Engineering Failure Analysis 94 (2018) 300–312

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Bushing failure in power transformers and the influence of moisture with the spectroscopy test

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ARTICLE INFO

Keywords:
Bushing
Moisture
Transformer
Spectroscopy

ABSTRACT

Distribution and Power transformers and their accessories are the main and important equipment used in the power system, one of their most delicate component is the bushing, and the first failure mode is the moisture. The moisture in the bushing appears in oil-paper (Kraft) insulation, the influence is in the insulation, it acts as a catalyst, due to the insulation degradation and aging. In that way, is very important to detect accurately the presence of humidity and water content within the insulation (oil and Kraft) early as to evade any pre-mature catastrophes. The 2 basic bushing scheme are non-graded and capacitance-graded. The prior is the simplest and the oldest bushing. The capacitance graded bushings are obtainable in four technologies: (i) Epoxy Resign impregnated paper (ERIP), (ii) Resin Impregnated Paper (RIP), (iii) Resin Bounded paper (RB), (iv) Oil-Impregnated Paper (OIP). The last one is the most common bushing. The explosion is the last stage for a failure, it begins with the bushing degradation. The last stage is frequently an expensive and catastrophic failure for the power system, this bushing cannot be repaired. In nowadays, the maintenance routine required a condition check, however, the traditional methods, for capacitive bushing, are inspections, capacitance, PFs, for non-capacitive are watts dissipated and inspections. In this research a study with a possibility of frequency domain spectroscopy (FDS), as frequency domain techniques (FDT), the measurements is developed, for bushings in the inductive equipment, and the limit failure has been done. An important knowledge contribution to the moisture in the bushing has been developed and the needed to update the international standards IEC 60137, IEC 60296, IEC 60422, ASTM D 3487 and ASTM D1305, it is one of the main points in this paper. On the other hand, the electrical capacity such as FDS is ideal, because of its straightforwardness and pragmatism. The goal of the research is to study and investigates the claim of FDS method and its swaying features under site acceptance test (SAT), condition using OIP model with disparities as temperature, aging rate and the conductivity for oil and paper. Finally, the research proposes new limits for bushing in power transformers, likewise, the assessment of this assets with a new update in the internationals standards.

1. Introduction

For the transformers, the main component are the bushings, because of the materials, performance in the availability and effectual performance of them, it is meaningfully impacts the reliability of the inductive equipment as power transformers and reactors, it is considered then, an component delicate and important, in the power systems, it is described in the Ref. [22]. The beginning of

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https://doi.org/10.1016/j.engfailanal.2018.08.006
Received 2 June 2018; Received in revised form 22 July 2018; Accepted 13 August 2018
Available online 16 August 2018
1350-6307/

bushings were introduced in 1890, for AC system applied to transformers. The core purpose, in these bushings are conducting the current with a voltage determinate by the transformers, through the tanks. At large, the power transformers failures caused by their bushings, consist of Kraft and oil degradation, it has been affected by key aspects as a result of moisture (water content), temperature rise and oxygen [4]. Availability and time period of inductive equipment is determined by the reliability of insulation, because of the permanent properties of Kraft and oil [5]. Nevertheless, the influence of humidity in the Kraft cause damage in the bushings, it is very aggressive in the insulation properties. Nowadays, there is just an available laboratory method, it is the coulometric, Karl Fisher Titration (KFT) method, where Kraft sample is required, according to the Ref. [7]. Actually, the availability and maintainability of the inductive equipment, as a vital component of the power system, extremely depend on the bushings' performance, on the other hand when a lightning phenomenon happens, the surge arrester and the transformer's bushing's transformers are the main element with the insulation and energy dissipation [24,29], especially when cables or guard wire have rupture close to the substation [28].

Traditional SAT are the following: i) Polarization index (PI), ii) Insulation resistance (IR), iii) Loss PF (tan∂), iv) Gas analysis diagnosis; however, they doesn't have positive association with humidity and water content. It is demonstrate in the Kraft condition which is the temperature rise dependent. These SAT doesn't provide clear evidence to meet the requirements, there are substantial variations in the dielectric properties of multipart scheme [4]. Newly, some development diagnostic methods have been developed, they are the followings: (i) Polarization & Depolarization Current Method (PDC), (ii) Recovery Voltage Measurement (RVM), (iii) FDS built according dielectric properties reaction of the insulation arrangement [6].

