Analysis Of Transformer Insulation Parameters Using Polarization And Depolarization Current Method And Frequency Domain Spectroscopy

Bhagyashree A. Dhande, Panchayya S. Swami, Dr. Archana G. Thosar

Abstract: Dielectric is an essential indicator for developing the ageing effect of transformer as they change their characteristics due to various stresses on transformer such as mechanical, chemical and electrical. The changes in dielectric property of oil-impregnated paper highly influence the transformer disaster. The basic intent of this paper is to be enlightened about the transformer health by analyzing the parameters of dielectric. This is evaluated by using a time domain test by deriving the polarization and depolarization currents of given dielectric under external field. The frequency domain is used to quantify the dielectric loss factor and complex capacitance, which is helpful to understand the transformer behavior. This paper also supports the comparison the proposed system with existing parameters of other existing system to get the knowledge about system health.

Index Terms: Polarization/depolarization current, transformer insulation, dissipation factor, Debye model, complex capacitance, moisture content, frequency domain spectroscopy

1 INTRODUCTION

Power transformers are one of the very expensive and essential components of power system. The average lifespan of transformer is 60 years if it undergoes thorough maintenance [3]. Time to time conditional assessment of a transformer is crucial for stability and reliability of power system. It is a fact that the condition of transformer is dependent on the state of the insulation used in it. The general insulation used is pressboard fiber paper immersed in industrial transformer oil. The performance of insulation deteriorates due to the electrical, thermal, mechanical and chemical processes occurring in system. There are various methods for performing the tests of insulation carried by observing the dielectric response. These types of tests follow up without disturbing the construction of transformer. The methods are Recovery Voltage Measurement (RVM), Frequency Domain Spectroscopy (FDS), Polarization Depolarization Current (PDC). If the moisture content in the insulation increases by double then the lifespan of insulation becomes half to the existing system. The effect of moisture content is so much that it can damage the insulation composition resulting into increase in reduction in breakdown voltage. Most of the moisture content is in pressboard paper and very less moisture content is in oil. Polarization depolarization current method is time domain as well as frequency response technique. It is a dielectric response test used to determine the conductivity of oil and paper also moisture content of the dielectric. This test is widely used and is very popular for its simple operations and its quick implementation. PDC method is also useful for being knowledgeable about the ageing of transformer insulation due to the relation between the polarization current with time [5].

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Polarization depolarization method uses an external electric field to test its behavior in it considering the physical appearance, construction and other properties. After applying it to the field, dielectric response is measured. Dissipation factor (tan δ) is newer method that has been useful to determine the parameters of transformer. The value of tan δ is developed for the values of frequency from 1 mHz to 1 kHz. To perform the dielectric test on the insulation it is essential to know the relation of dielectric processes and dielectric parameters [4]. This paper uses the extended Debye model as an RC equivalent of the sample of insulation used in the transformer. The parameters of Debye model can be calculated using PDC curves. The system has established using a MATLAB script. The result tables and graphs are the output graphs and values of system in code by certain initial data availability from other research papers. This system has the parameters of 45-MVA transformer insulation. This transformer is an aged transformer. This paper also compares the data with another comparatively new transformer to observe the aging effect in them.

2 SYSTEM METHODOLOGY

This paper corresponds to both the time domain and frequency domain. The insulation of transformer which is an oil-paper one is considered and separated as different branches of resistances and capacitances. This setup is popular as extended Debye model. The processes of PDC and other parameters will evolve in this paper.

2.1 Polarization Depolarization Test Procedure Algorithm

This process starts by applying a DC step voltage U_0 to the extended Debye model using an operational switch for a polarization time t_p or charging time t_c. In this time, the polarization process starts very rapidly and polarization current occurs in RC parameters of the system. After the polarization process gets over the DC voltage is detached using the operational switch and then it is short circuit for a depolarization time t_d, and the depolarization occurs in the dielectric and we can observe the depolarization current. On completion of depolarization process, the system is open circuited [8]. The equivalent circuit of Debye model for assessment of Polarization and Depolarization current (PDC) as given by Fig.1.

