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A Novel Method of Modeling of Power Transformer Winding for Insulation Condition Monitoring

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Abstract

Power Transformers act as coupling elements between the connected AC grids and are necessary for adapting the higher voltages. Insulating media in Ultra high voltage transformers consists of paper wrapped around the conductors in the transformer coils plus mineral oil and pressboard to insulate the coils from ground. From the moment a transformer is placed in service, both the solid and liquid insulation begin a slow but irreversible process of degradation. Considering the financial and strategic value of large UHV power transformer such as 765 KV,1100 and 1200 KV, it is recommended to perform without exception the state-of-the-art "fingerprint" measurements in the factory and/or before commissioning on-site as per CIGRE (GROUP REF. : A2).
The paper presents modelling of the insulation system of the transformer using FDS method. Influence of contamination of the insulation due to voids, moisture etc is considered in the simulation studies. This paper presents results of the simulation studies carried out using MATLAB / SIMULINK. The analysis presented will be useful in assessing the condition of the power transformer.

Keywords: Power transformer, polarization current, Frequency domain Spectroscopy MATLAB/ Simulink.

1. Introduction

The Demand for reliable electricity supply has significantly increased during the last few decades. Therefore fault free operation of power system has become very important. However due to high cost of power system components, especially transformers, it is not economical to replace them in order to increase reliability, by considering their age. Moisture increases the risk of dielectric failures and has a double function: it accelerates ageing and also ageing generates it. Additional moisture can penetrate from the atmosphere into the tank. Independent of its origin moisture is absorbed into the oil-pressboard insulation system. Hence, measurement of moisture in different stages of transformers life becomes a challenge for transformers experts. A relatively large number of power transformers that are still working in fairly good condition although they have been used longer than their designed life.

Therefore correct condition assessment of power transformer is needed before making any conclusion about replacement and refurbishment. Failures of power transformer mainly occur due to degradation of power transformer insulation, which mainly consist of oil and pressboard. Chemical and electrical measurements are used to monitor the condition of power transformer insulation. Among these, chemical analysis provide direct information on parameters, such as water content, degree of polymerization of paper ,sludge content in oil and quantity of different gasses dissolved in oil. However most chemical analysis must be performed under laboratory conditions. On the other hand, electrical measurements are simpler and it is possible to perform them on site. Due to this simplicity, Electrical tests, such as Insulation resistance (IR), Polarization index and loss factor (tan δ) provide very little information about the transformer insulation since they are limited to a single value measurement. To overcome this disadvantage, dielectric response measurements, namely return voltage measurements (RVM), polarisation and depolarisation current measurements (PDC) and frequency domain spectroscopy measurements (FDS), have been introduced for condition monitoring of transformer insulation, especially for the evaluation of water content in transformer pressboard. In the early stages, RVM was introduced because voltage measurements were simpler than measurements of low currents. The other two methods, requiring current measurements, were introduced recently due to improvements provided by the use of sophisticated electronic devices.

The focus of this paper is kept on FDS technique which is a non destructive testing method for determining the conductivity and moisture content in the insulation materials like oil and pressboard separately. This paper describes the effect of moisture on a prototype model which is similar tothat of power transformer insulation.

2. Methodology

The test set up required for the dielectric response measurements in frequency domain (FDS) is as follows. In this, an ac voltage source of (0-1000 V) with variable frequency 1mHz to1 KHz is connected across the sample and a voltage and current measuring instruments are to connected in parallel with the source and between guard point and the common point of coupling between source and guard respectively as shown in figure 1 below.

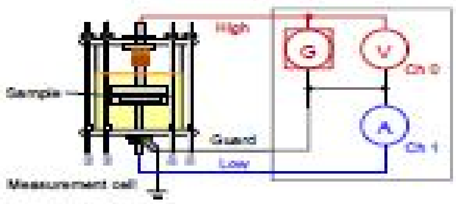

Figure 1: Test setup for the dielectric response measurements on samples.

