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Study on Life Management of Power Transformer

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Abstract This paper presents the general knowledge, theory and methodology of life management that used in electric power transformer. The paper also discusses the basic failure theory and method to establish failure model of power transformer. Insulation ageing is a problem due to dielectric, chemical, thermal and electro-mechanic stresses, which is highly depending on operational conditions. Life management of power transformer should include research of fault diagnostic, monitor methods and insulation reclamation to extend life, and establish life model of power transformer. Life management of power transformer should not only consider the fault model, quantitative assessment of the relevant remnant withstands strengths of transformers and operational stresses, but also establish the maintenance standard for power transformer.

Key Word: Life Management; Power Transformer; Rough Set Theory; Fuzzy Logic; Neural Networks; Reliability

1 Introduction

In the environment of low load growth of electricity and electric market liberalization, the electric utilities have to extend their substation equipment life span. In most areas of China, some power transformers have been in service for long time, with some ones even more than 40 years. Due to the consideration of cost, these very old veterans are now still operating. Therefore, it is of great importance to properly evaluate the aging condition of solid insulation. As the tests of tensile strength (TS) and degree of polymerization (DP) of insulating paper or pressboard can be finished only during the overhaul of the un-energized equipment, so the measurement of furfural contents in oil is now a promising method far the aging evaluation of cellulose insulation. To provide the reference of the aging assessment of solid insulation, some regulations about the statistic distributing values of furfural concentrations in oil have been given out. But in fact, corresponding regulations are mainly based on the result of accelerated aging experiments in lab, so it may differ from field situation of in-service. To meet the demand of field use, a lot of data are collected from in-service units, such as furfural concentrations, operating years, etc.

1.1 Equipment Management in China

Nowadays, power system in China has been changed from paying attention to increase of equipment's quantity to management of apparatus. During the 1991 to 1995, the failure of power transmission network directly aroused by equipment fault in China is 26.3 percent of all system failures [1]; thereby raising the reliability of equipment in service is the key to protect the power transmission system. Gathering the data of electric power equipment, including insulation condition, mechanic strength, aging condition etc, is the foundation of the equipment management. The current methods that based on periodical maintenance and preventive experiment in China are the methods to monitor equipment's conditions by operational experience. By establishing the code for preventive experiment and the code for maintenance, the periodical maintenance to equipments is arranged. This kind of traditional insulation monitoring and inspecting theory has a lot of shortage [2].

Along with the electric power system developing in China, there has been considerable interest in the subject of on-line monitoring, life management for the large electric power equipment.

1.2 Life Management

In recent years, along with the development of power system, there has been interest in life management of equipments.

To power system in China, The current insulation

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inspecting theory is based on evaluating the equipment condition using the code of preventive experiment and code of maintenance. The research on the method and theory of life management has not been carried out fully. Along with the thorough research of the insulation aging process and the fast development of the computer technique and expert system etc., it is possible to carry out life management to equipment of power system.

2 Life Management for Power Transformer

2.1 Life Management

The object of life management is to minimize the costs, which include the direct and indirect operational costs, maintenance costs and the costs of keeping unreliable equipment in service. This is particularly important to some large investment item. For example, the direct investment for replacing an electric power transformer is usually very enormous, and there has the indirect costs for installation etc. Therefore, it is very difficult to justify the replacement of the power transformer before the end of life failure. Only under some situations, such as the capacity of transformer can't satisfy the request, or the indirect outage costs are very high, or the costs for keeping the unreliable equipment in service are sufficiently high, the power transformer can be replaced before the end of life failure.

Because of adopting the different insulation material, the insulation deterioration of the equipment is not alike, and the factors affecting the life of the equipment are different. Regarding the circuit breaker, along with the SF6 circuit breaker adoption and manufacturing craft, the damages caused by the main insulation deterioration reduces greatly, but the mechanical fault becomes the main factor which causes the fault of the circuit breaker [3]. While for the power transformer, the insulation deterioration is the main factor, which affects the transformer's life.

The failure models of equipments are various because the models can vary greatly depending on local conditions. And the direct loss caused by failure or unreliable device, and also the costs of repair and refurbishment operations are also vary greatly between different utilities. So it is difficult to develop universal guidelines for life management. For many types of equipment, people nowadays unwilling discuss their failure statistics.

Clearly then, economic as well as technical and strategic factor determine the effective end of life of equipment.

2.2 Insulation Deterioration: Theoretical Analysis

Water, oxygen, oil aging products and particles of different origin are agents of degradation that can significantly shorten equipment life which use the oil and paper as the insulation material under impact of thermal, electric, electromagnetic and electrodynamics stress.

Regarding the power transformer, processes of insulation deterioration involve slow diffusion of water, gases, and aging products and therefore affect basically only a part of the insulation structure, the so-called thin structure (paper insulation of turn and coils, pressboard sheets, etc.) that comprises typically 40-60% of total mass. The heated mass of conductor insulation that is subjected to accelerate deterioration comprises typically 2-10% of the total mass of transformer insulation. In fact, the fluid is an integral part of the transformer and plays a dynamic role in the condition of the entire system. Aggressive decay products being adsorbed by insulation can destroy the cellulous and also affect the properties of new oil after refilling. Reconditioning of oil is a critical step of life extension.

