Deriving an Equivalent Circuit of Transformers Insulation for Understanding the Dielectric Response Measurements

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Abstract—Preventive diagnosis and maintenance of transformers have become more and more popular in recent times in order to improve the reliability of electric power systems. Dielectric testing techniques such as return voltage measurement (RVM) and polarization-depolarization current (PDC) measurement are being investigated as potential tools for condition assessment of transformer insulation. A better understanding and analysis of the dielectric test results are only possible with a clear understanding of the physical behavior of the insulation system in response to moisture and aging. A circuit model, which describes the dielectric behavior of the transformer’s main insulation system, has been parameterized in this paper. The values of the parameters of the model have been identified from the dielectric tests. A correlation has been developed between the physical condition of the insulation and the equivalent model parameters that enable a clear and transparent interpretation of the dielectric test results.

Index Terms—Depolarization current, dielectric response, equivalent circuit, modeling, polarization current, return voltage, transformer insulation.

I. INTRODUCTION

THE CONDITION of oil/paper insulation in a power transformer is deteriorated by the electrical, thermal, and environmental stresses during its operation. The physical and chemical deterioration processes (aging and moistening) induced by these stresses alter the molecular microstructure of dielectrics and thereby influence the conduction and polarization processes. recovery voltage measurements (RVMs) [1]–[5] and polarization-depolarization current (PDC) [5]–[10] measurements are examples of dielectric response measurements that have been used in recent times for the diagnosis of power transformers insulation condition. A greater part of the experts are, however, still circumspect about the implementation of dielectric tests for assessment of the insulation condition with certainty. One of the reasons for that has been the fact that the results of such testing cannot be interpreted confidently because the exact relationship between the measured dielectric parameters and the fundamental dielectric processes of insulations is not yet clearly understood.

The two fundamental dielectric processes—conduction and polarization arise in dielectric due to the presence of an electric field. Both processes are related to the microstructure of the insulation material. The change of structure is caused by the deterioration and moistening of insulation. The development, application, and interpretation of the dielectric test methods require the full and exact knowledge of the relationship between the basic dielectric processes and the dielectric parameters measured. The simulation of the dielectric processes gives the possibility to explain some exact relationships that may help to interpret the test results correctly.

An effort has been made in this paper to understand the dielectric response of oil/paper insulation as related to its fundamental structure and its behavior to an external electric field. A model of the insulation structure of transformers based on the principles of linear dielectric response has been derived. The model presented here allows quantitative analysis of the dielectric response of the composite oil/paper insulation system of a power transformer. The model takes into account the geometry of the transformer and the influence of the properties of the constituent materials (oil and paper). Examples are provided in this paper to demonstrate the effectiveness of this tool to analyze results from field measurements on transformers.

II. INSULATION MODEL FOR DIELECTRIC RESPONSE

Over the last few years, several researchers [3]–[15] have proposed a number of equivalent circuits for modeling the transformer oil/paper insulation system for a better understanding of the dielectric response. In essence, all of the models proposed so far have been derived from an extended Debye approach based on a simple RC model.

Gafvert et al. [16], [17] described the development and analysis of an insulation model for studying the polarization processes from the basic equations of dielectric physics. Houhanessian et al. [6], [7], [9], [13] described the derivation of an equivalent circuit from relaxation current (PDC) measurements. Many of the above researchers have also derived the RV spectra from the equivalent insulation model. The modeling processes as discussed so far in the above literature [11]–[17] were heavily dependent upon the correct knowledge about the design, geometry, and arrangement of insulation within the transformer. Such information may not be available easily from the utility
companies—making the proposed modeling task difficult. The simplified model discussed in this paper considers the insulation system as a “black box” and attempts to identify the individual effect of paper and oil condition on the model parameters without requiring any prior knowledge about their relative arrangements.

A. Basic Theory Behind the Model

In the presence of an electric field, a polarization current is developed due to the tendency of dipoles to align in the direction of the field. When the field is removed, the dipoles relax and return to the original state [11], [14]. In a polymer dielectric, every polar group can have a different configuration of neighboring molecules. Thus, the response time of the groups after the application of an electric field may differ from one to another [11]. These processes can be modeled by a parallel arrangement of branches each containing a series connection of resistor and capacitor as shown in the circuit of Fig. 1 [3], [4], [6], [10]–[14]. These dipoles, represented as \( R_i \) - \( C_i \), are randomly distributed, and have associated time constants given by \( \tau_i = R_i C_i \). Apart from the polarization current, conduction current flows in the insulation in the presence of an electric field. The conduction current in the insulation is due to the insulation resistance \( R_0 \) as shown in Fig. 1. \( C_0 \) represents the geometric capacitance of the insulation system [6].