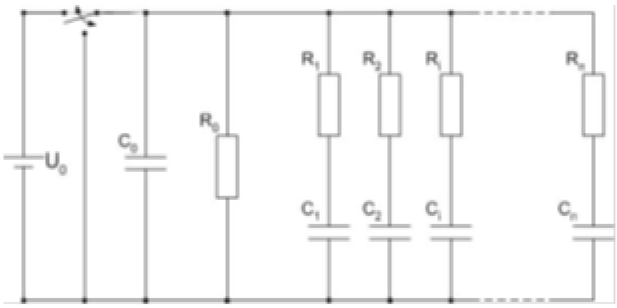

Fig. 1. *Equivalent circuit of PDC test*

The externally applied electric field makes the dielectric dipoles align with the field. After the removal of electric field, the dipoles are again shattered and reach to almost the pre-existing positions [7]. As the oil-paper insulation is a non-uniform composition, the different branches of extended Debye model have different values of resistances and capacitances from n number of branches. The capacitance C_0 is geometric capacitance, measured by the Power frequency capacitance method.

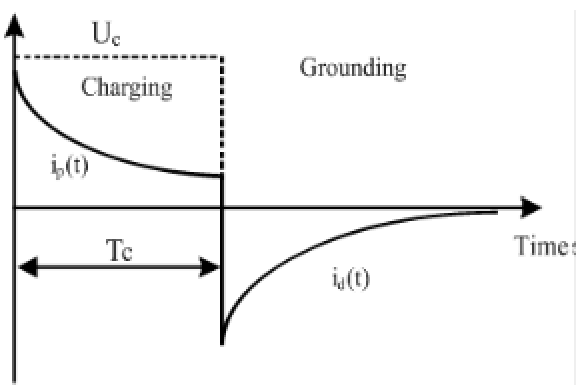

Fig. 2. *Timeline of PDC test representation.*

The geometric resistance is R_0, calculated by dividing the voltage of measurement with the addition of polarization and depolarization current at the largest measuring time [5]. Time constants (τ_i) are for different branches, evaluated by depolarization current equation. R_i - C_i branch parameters are related to the time constants (τ_i). The general timeline plot of the test is in Fig.2. It can be seen that, the polarization and depolarization current are almost of same shape and of opposite polarity. If the linear time is considered the PDC graphs are exponential. T_c represents the charging time and U_c represents the step voltage U_0.

2.2 Dissipation Factor (tan δ)

The Dielectric loss factor is popular as dissipation factor. It is nothing but the tangent of angle δ. This is an essential parameter in monitoring of dielectrics of various power equipments. The angular difference between conduction phase angle of θ and dissipation angle of δ shows the losses in the insulation. By using angular frequency ω in radians per second as a variable quantity, the loss factor is plotted. It is a fact that if the dissipation angle δ is of value zero, the insulation material has no losses [1].

$$\tan\delta = \frac{\text{Real Part Of Impedance}}{\text{Imaginary part of Impedence}} \quad (1)$$

2.3 Complex Capacitance

The complex capacitance occurs when the applied test voltage is at angular frequency ω in radians per second. Then the capacitance becomes complex in nature. The capacitance is dependent on permittivity of insulation material ε, area of insulation plate A and distance between two plates of capacitors d.

$$C = \varepsilon.\frac{A}{d} \quad (2)$$

The complex capacitance is combination of real and imaginary capacitances. These quantities of capacitances are also dependent on permittivity of the insulation [6].

$$C(\omega) = C'(\omega) - jC''(\omega) = (A/d)(\varepsilon'(\omega) - \varepsilon''(\omega)) \quad (3)$$

The capacitance $C''(\omega)$ is a representation of dielectric loss. The dielectric loss is also dependent on real and imaginary values of capacitances at different frequencies.

2.4 Debye Model Parameters

The DC voltage U_0 applied for a time t_c make the polarization process begin for the n number of branches of Debye model and it is quite possible that in the time of polarization which are in seconds all the RC components are not fully charged hence their values differ from the values of starting branches. Time constants of all branches are τ_i where i represent the number of branch, i =.1, 2, 3…..n.

$$\tau_i = R_i.C_i \quad (4)$$

Polarization current i_p and depolarization current i_d are time domain quantities, which are dependent on both the real time and time constants. Eq.(5) and Eq.(6) gives the polarization and depolarization currents [4]

$$i_p = \frac{U_0}{R_0} + \sum_{i=0}^{n}\left[\frac{U_0}{R_i}e^{\left(-\frac{t}{\tau_i}\right)}\right] \quad (5)$$

$$i_d = \sum_{i=0}^{n}.(A_i.e^{\left(-t/\tau_i\right)}) \quad (6)$$

Eq.(7) gives current coefficients for different branch

$$A_i = \left[\frac{U_0}{R_i}.\left\{1 - e^{-t/\tau_i}\right\}\right] \quad (7)$$

These parameters are most essential for and the main results of the PDC test. The values plotted in graphs are with respect to time.