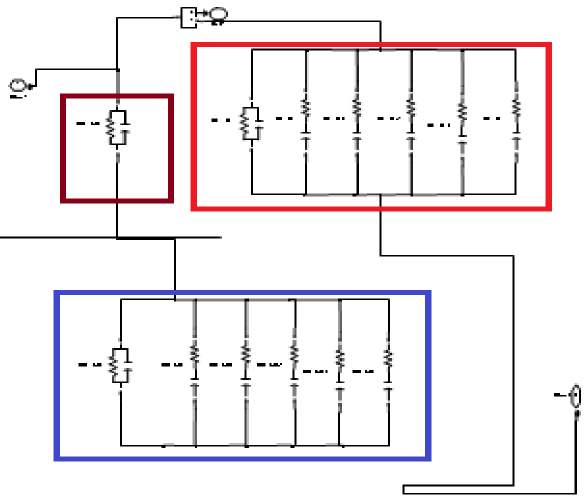

Figure 2: HV winding Insulation Model using Simulink.

The figure 2 above shows that, electrical equivalent circuit of power transformer insulation as: the red marked portion indicates spacer part of the transformer insulation; the blue marked portion indicates paper insulation of transformer and the brown marked part of the model indicates equivalent of oil. In this paper, the Insulation model using Simulink is proposed to study for the practical transformer insulation system.

The specifications taken for the study are:

1. For Transformer oil :
   Resistance Ro= 1 X $10^{14}\Omega$, and Capacitance Co= 1 pF
2. For Transformer Spacers:
   Resistances Rs= 1 X $10^{14}\Omega$, and Capacitances Cs= 1 nF
3. For Transformer Paper:
   Resistances Rs= 1 TΩ, and Capacitance Cs= 1 pF
4. For Transformer Press Boards:
   Resistance Rs= 1 X $10^{14}\Omega$, and Capacitance Cs= 1 nF

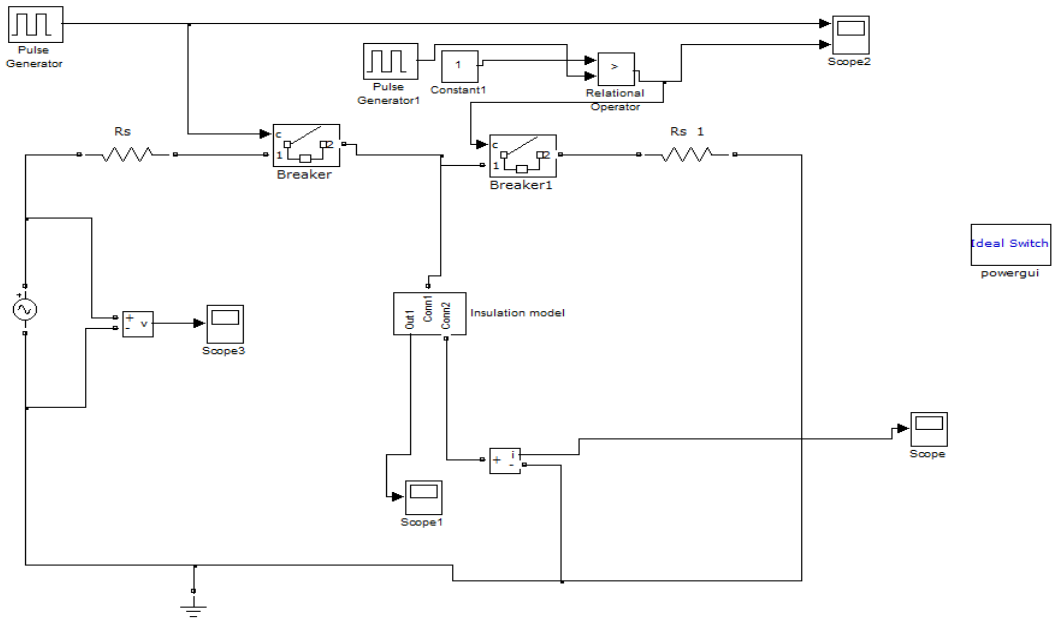

Figure 3: Frequency domain spectroscopy Measuring circuit Model using Simulink.

The figure 3 above shows that, the circuit arrangement for frequency domain spectroscopy of the proposed Simulink model of Insulation of a high voltage winding.