Increasing the power, energy and availability demands require a superior insulation, the analytical models and methods for inductive equipment and their components. In last decades, the FDS has been widely used for many applications based on dielectric and insulation diagnosis [1]. The dielectric measurements are a distinguished and extensively satisfactory method for the condition diagnosis of oil and Kraft, with the benefit of retaining the reliability of insulation [2]. The capacity of these methods are categorized into FDT [3]. The introduction of reliability, availability and maintainability studies should be applied in the bushing test [27].

An important knowledge contribution to the moisture in the bushing has been developed and the needed to update the international standards IEC 60137 [9], IEC 60296 [10], IEC 60422 [11], ASTM D 3487 [12] and ASTM D1305 [13], it is one the main points in this research. On the other hand, electrical test such as FDS is preferred because of its straightforwardness and pragmatism. The objective of this research is to study and investigates the application of FDS methods and its prompting factors under SAT using OIP model and variations like temperature rise, aging rate, oil and Kraft conductivity and to propose new limits for bushing in power transformers, likewise, the assessment of this assets with a new update in the internationals standards.

2. Methodology

2.1. Bushing assessment with traditional methods

The solution of differential equations can mostly be considered into the mathematical and systematic techniques and methods. An important knowledge contribution to the moisture in the bushing has been developed and the needed to update the international standards IEC 60137 [9], IEC 60296 [10], IEC 60422 [11], ASTM D 3487 [12] and ASTM D1305 [13]. Many energy companies specifies bushings for power transformers following standard IEC 60137 [9]. For this reason, the PF value must be $< 0.7\%$ in both OIP and RIP bushings. Since the implementation of company inspection standards for maintenance, we use IEEE standard C57.152 [14], where it is defined that an increase between 1.5 and 2 times the PF (PF) measured in SAT or Factory Acceptance Test (FAT) of the bushing in a period of time, we must increase test frequency or remove from service [16].

In case there is no record of the PF value obtained in the FAT or SAT tests, the typical values indicated in technical brochure TB-445 [15] of the CIGRE can be used.

Finally, not only the reading of the PF is recommended. The capacitance is also determining when evaluating a bushing. In accordance with the IEEE C57.152 [14] standard already mentioned, a variation of the capacitance $> 5\%$ of the value indicated on the plate can be sufficient reason to evaluate remove of service. A standard of tan delta $< 0.4\%$ for new bushing (both OIP and RIP). There is an additional limit of change in tan delta allowed up to a limit of $+/-$ 0.1% w.r.t. pre-commissioning values during any maintenance tests.

Earlier, the limit used to be 0.7% [9–11]. However, the standards were revised around 2010 due to very high failure rate of bushings. Since, the change in norms, the failure rate has substantially decreased. In this regard, please inform the bushing tan delta norms being followed in your utility for both OIP and RIP.

The tendency in the diagnosis of bushings is not to perform the analysis only at the frequency of 60 Hz or 50 Hz. A variable frequency PF test is emerging as a more valued diagnostic solution. Currently in the substation maintenance activities we include the PF test at different frequencies in the range of 40–400 HZ. New proposal to include, a new update of diagnostic rules, it includes the analysis of this new information. The analysis is basically based on comparing the behavior between bushing of the same family and the behavior of the slope of the data given that they tend to have a relatively flat linear response when the insulation is in good condition.

Moisture contamination can be detected earlier with Variable Frequency PF (VFPF) measurement than is possible using a single pint, line frequency PF test. This contamination is more evident in low frequency range [23]. This means that the (VFPF) measurement eliminates the “blind spot” associated with a single- point measurement.

For example, both devices at 60 Hz have a PF lower than 0.5% which is considered normal, but at low frequencies bushing A has a high PF, and does not increase with frequency, which may be an indication of moisture in the insulation, it is the knowledge management in energy company [20].