B. Identification of the Model Parameters

For this model, most of the circuit parameters have been derived from measured polarization and depolarization currents \( i_p \) and \( i_d \). The capacitance \( C_0 \) is determined by conventional capacitance measurement techniques at power frequency [6]. The insulation resistance \( R_0 \) is calculated from the difference between polarization and depolarization currents at larger values of time [13]. The depolarization current is comprised of summation of various relaxation mechanisms that appear at different locations within the transformer insulation [5]. Various parts of the insulation have their unique relaxation characteristics depending upon the aging and moisture condition [5], [10], [11]. The paper and pressboard insulation have a different time constant of polarization as compared to the time constant of oil. The relaxation currents can thus be modeled as the sum of exponentials of the various relaxation mechanisms. The individual elements \( R_i - C_i \) with the corresponding time constants \( \tau_i = R_i \cdot C_i \) can then be determined by fitting the depolarization current with the following equation:

\[
\dot{i_d} = \sum_{i=1}^{n} \left( A_i \cdot e^{-t/\tau_i} \right)
\]

(1)

where

\[
A_i = \frac{U_0 \cdot (1 - e^{-t_p/\tau_i})}{R_i}
\]

(2)

The first task in the modeling work is to identify the \( \tau_i \) and \( A_i \) corresponding to different branches. The process starts with the largest time constant branch. The depolarization current at longer times can be assumed to be due only to the largest time constant branch, with the influences of the rest of the smaller time constant branches dying down well before that time. Hence, the final part of the depolarization current is used to find out the values of \( \tau_i \) and \( A_i \) corresponding to the largest time constant branch using an exponential curve-fitting technique. Once the exponential component with the largest time constant is identified, it is then subtracted from the original depolarization current to go to the next level. In this level, like before, the final part of the resultant current curve is influenced by the second largest time constant only, with the next smaller time-constant branches practically going to zero well before that time. Following the same exponential curve-fitting procedure, the values of \( \tau_i \) and \( A_i \) corresponding to the second largest time-constant branch are found out. Proceeding in the same way—all of the other time-constant branches are identified. Once the values of \( \tau_i \) and \( A_i \) corresponding to different time-constant branches are found, the values of \( R_i \) and \( C_i \) can be easily separated and the equivalent model can be constructed.

The number of branches in most practical modeling purposes varies from six to ten depending upon the nature of the depolarization current. The range of the values of the individual time constants, resistances \( R_i \) and \( C_i \), are found to be dependent upon the oil and paper conditions. The values of \( R_i \) and \( C_i \) corresponding to the smaller time-constant branches are found to be more related to the condition of the oil—whereas the condition of the paper insulation is found to be responsible for affecting the higher time-constant branches.

Fig. 2 shows a sample plot a depolarization current from a 45-MVA transformer with the corresponding exponential function components that have been used to model the insulation. The simulated depolarization current is also plotted in Fig. 2, which shows a reasonably good agreement with the measured current. Table I contains the calculated values of the \( A_i \), \( R_i \), \( C_i \), and \( \tau_i \) corresponding to different branches of the simulated model of the transformer. The parameter values are rounded up for easy readability. Since the magnitude and nature of depolarization current is related to the geometry and the condition of the insulation, the values of these \( R_i - C_i \) parameters obtained through curve fitting on the depolarization current are expected to take the effects of both geometry and condition of the insulation into account.

The difference between the polarization and depolarization currents is the time-dependent dc current [18]. The initial portion of this current is influenced by the high mobility of the charge carriers in the liquid dielectric (oil). However, after few
tens of seconds, this transient part dies down and the conduction current due to the insulation resistance $R_0$ only flows. The value of $R_0$ is then obtained from the long time-constant values of this conduction current. For accurate modeling of the polarization current, however, the initial transient part also needs to be fitted by more than one exponential function representing the decay of this time-dependent dc component of current at smaller times.

