ESTIMATING THE AGEING OF OIL PAPER INSULATION SYSTEM IN HIGH VOLTAGE POWER TRANSFORMER IN TNB'S SYSTEM BY STUDYING THE RELATIONSHIP OF FURFURALDEHYDNE AND DIELECTRIC RESPONSE ANALYSIS.

HASREE BIN ISMAIL

UNIVERSITI TEKNOLOGI MALAYSIA

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HASREE BIN ISMAIL

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To my beloved wife, daughters
as well as family and friends

Thank You

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Alhamdulillah, this project is finally completed successfully. Praise be to Allah S.W.T., the Most Merciful and the Most Compassionate. Peace is upon him, Muhammad S.A.W., the messenger of Allah S.W.T.

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ABSTRACT

Power transmission and distribution depends on a lot of equipment and these equipments have their very own function in order to achieve a reliable and optimal power supply to the consumer.

Among one of the most important equipment that exist in this system is the power transformer. As it is one of the most expensive equipment found in a transmission and distribution substation, its importance and well being are almost certain one of the most concerned. As it is usually very expensive to replace a power transformer, it is not economically viable to keep the power transformer as a strategic spare. While buying for a replacement would take a very long time, its maintenance regime, and finding the ‘right time’ to replace a power transformer takes great study to balance its economics of operation.

This study would try to establish the use of Furan analysis as a method to study the effect of Furan formation as the transformer aged. The Furan data specifically the 2-Furfuradehyde (2FAL) of various power transformers under various voltage level and transformer rating in TNB’s system shall be collected and analyzed.

As a single test, Furan Analysis cannot be a single determining factor for decision making in terms of the transformer’s reliability and life span, but together, a more comprehensive indication and decision can be made.

To complement the data for the Furan, Frequency Dielectric Spectroscopy (FDS) shall also be used to ascertain the level of ageing for the power transformers studied.

Both of this methods combined can provide a useful tool for the diagnostics of power transformer in the field. Decision whether to continue a transformer in service or to decommission any transformer before any insulation failure happens can be made by accessing the transformer by using both of these methods as it complements one another in terms of accessing the condition of the transformer’s winding and insulation condition.

ABSTRAK

Sistem penghantaran dan pembahagian tenaga elektrik banyak bergantung harap kepada peralatan dan peralatan-peralatan ini memepunyai tugas mereka sendiri dalam memastikan bekalan yang berdaya harap dan pada kos yang optimum dapat dibekalkan kepada pihak pengguna.

Antara peralatan elektrik ini yang amat penting dalam sistem adalah alatubah kuasa. Disebabkan peralatan alatubah kuasa ini adalah antara yang paling mahal diantara peralatan didalam sebuah pencawang elektrik, kepentingan untuk mengendali dan menyelenggara adalah antara keutamaan. Disebabkan kos untuk menukar alatubah kuasa ini adalah amat mahal, untuk menyimpan peralatan ini sebagai barang simpanan strategic adalah kurang ekonomi bagi sesebuah syarikat utiliti. Tempoh bagi membeli dan mendapatkan alatubah kuasa ini juga akan mengambil masa yang lama, jadi rejim senggaraan dan memastikan bahawa penukaran alatubah kuasa disebabkan usia atau hentitugas memerlukan kajian bagi meyeimbangkan kos penukarannya.

Kajian ini akan cuba untuk mengaitkan penggunaan *Furan Analysis* sebagai satu cara untuk mengkaji kesan terhadap pembentukan Furan semasa penuaan alatubah kuasa. Data bagi Furan ini atau spesifiknya 2-Furfuraldehyde (2FAL) pelbagai alatubah kuasa di bawah pelbagai peringkat voltan dan keupayaan alatubah dalam system TNB akan dipungut dan dianalisa.

Furan Analysis walaubagaimanapun tidak boleh digunakan sebagai ujian tunggal bagi menentukan kebolehharapan dan jangka hayat alatubah, tetapi kombinasi kedua-duanya akan membolehkan keputusan secara komprehensif dibuat.

Bagi menyokong data untuk Furan, *Frequency Dielectric Spectroscopy* akan digunakan sebagai salah satu cara untuk menentukan kadar penuaan alatubah kuasa yang dikaji.

Kedua-dua ujian berkenaan sekiranya digunakan bersama-sama dapat dijadikan sebagai alat yang berguna untuk mengdiagnosa alatubah di tapak. Keputusan samada alatubah boleh digunakan selanjutnya atau dihentitugaskan dapat dilakukan dengan mengambil kira kedua-dua keputusan ujian ini.