3. Simulation Results and Discussions

The simulation results obtained are presented here in the form of bode plots of polarization current of simulink HV winding insulation model measured between the guard point and the ground. The bode plots of the current measured under simulated moisture conditions are as follows:

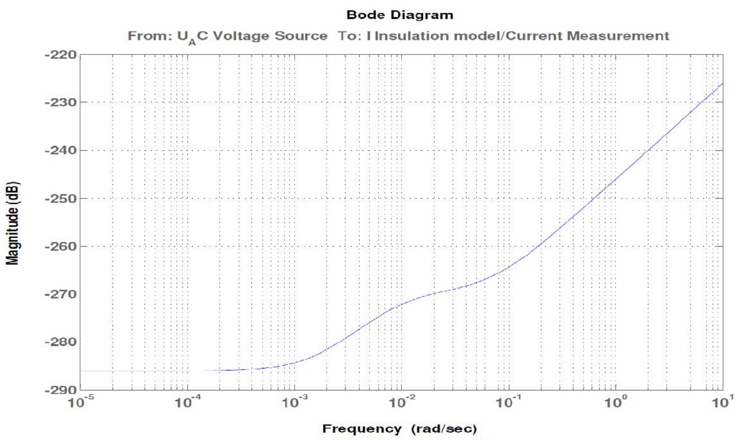

Figure 4: Magnitude of current for Insulation in Normal condition when it is dry.

From the above figure 4, it is observed in the bode diagram of polarization current, magnitude remains constant up to 10^{-4} rad/sec frequency and then gradually rises and thereafter it increases exponentially up 1rad/sec. This exponential rise in current can be attributed to capacitance of the insulation. This phenomenon is observed when the insulation is dry i.e. devoid of any moisture content.

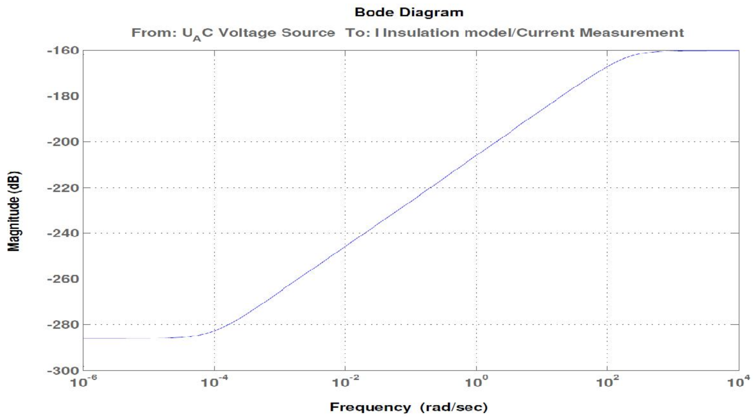

Figure 5: When Moisture ingresses in board in small portion.

From the above figure 5, it is observed that in the bode diagram of polarization current, magnitude remains constant from 10^{-6} rad/sec up to 10^{-4} rad/sec frequency and thereafter, there is a linear rise in the current up to around 10^{2} rad/sec frequency and again remains constant up to 10^{4} rad/sec. This nature of the current can be attributed to decrease in resistance due to increase in moisture.

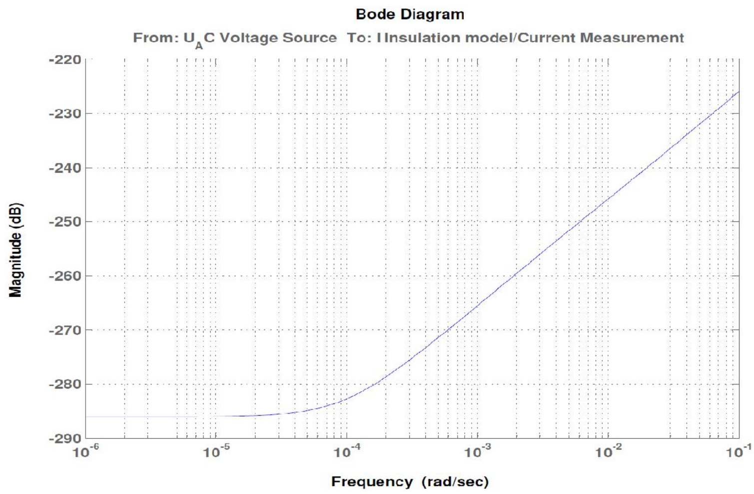

Figure 6: When Moisture ingresses in board in large portion.

From the above figure 6, it is observed that in the bode diagram of polarization current, magnitude remains constant from 10^{-6} rad/sec up to over 10^{-5} rad/sec frequency and thereafter, there is a ramp type rise in the current up to around 10^{-1} rad/sec frequency continuously. This nature of the current can be attributed to further decrease in resistance due to increase in moisture as compared to case shown in figure 5.