3 PROPOSED SYSTEM MODELLING

In order to perform PDC test of a 45MVA transformer the insulation sample extracted to external electrical field. The standard thickness of sample of paper insulation is around 1mm and the radius is 65mm. This transformer established in the year 1959, which is a very old transformer. The oil-paper insulation sample has pressboard of thickness 1mm and radius of 66mm immersed in 25 mineral oil.

TABLE 1 *Debye model Equivalent circuit parameters values*

Branch	R_i(GΩ)	C_i(nF)
1	70	68
2	30	22
3	9	18
4	13	3.5
R_0(GΩ)	140	
C_0(nF)	3.3	

R_i = resistances, C_i = capacitances

3.1 The RC Debye Model Evaluation

The supply voltage U_0 of 500V is applied to the proposed Debye model for a time t_c of 1000s. This voltage is detached at tc. The test insulation is then short-circuited for a period half to the charging time. The Debye model RC parameters of branches are values got after reclamation of oil at temperature of 25℃ derived from an experiment by a researcher [2]. These values of RC parameters are used in this paper to develop the test by using MATLAB software script.

3.2 Dissipation Factor

The frequency domain spectroscopy is used to derive the dissipation factor. In this test the dielectric response is measured in terms of frequency in the range of 1mHz to 1kHz [5]. The simplified tan δ equation by separating the impedances by real and imaginary parts we get it as

$$tan\,\delta = \frac{\frac{1}{R_0} + \sum_{i=0}^{n}\left(\frac{R_i.(\omega C_i)^2}{1+R_i(\omega C_i)^2}\right)}{\omega C_0 + \sum_{i=0}^{n}\left(\frac{\omega C_i}{1+R_i(\omega C_i)^2}\right)} \qquad (8)$$

Fig.3 represents the plot of dissipation factor with respect to frequency.

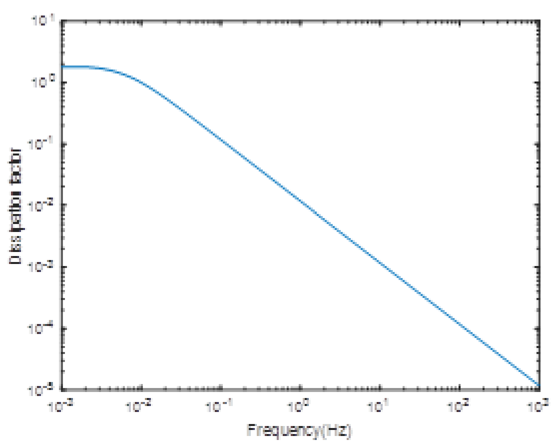

Fig. 3. *Dissipation factor plotted for model.*

3.3 Complex Capacitance

The parts of complex capacitance of the equivalent parameters real and imaginary in terms of frequency is given as

$$C'(\omega) = C_0 + \sum_{i=1}^{n}\frac{C_i}{1+R_i(\omega C_i)^2} \qquad (9)$$

$$C"(\omega) = \frac{1}{\omega R_0} + \sum_{i=1}^{n}\frac{\omega R_i {C_i}^2}{1+R_i(\omega C_i)^2} \qquad (10)$$

The frequency limit of the range used in this test is as per limitations specified in IDA 200 hardware. The MATLAB program results for calculation of complex capacitance are visible in Fig.4

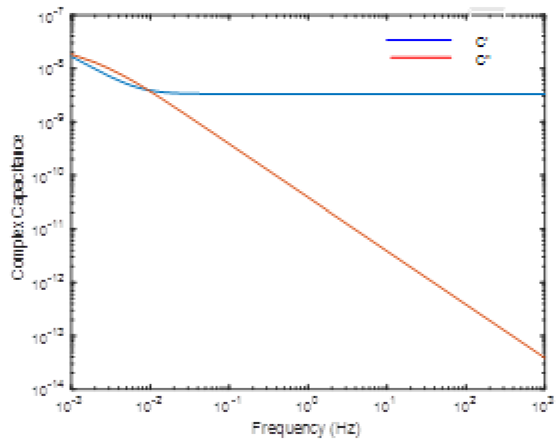

Fig. 4. *Complex- real and imaginary Capacitance plot*

Imaginary part of this capacitance signifies the losses such that lesser the $C"(\omega)$ lesser are the losses.