Fig. 3 is a sample plot for the time-dependent dc current (difference between polarization and depolarization currents) as a function of time. The exponential functions used for modeling the initial decaying nature are also shown in the same figure. It is also seen in Fig. 3 that the initial decaying part dies down fast and the difference current practically remain constant for the rest of the time.

The value of $R_0$ obtained from the above plot is 2.5 $\text{G} \Omega$ for the same 45-MVA transformer. The value of the capacitance $C_0$ measured at 50 Hz by an AC bridge is 10.2 nF.

### C. Calculating Return Voltage From the Equivalent Model

During the charging up process with the time $t_p$, the capacitor $C_0$ is charged to its full capacity almost instantaneously, whereas the other branch capacitors $C_i$ are charged up to different levels according to their associated time constants. After the predefined charging time, the voltage source is disconnected and the dielectric is short-circuited. The depolarization process starts with the immediate discharge of $C_0$; the other capacitors $C_i$ are slowly discharged depending upon, once again, their associated time constants. For measurement of the RV, the discharge process is interrupted in-between (at time $t_d$) and a high impedance voltmeter is connected across the terminals of the dielectric. During the incomplete depolarization process, each branch capacitor discharges up to different levels. After connecting the voltmeter, the charge distribution inside the dielectric attains a new equilibrium state and in the process brings the return voltage. The relation between the return voltage $U_{ri}$ and the voltage $U_{ci}$ in the capacitor $C_i$ for any particular cycle with charging time $t_p$ is given by (3)

$$U_{ri}(s) = \frac{s^n N_{ni} + s^{n-1} N_{n-1} i + \cdots + N_0}{s^{n+1} D_{n+1} + s^n D_n + s^{n-1} D_{n-1} + \cdots + D_0}$$

$$U_{ci}(s) = \frac{s^n N_{ni} + s^{n-1} N_{n-1} i + \cdots + N_0}{s^{n+1} D_{n+1} + s^n D_n + s^{n-1} D_{n-1} + \cdots + D_0}$$

The zeros ($z$) and poles ($p$) of the transfer function given by (3) can be obtained by solving the numerator polynomial and denominator polynomial, respectively. The coefficients ($N$ and $D$) of these polynomials are obtained from circuit solution of the equivalent model as combinations of the $R$-s and $C$-s. The return voltage due to the capacitor $C_i$ in time domain is then obtained by computing the inverse Laplace Transform from (3). The total recovery voltage due to all of the branch capacitors is obtained simply as the summation of their individual contributions.

These steps are repeated for various charging times in increasing order to obtain the so-called RV-spectra—which is nothing but a plot between the peak voltages of each RV cycle versus the corresponding charging times. The general equation for the peak voltage of the RV cycle with $t_p$ charging time is given in (4).

$$U_{r\text{max}}(t_p) = U_0 A_{\text{max}1}(t_m) \left( 1 - \exp \left[ \frac{-t_p}{R_1 C_1} \right] \right) \cdot \exp \left[ \frac{-t_p}{2R_1 C_1} \right] + \cdots + U_0 A_{\text{max}n}(t_m) \cdot \left( 1 - \exp \left[ \frac{-t_p}{R_n C_n} \right] \right) \cdot \exp \left[ \frac{-t_p}{2R_n C_n} \right]$$

---

**TABLE I**

<table>
<thead>
<tr>
<th>Branch</th>
<th>$A_i$ (amp)</th>
<th>$\tau_i$ (sec)</th>
<th>$R_i$ (G$\Omega$)</th>
<th>$C_i$ (nF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$7.0 \times 10^8$</td>
<td>6800</td>
<td>7.0</td>
<td>950</td>
</tr>
<tr>
<td>2</td>
<td>$8.5 \times 10^8$</td>
<td>880</td>
<td>6.0</td>
<td>150</td>
</tr>
<tr>
<td>3</td>
<td>$1.0 \times 10^7$</td>
<td>140</td>
<td>4.5</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>$1.5 \times 10^7$</td>
<td>30</td>
<td>3.5</td>
<td>8.5</td>
</tr>
<tr>
<td>5</td>
<td>$8.5 \times 10^8$</td>
<td>5.5</td>
<td>6.0</td>
<td>0.9</td>
</tr>
<tr>
<td>6</td>
<td>$2.0 \times 10^7$</td>
<td>0.8</td>
<td>2.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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Fig. 2. Measured and simulated depolarization current with the constituent exponential components.