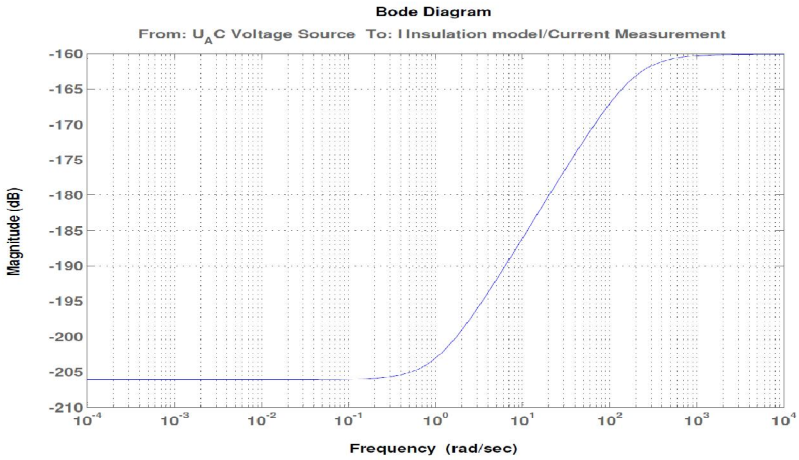

Figure 7: When Moisture ingresses in Spacers in small portion.

From the above figure 7, it is observed that in the bode diagram of the polarization current magnitude remains constant from 10^{-4} rad/sec up to 10^{-1} rad/sec frequency and thereafter, there is a linear rise in the current up to around 10^{2} rad/sec frequency and again remains constant up to 10^{4} rad/sec. In this case, moisture is considered only in spacers and other insulation is devoid of water content. In case moisture enters in small portion of spacers only, then the bode diagram of the polarization current can obtained as shown in above figure.

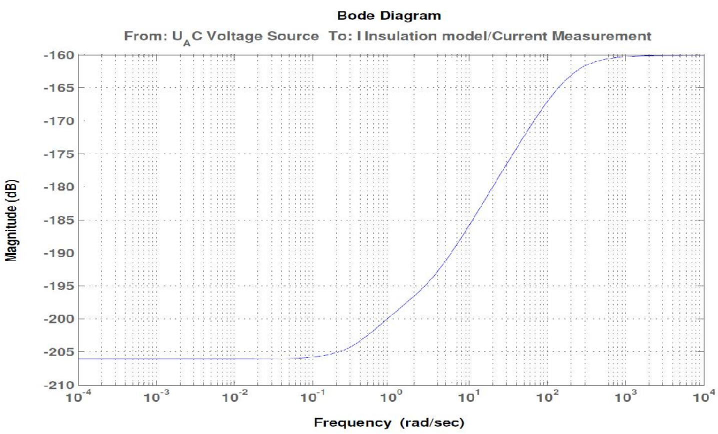

Figure 8: When Moisture ingresses in Spacers is increasing.

From the above figure 8, it is observed that in the bode diagram of the polarization current magnitude remains constant from 10^{-4} rad/sec up to 10^{-1} rad/sec frequency and thereafter, there is a linear rise in the current up to around 10^{2} rad/sec frequency and again remains constant up to 10^{4} rad/sec. In this case, small increase in moisture is considered only in spacers and the bode diagram shifts slightly from its position in the lower portion as compared to the previous case as shown in figure7.

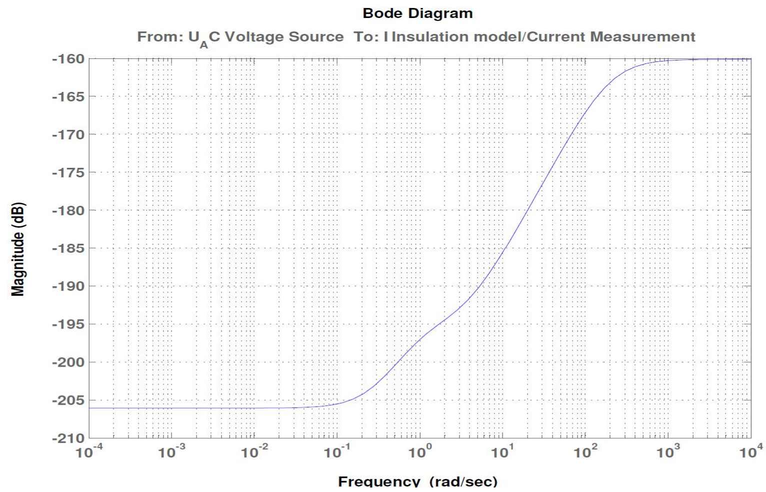

Figure 9: When Moisture ingresses in Spacers in 50% portion.