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p	-	Dipole Moment
q	-	Charge
E	-	Electric Field
α	-	polarisability
d	-	distance
P	-	Polarization
χ	-	dielectric susceptibility
ε_o	-	permittivity of vacuum
D	-	dielectric flux density
t	-	time
ε_r	-	relative permittivity
P_s	-	Static polarization
$j(t)$	-	Current density
i_{pol}	-	polarization current
C_0	-	Vacumm capacitance
σ_0	-	DC Conductivity
$\tan\delta$	-	dielectric dissipation factor

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The electrical generation, transmission and distribution system plays an integral part of our lives. It is not wrong to say that electrical power plays a vital role in ramping the nation's progress since its independence day. Most of our daily lives depend on the consumption of electrical power to accomplish even the most trivial task. In this modern age of innovation and convenience, living without electrical power is almost unheard of.

The generation, transmission and distribution of electrical power depend on the transformation of different level of voltages from the generation, to the transmission and the distribution of these energies to the consumer. The transformation of power at these different voltage levels is important at the economics level as power needs to be transmitted optimally with minimal loss so that the power generators and the utility company can make profit without burdening the people and the industry which consumes it.

In the electrical transmission and distribution business the capability to quickly and effectively transform electrical energy from one voltage level to another translate to revenue and form the basic structure of the electricity business. The transformations of electricity from different voltages are achieved by using power transformers at the generation, transmission and distribution level.

The transmission and distribution system is Malaysia primarily consists of the voltage levels at 500kV, 275kV, 132kV, 33kV, 11kV and 415V at the consumer level. The common transformer ratings are at 240MVA at the 275kV/132kV level, 90MVA and 45MVA at the 132kV/33kV level, 30MVA and 15MVA at the 132/11kV level and 30MVA and 15MVA at the 33/11kV level.

In any power transmission and distribution system, power transformer is regarded as the highly and heavily maintained equipment as it is the most expensive (per unit value) in the substation and takes the most lead time to manufacture. For any utility, keeping the power transformer as a strategic spare is important so that long power outages can be eliminated in any case of power transformer failure. This however, proves to be expensive as the cost of power transformer at any voltage level higher than 33kV would be in the value of millions of ringgit.

Another option that power utility is taking other than to provide strategic spares is to develop as more accurate maintenance plan for its power transformer. A more traditional method is to do scheduled maintenance on the plant. The scheduled maintenance of these power transformers often involved outages as the power transformers needs to be physically accessed for it to be maintained. The practice of taking outages and maintaining power transformer is a hassle as the transmission or distribution system needs to be shutdown and the load for these outaged transformers need to be dispatched elsewhere. In the case that the system does not have redundancy or a ‘ring system’ the consumer’s supply would be interrupted and load shedding is compulsory.

In the economics of things, current consumers and industry players could not tolerate frequent outages as it involved in lessening of profit to the utility and to the industry that depends of the electric power to produce.

For a shift to the future, new maintenance philosophy must be introduced to counter this problem. This involves switching the utility’s maintenance practice from the conventional time-based maintenance or corrective maintenance to a more accurate preventive maintenance based on regimes of condition monitoring tests and analysis.

As the current trend of maintenance is switching from time-based maintenance to a more reliable and cost effective preventive maintenance, the ability to correctly pin-point the condition of the equipment to be maintained is crucial. For other equipment in the varying voltage level in transmission and distribution system in Malaysia, the criticality and the complexity of singling out the whether the equipment can still be reliable in service is not as hard as that of the power transformer.

This paper would try to study the effect of the degradation of the transformer's paper winding in terms of its ageing by using two established testing techniques that is the Furan Analysis (chemical test) and Dielectric Response analysis (electrical test) of the power transformer in service and out of service in TNB system and reach a conclusion.

1.2 Problem Statement

The power transformer's condition monitoring has to deal with a lot of variables mainly due to its construction. As the main part of the power transformer is mainly made of paper wound copper conductors made into its primary and secondary winding; with insulating oil as a medium of cooling and insulation, many variable have to be taken into account to confirm the service reliability.

From the operational point of view, it is well known that since the construction of these power transformers are mainly of kraft paper insulated copper and insulating oil, the number one enemy of the power transformer is moisture. It is also the number one cause of transformer's insulation failure. The complex nature of the insulation oil's property and its change under heat and moisture would also be another cause of transformer failure as its insulation property degrades.

The physical property of the kraft paper insulation of the power transformer itself would also show sign of degradation under various site conditions so long as the transformer is in service as the its operating temperature varies throughout the day and under different load conditions.

To physically access the condition of the transformer insulation by determination of the ageing of its kraft paper would be very difficult as the power transformer itself needs to be taken out of service and the kraft paper physically condition needs to be put through a test called the Degree of Polimerisation to ascertain its properties. Under the heavily scrutinized operating requirement in which an outage on a highly critical substation is under no circumstances allowed, it is virtually impossible to accurately confirm the ageing of the transformer insulation for preventive maintenance purposes.