Fig. 3. Nature of the variation of conduction current.
where \( t_m \) is the time to reach the peak of the corresponding return voltage curve
\[
A_{\text{max},i}(t_m) = A_{k,1}e^{t_m p_1} + \cdots + A_{k,n+1}e^{t_m p_{n+1}}
\]
(5)
\[
A_{i,j} = \frac{b_i p_j}{\prod_{k \neq j} (p_j - p_k)}
\]
(6)
\[
b_k = \frac{N_{n,i}}{D_{n+1}}
\]
(7)

The detailed procedure for obtaining the return voltage from the insulation model has been discussed by Jota et al. in [14]. Fig. 4 shows the RV spectra obtained from measurement as well as simulation for a 45-MVA transformer in relation to Fig. 2 with parameters obtained as shown in Table I.

III. DEPENDENCE OF THE MODEL PARAMETERS ON CONDITION OF INSULATION

It has been pointed out by [9] and other researchers that the condition of the paper and pressboard influences mainly the shape of the polarization and depolarization currents at long time range. In contrast, the initial time dependence of these currents is very sensitive to the condition of the oil. In the present paper, the physical behavior of the model parameters including \( R_i - C_i \) of the different branches and their associated time constants, the value of the geometric capacitance \( C_0 \) and the insulation resistance \( R_0 \), have been investigated with variations of oil and paper conditions.

A. Variation of \( R_i \) and \( C_i \)

The values of the parallel branch resistors and capacitors \( R_i \) and \( C_i \) (i.e., the polarization parameters and their associated time constants) are related to the condition of the oil and paper insulation [5], [10], [11]. As shown in Figs. 5 and 6, the variation in the values of \( R_i \) and \( C_i \) for the smaller time constants (less than 10 s in the case shown, that is, the branches 5 and 6 in Table I) shifts the initial values of polarization and depolarization currents. Since the initial parts of these relaxation currents are related to the oil condition [16], it can be interpreted that the values of \( R_i \) and \( C_i \) for the smaller time-constant branches are governed by the condition of the oil. A better condition of oil tends to increase the value of \( R_i \)-s and decreases the value of \( C_i \)-s for the smaller time-constant branches and thereby reduce the magnitude of initial portion of polarization and depolarization currents. On the other hand, aged and moist oil will increase the initial magnitudes of polarization and depolarization currents as a result of decrease in \( R_i \)-s and increase in \( C_i \)-s for the smaller time-constant branches.

Fig. 7 is the plot of the simulated RV spectra obtained for the three different pairs of \( R_i - C_i \) for the smaller time-constant branches as mentioned above. The CIGRE Task Force 15.01.09 published a comprehensive report [19]—in which it has been reported that there may be another subsidiary peak of the RV spectra away from the dominant time constant. In such a case, the dominant time constant corresponds to the oil peak and any subdominant maximum would stem from polarization phenomena in the solid insulation.
As can be seen in Fig. 7, the variations in the \( R_k \) and \( C_l \) values of the smaller time-constant branches shift the dominant central time constants of the RV spectra without affecting the position of the subsidiary peaks which occur at much higher times. Thus, RV spectra with higher \( R_k \) and smaller \( C_l \) (better insulation condition) are found to have higher values of dominant central time constants (first peak) as compared to the RV spectra with lower \( R_k \) and higher \( C_l \). This supports the observation that the values of \( R_k \) and \( C_l \) for the smaller time-constant branches correspond to the condition of the oil, which affects the initial portion of the polarization and depolarization current and only the first dominant peak of the RV spectra. This is a significant finding, which will help to interpret RV results.

On the other hand, the final long-term magnitudes of the relaxation currents are found to depend only on the values of \( R_k \)-s and \( C_l \)-s of the larger time-constant (around 1000 s or more) branches. Figs. 8 and 9 are plots showing variations of polarization and depolarization currents due to change of \( R_k \)-s and \( C_l \)-s for the larger time-constant branches (branches 1 and 2 in Table I).

It is thus found that the final parts of the relaxation currents are governed by the larger time-constant branches, values of which are dependent on the condition of the paper insulation [16]. A better condition of the paper tends to increase the value of \( R_k \) and decrease the value of \( C_l \) for the larger time-constant branches thereby reducing the relaxation current magnitudes at larger values of time. Aged and moist paper on the other hand, decrease the value of \( R_k \) and increase the value of \( C_l \) for the larger time-constant branches resulting in reduction of the relaxation current magnitudes at longer times.