From the above figure 9, it is observed that in the bode diagram of the polarization current magnitude remains constant from 10^{-4} rad/sec up to 10^{-1} rad/sec frequency and thereafter, there is a exponential rise in the current up to around 10^{2} rad/sec frequency and again remains constant up to 10^{4} rad/sec. In this case, there is bulging in the lower part of the bode diagram and this is slightly increased as compared to that in figure 8. This is due to increase in capacitive reactance of the insulation. This can be attributed to increase in moisture content.

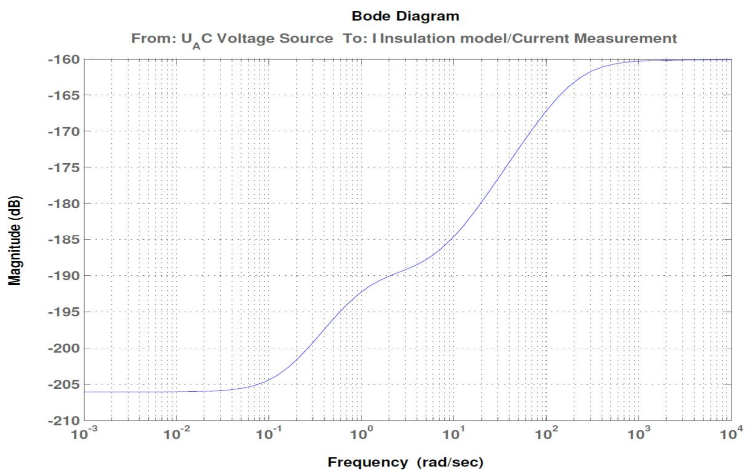

Figure 10: When Moisture ingresses in Spacers in more than 50% portion of Spacers.

From the above figure 10, it is observed that in the bode diagram of the polarization current magnitude remains constant from 10^{-3} rad/sec up to 10^{-1} rad/sec frequency and thereafter, there is a exponential rise in the current up to around 10^{3} rad/sec frequency and again remains constant up to 10^{4} rad/sec. In this case, there is bulging in the lower part of the bode diagram and this is slightly increased as compared to that in figure9. This is due to increase in capacitive reactance of the insulation. The bode curve is shifted to lower frequency region. This can be attributed to further increase in moisture content.

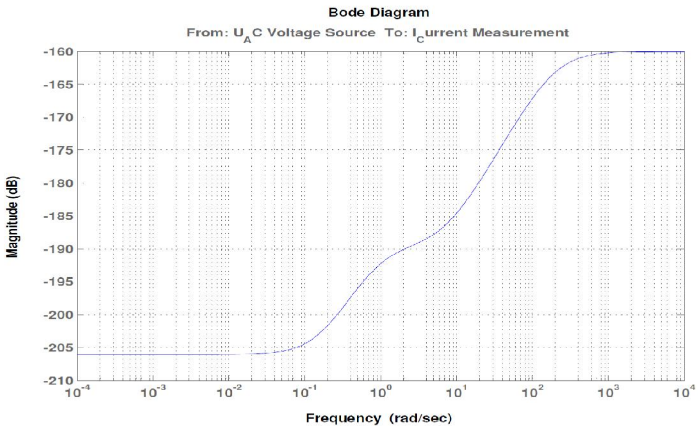

Figure 11: When Moisture ingresses in Spacers in full portion.

From the above figure 11, it is observed that in the bode diagram of the polarization current magnitude remains constant from 10^{-4} rad/sec up to 10^{-1} rad/sec frequency and thereafter, there is a exponential rise in the current up to around 10^{3} rad/sec frequency and again remains constant up to 10^{4} rad/sec. In this case, there is bulging in the lower part of the bode diagram and this is slightly increased as compared to that in figure10. This is due to increase in capacitive reactance of the insulation. The bode curve is still shifted to lower frequency region. This can be attributed to further increase in moisture content.

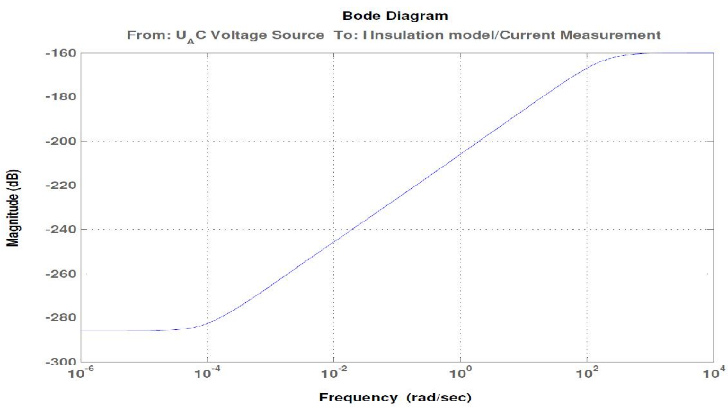

Figure 12: When Moisture ingresses in Paper in small portion.