There are three sources of excessive water in transformer insulation: residual moisture in the "thick structure" components not removed during the factory-drying out, ingress from the atmosphere, and aging of cellulose and oil.

The origins of particles are manifold. Cellulose fibers, iron, aluminum, copper and other particles resulting from the manufacturing process, are naturally present in transformer oil.

Insulation decomposition is a chemical phenomenon. Three mechanisms of degradation: hydrolysis, pyrolysis and oxidation act simultaneously. Temperature, water and oxygen are the main agents of cellulose degradation as well as oxidation of the oil.

To study on the mechanism of insulation deterioration and the cause for the fault of equipment, the aging processes and mechanism for power equipment can be found out, and providing the theory foundation for life management.

2.3 Basic Failure theory

Nowadays, equipments with expected service lives are very reliable because of development in manufacture. Lot of manufactory usually promises equipments in service without maintenance for 15-20 years. But the

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design factor of system and the operation condition are varied, the circumstance and the condition of power system for the same type equipment are also different, it's difficult to establish the fault model for equipment. We can suppose that there is a kind of fault model for all equipment. The main factors of the model are the same, but the cause that affects the factor is unlike for different equipment. We can consider some key parameter and function, for example insulation dielectric strength, mechanism strength, etc. How to find out the key parameters is critical for establish the fault model.

Regarding the power transformer, the withstand strengths of a transformer will naturally decrease over its life due to various ageing processes (normal ageing), but may deteriorate faster than normal under the influence of agents of deterioration (e.g. moisture) or if some abnormal destructive deterioration process (e.g. tracking) occurs. Theoretically it is possible to distinguish between reversible processes (often referred to as defects) and irreversible ones (faults), although such a distinction is not always clear-cut. Ideally, the presence of defects or faults would be detected by monitoring and diagnostic tests.

Operational stresses are usually dominated by intermittent events such as lightning strikes or short circuits. As an example of the changing stresses over the life of a transformer, consider the mechanical stresses imposed on a winding. When the transformer is new, the windings will be well clamped and therefore have a high strength, while the electromagnetic centers of the windings will be aligned to minimize the stresses of electromagnetic forces during short circuits. As the transformer insulation ages, the paper insulation will shrink and may result in a reduction of clamping pressure, thereby reducing mechanical strength. If a short-circuit occurs and the windings move slightly, the electromagnetic centers of the windings may move slightly, which will lead to much higher stresses during subsequent faults. It is probably through such a process of falling strength and increasing stresses that the mechanical condition of a transformer will degrade rapidly over a few short-circuits immediately preceding the final failure.

Because of the random nature of the key operational stresses it is unlikely that it will be possible to predict when the final failure will occur. However, if remnant strength and operational stress could be quantified adequately, it would be possible to determine when the circumstances were such that a failure could occur, i.e. the onset of increased unreliability. A key task in managing transformer service lives would therefore appear to be the quantitative assessment of the relevant remnant withstands strengths of transformers and operational stresses.

2.4 Life Management of Power Transformer

Different equipments, according to the insulation aging and basic failure theory, can establish the basic fault model.

The life cycle of transformer is correlated with stress, contamination aging and remedial [4]. The fault model can established using parameters as stress, contamination aging, etc. Remedial repair can extend life of power transformer. Therefore, life management of power transformer should not only consider the fault model, quantitative assessment of the relevant remnant withstands strengths of transformers and operational stresses, but also establish the maintenance standard for power transformer.

Transformers are generally very reliable items of equipment with expected service lives of 40 years or more, so it is difficult for individual engineers to build up sufficient first hand experience of problems and how best to deal with them. The fault process of equipments is usually very complex, sometime correlated with manufacture. So a flood of related data should be gathered to establish the life model of transformer.

Along with the development of monitoring and diagnostic technique, the data for analysis and synthesis can be gathered through off-line (periodically preventive experiment) or on-line (on-line monitoring, on-line testing) method. To transformer, some models or equations have been present. For example, the equation of lifetime and DP (degree of polymerization) value of insulation paper [5], the model for life and thermal [6], general equation of the decline in the electric strength for combined thermal and electrical stresses [7], the equation of life and insulation [8] etc. Not all the factors affecting the life of transformer are considered in those models and equations.

3 Methods Used In Life Management of Power Transformer

3.1 Rough Set Theory

Rough set theory introduced by Zdzilaw Pawlak[9] in the early 1980s is a new mathematics tool to deal with vagueness and uncertainty. RS provides a series of tools for data analysis and reasoning from imprecise and

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ambiguous data[10]. It has already found practical applications in many areas[11], including approximate classification, machine learning, process control, knowledge acquisition, expert system and data mining. RS has been successfully used for pattern classification of patients based on medical data attributes. Recently, RS technique has been applied in power system to classify the operation point[12]. RS is a set theory that classifies objects based on the attributes of the objects.