It is observed that the effects of changing the values of \( R_k \) and \( C_l \) for the dominant central time constants (first peak) of the RV spectra. The subsidiary peaks (second peak) of the RV spectra, however, are found to vary significantly. This once again supports the observation that the \( R_k \) and \( C_l \) values for the larger time-constant branches of the insulation model correspond to the condition of the paper and they affect the final portion of the polarization and depolarization currents and the subsidiary peaks of the RV spectra. This major finding will alleviate some confusion over the interpretation of RV results.

Fig. 10 is the simulated RV spectra plotted for the three different pairs of \( R_k-C_l \) for the larger time-constant branches.

Changing the values of \( R_k \) and \( C_l \) for the intermediate time-constant branches (branches 3 and 4 in Table I) affect the shape of the polarization and depolarization currents in the intermediate region of time, around the 10–1000-s range. In this region, the “interfacial” effects of oil and paper are predominant [9]. The plots for polarization current depolarization current and RV spectra are shown in Figs. 11–13 respectively.

It was pointed out by the authors of [9] that the dominant central time constant (first peak) of the RV spectra is largely influenced by this “interfacial polarization” between the oil ducts and paper/pressboard. It is observed in Fig. 13 that both the dominant and the subsidiary peaks of the RV spectra are being affected by the changes in \( R_k \) and \( C_l \) values of the intermediate time-constant branches. These intermediate \( R_k \) and \( C_l \) branches can thus assume to be attributed to the “interfacial polarization” phenomena in the composite dielectric.
B. Variation of $R_0$ and $C_0$

The insulation resistance $R_0$ provides information about the overall status of the insulation. A higher value of $R_0$ indicates better condition of insulation whereas lower $R_0$ corresponds to aged and moist insulation. Figs. 14 and 15 show the variation of polarization and depolarization currents and RV spectra respectively corresponds to two different values of the insulation resistance $R_0$. Higher values of $R_0$ tend to reduce the polarization current magnitudes but the shift of the first dominant peak of the RV spectra is found to be too insignificant. There is, however, a noticeable shift in the subsidiary peak of the RV spectra with the change of the value of $R_0$.

The dependence of the simulated RV spectra on the value of geometric capacitance $C_0$ of the insulation model is shown in Fig. 16. The value of this capacitor is dependent on the geometry of the insulation arrangements inside the transformer. Hence, as expected, changing $C_0$ alters the magnitude of the RV spectra along with shifting the central time constants [19]. The variation of the geometric capacitance $C_0$ thus has a significant impact on the RV spectra. In (1) and (2), however, depolarization current is first normalized with the geometric capacitance and then curve fitted to obtain the values of $R_i$-$C_i$. That is the reason the impact of $C_0$ on depolarization current (2) is not visible. In practice, the polarization and depolarization currents depend on geometry and size of the insulation system.

IV. ANALYSIS OF FIELD TEST RESULTS

With these background observations about the dependence of the equivalent model parameters on the condition of the oil and paper insulation, an attempt has been made in this section to analyze the results of dielectric testing on a field transformer. The transformer was undergoing an oil-reclamation process and the tests were performed both before and after the oil-reclamation to study the effect of the reclamation process on the dielectric response. According to the information available from the utility,
the oil-reclamation process basically consisted of recycling, filtering, and drying the oil through vacuum and at high temperature. The dry and filtered oil was pumped back to the tank and the whole process was continued in a close cycle. In such a close cycle oil reclamation process, it is expected that some moisture and other degradation byproducts will be driven off the oil. At the same time when dry oil is circulated through the transformer, some moisture will also migrate out of the paper toward the relatively dry oil. Thus, in such an oil-reclamation process, the oil moisture content and other aging byproducts are expected to go down along with some improvement in the paper moisture condition as well. The oil moisture content values both before and after oil reclamation, measured by Karl Fischer Titration method are presented in Table II. Table II also contains the paper moisture content values determined using the equilibrium chart [20] from the measured oil moisture content values at the corresponding oil sampling temperatures.