3.4 Time Constants and Current Coeffiecients

Time constants (τ_i) and current coefficients (A_i) in Table II are derived from equations, Eq.(4) and Eq.(7). These parameters are specified in following table [2].

TABLE 2 *Time constants and current coefficients of debye model*

Branch	τ_i(s)	A_i(A)
1	4760	7.125e-10
2	660	8.853e-09
3	162	5.302e-08
4	45.5	3.846e-08

τ_i = time constants, A_i = current coefficients

After getting the values of these parameters, polarization and depolarization current is plotted at different time from 0 to 1000 seconds.

3.5 Polarization and Depolarization Currents

The measurement of polarization current slows down when the polarization current comes to rest at constant. The polarization current is dependent upon the conductivity of the insulation used that is different for oil as well as paper. After oil reclamation the oil and paper dries up reducing the moisture content. This reduction also helps in reducing the conductivity of the respective insulation. According to this transformer data collected the oil conductivity for proposed system is 2.9 (pS/m) and paper conductivity is 9.7 (pS/m) [1]. Also the moisture content at 25℃ in oil insulation sample is 10 (ppm) and in paper insulation of the sample is 2.5%.The changes after oil reclamation in the moisture content of paper insulation is about 30% and as in oil insulation it is 64% [2]. The plots for Polarization and depolarization currents are shown in Fig.5 and Fig.6

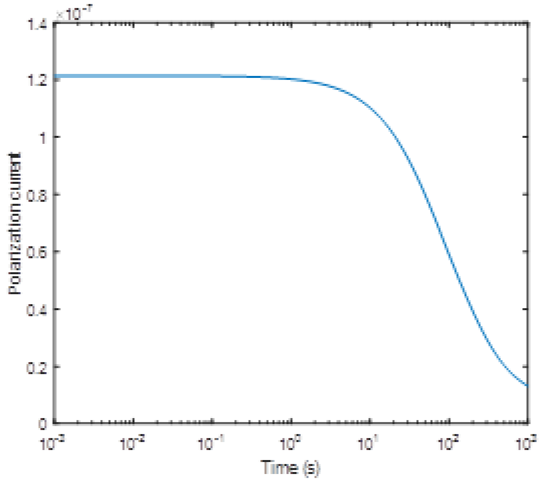

Fig. 5. *Polarization current plot of proposed system*

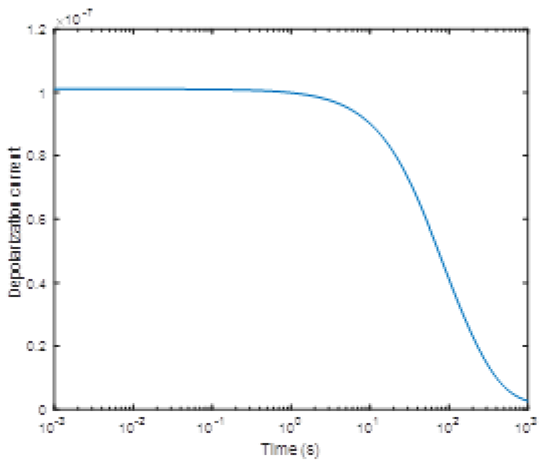

Fig. 6. *Depolarization current plot of proposed system*

The Depolarization current i_d is not dependent on dc conductivity of the Debye model. The value of depolarization current at the tail time is mostly observed due to contribution of largest time constants amongst the branches. Average conductivity of the insulation is directly proportional to difference between polarization current and depolarization current [19].

$$\sigma_r = \frac{\varepsilon_0}{C_0 . U_0}\left(i_p - i_d\right)$$

Where ε_0 is vacuum permittivity.
It can be observed from the graph that there is very less difference between polarization current and depolarization current, which means that the material has very less conductivity.

4 Comparison of the proposed system with Neka power plant transformer

Exactly 20 years after establishment of power transformer of the proposed system with capacity of 45MVA, in year 1979 Neka power plant was established having capacity of 2214 MW.