RS theory provides a methodology for generating rules from empirical data represented as a data table. The table contains information about some objects in its rows. Its columns contain the values of attributes describing the objects. Two kinds of attributes are distinguished in RS theory: condition and decision. The data table are represented as a decision table (also called information table), which is a key tool used in the RS method. A decision table contains rules specifying what decisions should be made when certain conditions are satisfied. Each row of the decision table contains a production rule of the form:

If {set of conditions) Then {set of decisions)

The machine learning method investigated in the framework of rough set commonly belongs to Learning From Examples, in which the training cases are represented in terms of attributes and their values.

It is one of the most common approaches to get knowledge from expert. The process is also called Case Based Learning (CBL). The idea behind the knowledge base acquisition is the simplification of the set of examples in a decision table. The method of reduction can be shown using algebraic developments or based on logical relations. The algorithm that provides the reduction of conditions has been proposed, and can be represented by the following steps:

Step 1: Build a decision table describing the example cases of the interested domain.

Step 2: Eliminate identical attributes and cases

Step 3: Compute the reduce of the decision table.

Step 4: Merge possible cases.

Step 5: Generate the final set of rules.

Example:

A power transformer in a 220kV substation was broken down shortly after the maintenance. The DGA values are:

CH_4 151.1 C_2H_2 10.3 C_2H_4 56.2 C_2H_6 318.4. The PD values is:220pc

Based on the rules 2 and 4, The Core earthling or Short Circuit Fault and OTLC Fault could be judged. This power transformer was returned to the factory.

The reduction method of the decision table of Rough Set Theory can handle missing or wrong failure symptoms of transformer. In the condition of imperfect data, it can also gain correct diagnosis results and has certain tolerance. So this method is very suitable for fault diagnosis of power transformer.

Using the fault symptoms and the fault types of power transformer as the conditions attribute, we can find the diagnosis rules basing on decision table. The fault diagnosis model could be obtained.

3.2 Fuzzy Logic and Neural Networks

Depending on the energy involved, the degree of localization, and intermittent or continuous occurrence, each fault type "cooks" the oil or paper in a different way, generating characteristic relative amounts of dissolved fault gases in the oil. For example, overheating of the oil tends to produce high levels of ethylene, while arcing in oil usually generates significant amounts of acetylene and hydrogen.

Periodic maintenance of large transformers includes chromatographic analysis of the insulating oil to measure concentrations (μV/V) of dissolved hydrogen (H_2), methane (CH_4), ethane (C_2H_2), ethylene (C_2H_4), acetylene (C_2H_6), carbon monoxide (CO), and carbon dioxide (CO_2). Differing operating conditions and structural peculiarities of transformers distort the chromatographic signatures of faults, making it advisable to apply several DGA methods to the data simultaneously to obtain a reliable diagnosis.

Fuzzy logic can be used to automate standard methods of transformer oil DGA, providing enhanced information for the maintenance engineer while remaining faithful to the original methods. In some cases, neural networks can be used in combination with fuzzy logic to implement more complex diagnostic methods while maintaining a straightforward relationship between the enhanced method and the original one. New powerful diagnostic method based on large neural networks may be possible, but their development requires the assembly of a large database of examples for training and validation.

3.3 Reliability Theory

A large number of utilities have begun to establish data bases from which the reliability of products, such as transformers, may be established. In many cases, the true hazard function or 'Bathtub' curve, for older units on the system cannot be directly establish without several years of data..

The key to accurate reliability measurement is data which has been collected over a long period of time.

Data on the both failures and the number of items exposed to failures must be collected. Both the year-to-year stability and long-terms trends of the underlying manufacturing process may be examined with this type of data base. In addition, the reliability versus age characteristics of the equipment can be investigated.

Not until recently was the power transformer loading control based on the instant power running on the equipment in relation to the nominal. Nowadays, the loading came to be controlled through a hybrid process which involves the current and the oil and winging temperature. Even so, the conventional limits adopted for the oil and winding overheating protections are conservative. Those great margins of security conventionally adopted between the thermal level of shutting-off and the respective real limit of operation are the result of little awareness about the transformer's operational conditions.

The equipment monitoring and the implementation of automation platforms in substations tend to a less conservative limit of transformer loading. New and more reasonable loading practices, centered on the equipment reliability and on much more daring temperature limits have just come up. This is only more safely applicable before the implementation of a more precise transformer loading control process.

4 Conclusions

This paper has discussed the general knowledge, theory and methodology of life management that used in electric power transformer. Life management of power transformer should include research of fault diagnostic, monitor methods and insulation reclamation to extend life, and establish life model of power transformer. Life management of power transformer should not only consider the fault model, quantitative assessment of the relevant remnant withstands strengths of transformers and operational stresses, but also establish the maintenance standard for power transformer. Some method used in life management of power transformer also discussed in this paper.

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