – 6 points in the front, 6 in each lateral position and 16 in the back – allowing for the location to be considered an inter-subject factor of our test and the measurement years to be the intra-subject. The analyses were performed using the Statistics program [15] from the calculated vibration areas of the measurement during the years at the two SEs.

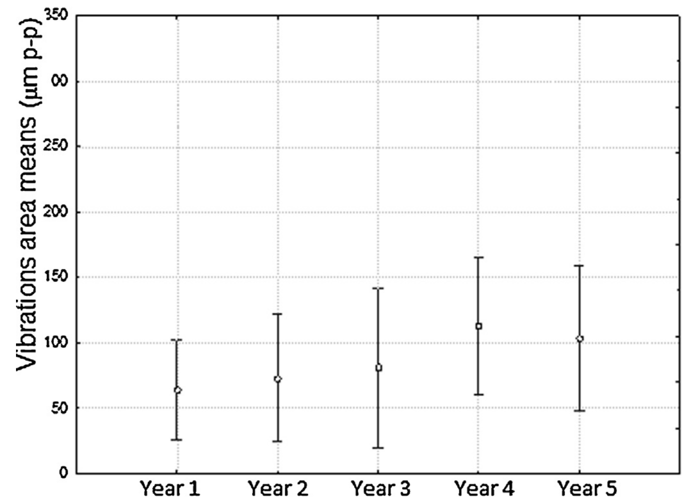

Fig. 1. Mean vibration differences throughout the years.

2.3. Fuzzy logic

Fuzzy logic handles verbal, inaccurate, qualitative expressions, inherent in human communication, which have varying degrees of inaccuracy, translating the values into fuzzy terms understandable by computers [16]. These values are placed in an expression with a certain degree of relevance, always in an interval of [0,1], where 1 is the highest possible relevance.

Generally, a fuzzy system consists of four components [17,18]: the fuzzifiers, that convert real entry values (inputs) into a relevance degree for the fuzzy sets, to be processed by a fuzzy inference machine; the rule base, which consists of a set of rules based on inputs and outputs; the fuzzy inference engine, which uses fuzzy principles for combining the existing fuzzy rules into the rule base for mapping a fuzzy set input to a fuzzy set output; and a defuzzyfier, that maps the fuzzy set, obtained in the inference engine, into a real value (output).

For the purposes of this study, we used a data processing model based on the classical rules of fuzzy logic. The means and standard deviations of the vibrations (µp–p) obtained by a transformer monitoring system of a same model transformer at substation SE1 in July 2006 were used to construct the rule base for the fuzzy system, implemented through use of the Fuzzy Logic Toolbox of the software Matlab 7.0 [19].

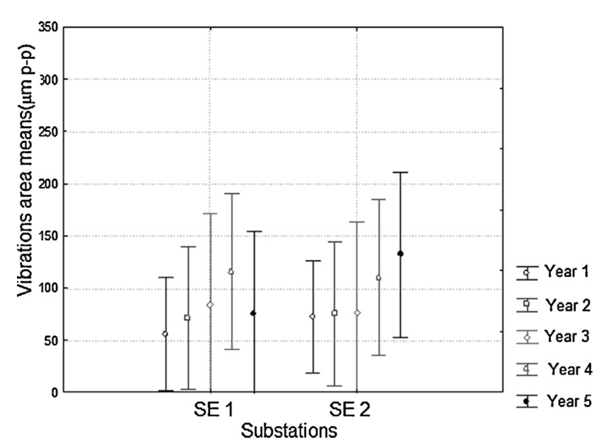

Fig. 2. Mean vibration differences throughout the years by substation.