As seen in Table II, the estimated paper moisture drops to a value of 3.5% after oil reclamation from the initial value of 5% before the oil reclamation. It, however, remains a fact that the accuracy of the equilibrium chart [20] is questionable at the lower ranges of oil and paper moisture content values. Even then, it is not beyond expectation that during such an oil-reclamation process, some moisture has migrated out of the paper insulation toward the relatively dry oil. Figs. 17 and 18 are the plots for the polarization and depolarization currents and simulated RV spectra for the transformer both before and after the oil-reclamation process. Table III summarizes the values of the equivalent circuit parameters for the transformer.

As can be seen from Fig. 17, the polarization and depolarization currents during the initial period are much lower after oil reclamation as compared to those before the oil-reclamation process. The long term values of the currents are, however, not very different—indicating the fact that oil-reclamation alone cannot improve the paper condition appreciably, even if the oil condition improves to a certain extent.

As seen in Fig. 18, the first dominant peak of the RV spectra shifts toward a higher time—indicating an overall improvement in the condition of the oil after the oil-reclamation. However, the subsidiary peaks of the two RV spectra are only slightly different. As mentioned in [19], these subsidiary peaks are related to polarization of the paper insulation. This once again supports the observation that after the oil-reclamation though the oil condition improves, the paper condition is not improved significantly.
Branches 4, 5, and 6 have higher values of $R_i$ and lower values of $C_i$ after the oil-reclamation process when compared to the corresponding values before the oil reclamation process. Since the geometry of the insulation system is essentially the same before and after the oil reclamation, this variation in the equivalent model $R_iC_i$ parameter values for the smaller time-constant branches can solely be related to the change in condition of the oil. On the other hand, the difference between the $R_i$ and $C_i$ values for the larger time constant branches (branches 1 and 2 in Table III) corresponding to before and after oil-reclamation are not too different from each other—indicating the fact that the oil-reclamation does not improve the paper condition appreciably. However, a comparatively small improvement in the paper moisture content (from 5% to 3.5%) has been reflected as a slight increase in the values of $R_i$ and a decrease in the values of $C_i$ for the higher time-constant branches 1 and 2. The insulation resistance $R_0$ is found to have higher value after the oil-reclamation—one again indicating an overall improvement of the condition of the insulation along with drying up of the paper to a certain extent. The value of $C_0$, however, as mentioned before, almost remains the same—since it is more dependent on the geometry of the insulation than its condition. It thus seems possible to assess the condition of the insulation as a whole from the insulation resistance $R_0$ and also oil and paper condition separately by having a close study of the values of the $R_i$ and $C_i$ parameters of the branches corresponding to different time constants.

The experimental results presented in the above Section IV involve test data on a single transformer both before and after oil reclamation. Thus, the geometry of the insulation structure essentially remained the same in both the cases of before and after oil reclamation. The results thus presented clearly indicate the dependence of the equivalent model parameters on the condition of the oil and paper, with the geometry remaining invariant. However, in order that this approach be applied to different transformers with different insulation geometry and size—it is essential that the polarization and depolarization currents be made independent of geometry before applying the curve-fitting procedure to find out the values of $R_iC_i$ of the different polarization branches. This can be achieved by dividing the polarization and depolarization currents by the geometric capacitance of the transformer before starting the curve-fitting procedure. This will ensure that all of the currents are normalized to the same scale of geometry and that the values of $R_i$ and $C_i$ thus obtained will be dependent only on the condition of the oil and paper.

V. CONCLUSION

A model of the transformer’s main insulation system, which describes its dielectric behavior, has been presented in this paper. The values of the parameters of the equivalent model have been obtained from PDC measurements. Once the model has been parameterized, dielectric responses such as the polarization, depolarization currents, and the return voltage can be simulated. A good agreement has been found between the measured PDC and RV spectra and the corresponding simulated curves, demonstrating a higher accuracy of the model.

So far, the interpretations of the dielectric response measurements are often convicted of being too simplistic—without
addressing the physical behavior of the insulation. The approach adopted in this paper promises to overcome most of the controversies in the interpretation by correlating the dielectric responses to the basic components of the insulation model. The variations of the PDC and the RV spectra of the values of the equivalent model parameters have been investigated. In this way, the dielectric behavior of a complex insulation system has been explained from the properties of the basic model. The oil and paper conditions are found to affect the parameters of the equivalent model in a definite and distinct way—thereby enabling correct and transparent interpretation of the dielectric diagnosis results.

REFERENCES


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