As such, a less intrusive method for studying the degradation of the power transformer winding is required. Current method of condition monitoring uses various testing methods for determination of the transformer insulation winding's properties. Some of the currently employed methods are:

1. Recovery Voltage Measurement.
2. Tan-delta analysis.
3. Frequency response and sweep frequency response analysis
4. Frequency Dielectric Spectroscopy (FDS).
5. Degree of Polymerization.
6. Furan Analysis.
7. Dissolved Gas Analysis.
8. Polarization and Depolarization current method (PDC).
9. Transformer oil moisture content and dialectric breakdown voltage.

Among the entire test indicated above, some only deals with the basic measurement of the transformer insulation oil properties and cannot be directly used as the method to confirm on the ageing of the power transformer's ageing insulation. While some on its own would only access some property of the transformer insulation, moisture and other chemical content of the transformer oil, the use of a single method cannot be proven to be the method to confirm on the ageing of the power transformer oil paper insulation.

Another method introduced and has become the standard to access the ageing of power transformer insulation winding is via a chemical test of its insulating oil as the degradation of the kraft paper insulated winding would introduce chemical compound known as Furans in the transformer oil.

This paper would try to establish the use of Furan analysis as a method to study the effect of Furan formation as the transformer ages. The Furan data specifically the 2-Furfuradehyde (2FAL) of various power transformers under various voltage level and transformer rating in TNB's system shall be collected and analyzed. In this paper, the Furan compound that existed in the insulating oil of power transformer will be studied to determine the level of ageing of the transformer oil-paper insulation.

This method alone is not sufficient in determining whether the insulation of the transformer is still reliable enough to be left in service. Degradation of the windings cannot be confirmed on the values of the Furan test alone thus other test on other property of the transformer winding is required to ascertain the level of its degradation of insulation.

As Furan analysis cannot be used as a single test to confirm that the windings of the power transformer is in good condition in terms of its insulation ageing, other site test data shall also be used.

To complement the data for the Furan, Frequency Dielectric Spectroscopy (FDS) shall also be used to ascertain the level of ageing for the power transformers studied.

1.3 Objective

The objectives of this project are to conduct case studies based on actual site Furan Analysis and Frequency Dielectric Spectroscopy (FDS) data for different power transformers at different voltage levels to determine its relationship to the ageing of power transformer's insulation.

Corresponding to the above paragraph, the objectives of this project is listed as follow:

i) To study on the site Furan Analysis data for different power transformers at different voltage levels with the intention of determining the relationship between Furan formation specifically 2-Furfuradehyde (2FAL) and the age of the power transformers.
ii) To study on the site Dielectric Spectroscopy (FDS) data for different power transformers and determine the relationship of these data with the ageing of power transformers.
iii) To develop a relationship between Furan Analysis and Frequency Response Spectroscopy as a tool to determine the ageing of power transformer.

1.4 Scope

The scopes of this project is to collect the Furan analysis data from variety of power transformers in Tenaga Nasional's (TNB) transmission and distribution system covering variety of voltage level transformation and different load rating.

The collected data will be studied analytically and compared to try to develop a suitable relationship of its 2-Furfuradehyde (2FAL) formation and concentration to transformer ageing.

As Frequency Dielectric Spectroscopy using the Diarana test equipment is introduced as a method to determine the insulation properties of the power transformers in TNB's system, these data would also be collected to complement the study of transformer ageing.

These data would also be studied analytically and compared to develop a suitable model for determination of transformer ageing.

1.5 Report Outline

Generally this report is divided into five chapters. The main outline of these report are Introduction, Literature Review, Research Methodology, Results and Discussions and finally Conclusion and Recommendation

Chapter 1 is an overview of the work in whole, the problem statement, objectives and scopes of research project. The work that will be done is based on the objectives and scopes that have been stated earlier.

Chapter 2 is dedicated to the understanding the built up of power transformers more specifically the transformer oil's property, the degradation of its insulating paper due to interactions during service and the study of the Furan Analysis method and how it relates to transformer ageing.

Another method that shall be looked upon is the Frequency Dielectric Spectroscopy and how it is used to determined the condition of the transformer windings and its relation to transformer ageing.

Chapter 3 will discuss on the methodologies of the test implemented for the Furan analysis and that of the Frequency Dielectric Spectroscopy. A brief introduction of the method used and the equipment for measurement.

Chapter 4 will confer on the results and discussion for the data collected for the transformers in service in Tenaga Nasional Berhad Main Intake. The voltage levels for these transformers consists those that are in the 500kV, 275kV 132kV, 66kV 33kV, 22kV, 11kV and 0.415kV voltage levels with different transformation ratios.

FDS data of transformer in service would also be presented for discussion and analysis.

Chapter 5 will conclude all the study discussed in this report. Last but not least are the future recommendations for this project.

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