TABLE 3 *equivalent circuit parameters and other PDC parameters of Neka power transformer*

Branch	A_i(A)	τ_i(s)	R_i(GΩ)	C_i(nF)
1	5.0642e-8	10161	34.96	290.65
2	1.4811e-7	1408.4	13.5	104.3
3	4.7025e-7	303.5520	4.25	71.373
4	2.0102e-6	54.2026	0.9949	54.480
5	3.0120e-6	13.5507	0.2237	24.473
6	4.1703e-6	2.8214	0.4795	5.883

τ_i = time constants, A_i = current coefficients, R_i = resistances, C_i = capacitances

Table 3 shows the Time constants, current coefficients and equivalent circuit parameters calculated by researchers on Neka power plant [7].

4.1 Dissipation factor

The Dissipation factor of proposed system is compared with Neka power transformer in Fig.(7) and Fig.(8)

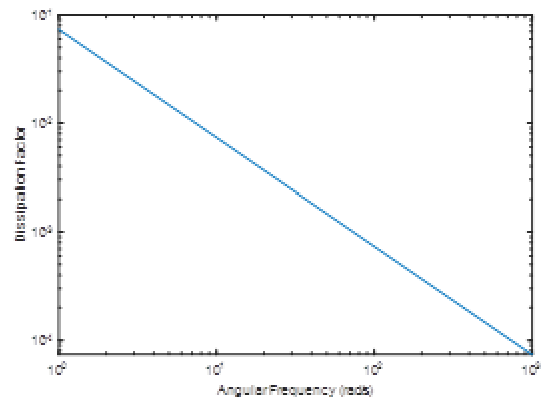

Fig.7 *Dissipation factor of proposed system*

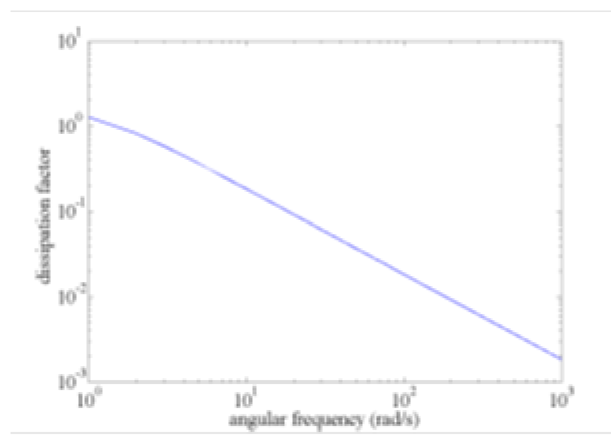

Fig.8 *Dissipation factor of Neka transformer system*

It can be observed from the comparison that dissipation factor of Neka insulation system is higher than that of the system proposed in this paper. This means that the Neka power plant transformer insulation is aging rapidly. By observing the tail of these plots, we can easily say that the moisture in the paper insulation is relatively less in proposed system.

4.2 Depolarization Current

The depolarization current plot is given in Fig.9.

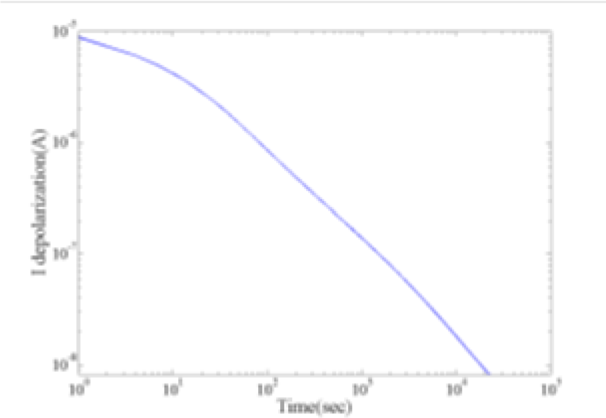

Fig.9 *Depolarization current of Neka power transformer*

The depolarization current is greater in case of Neka power plant. In other words, the insulation used in this transformer takes more time to get discharged. Hence, there is more conductivity in Neka transformer insulation.

5 Conclusions

This paper enlightens about the recent tests performed on insulation without disturbing the structure of power transformer. The tests performed using the MATLAB software include the PDC test and Frequency domain tests such as dissipation factor and complex capacitance. By knowing the relation between the system parameters used and the significance of changes in each essential parameter of the system, one can easily say about the condition of transformer. The values of PDC test are obtained in time domain. This paper uses logarithmic references for the plots to develop the responses at transient period.

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