From the above figure 12, it is observed that in the bode diagram of the polarization current magnitude remains constant from 10^{-6} rad/sec up to 10^{-4} rad/sec frequency and thereafter, there is a linear rise in the magnitude of the current with respect to frequency. Up to 10^{2} rad/sec frequency, it remains linear and then becomes constant. In this case moisture is considered present only in paper.

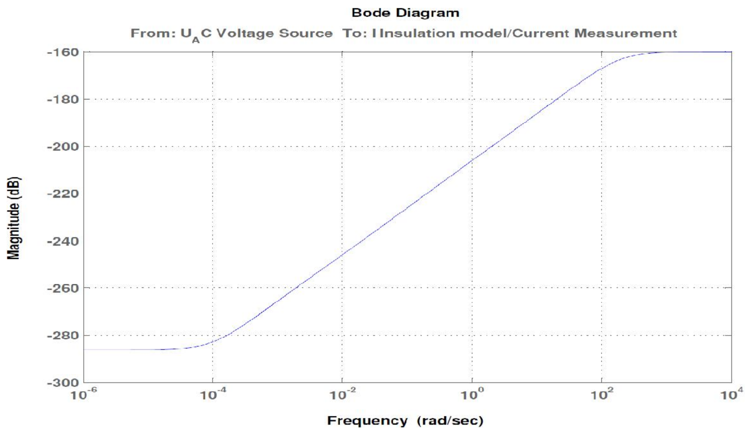

Figure 13: When Moisture ingresses in Paper in full portion.

From the above figure 13, it is observed that in the bode diagram of the polarization current magnitude remains constant from 10^{-6} rad/sec up to 10^{-4} rad/sec frequency and thereafter, there is a linear rise in the magnitude of the current with respect to frequency. Up to 10^{2} rad/sec frequency, it remains linear and then becomes constant. In this case moisture is considered present only in entire paper portion.

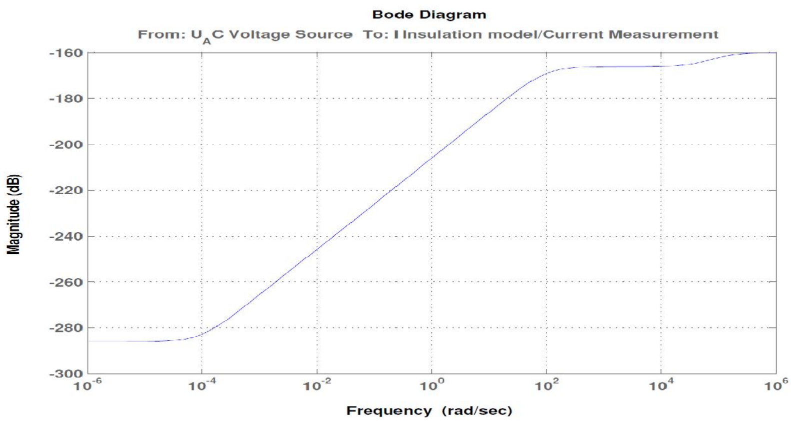

Figure 14: When Moisture ingresses in Oil-Paper in worst condition of Insulation.

From the above figure 14, it is observed that in the bode diagram of the polarization current magnitude remains constant from 10^{-6} rad/sec up to 10^{-4} rad/sec frequency and thereafter, there is a linear rise in the current up to around 10^{2} rad/sec frequency and again fluctuates up to 10^6 rad/sec. In this case, the bode curve is still shifted to lower frequency region. This can be attributed to further increase in moisture content.

Conclusion

It is observed from the results of bode diagrams of polarization currents in frequency domain there is, a clear separation of the contributions by the solid insulation, the insulating liquid is possible. It can be concluded that, the bode diagrams are shifting towards lower frequency regions if moisture content in the oil-paper insulation is more. It is also observed that, low frequencies of the order of 0.001 to 0.0001 Hz are of great importance for determining moisture content.

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