Simulation of Dissipation Factor (Tan δ) and Its Correlation to Varied Frequency Values in Transformer Insulating Oil

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Abstract--- **Dissipation factor (Tan δ) is one of the characteristics used to determine the insulation performance. Previously, measurement of the dissipation factor over frequency has not much been done to assess the condition of insulation. This project focused on finding the relationship of varied frequency to the value of tan δ of transformer insulating material and its winding. A circuit model, which describes the behaviour of the transformer's insulation system, has been drawn into MATLAB software and simulated by varying the components. A better analysis and understanding of the results is only possible with a clear understanding of the insulation system in response to frequency by using Schering Bridge. This paper then present discussions and it was found that tan δ decreases with the increased frequency value.**

Index terms---- **Dissipation Factor, Tan δ, Schering Bridge, Transformer, Frequency**

I. INTRODUCTION

A. General Concept of Dissipation Factor (tan δ)

When a sinusoidal voltage is applied across an insulator, the current through the insulator leads the voltage by less than 90^0 because of the losses in the insulator [1]. If the voltage and current are both sinusoidal, phasor diagram can be depicted as shown in Fig. 1. The loss angle δ is $90^0 - \theta$, where θ is the phase angle by which the current (I) leads the voltage (V). The loss tangent is tan δ and usually values of δ is very small, such that;

$$\delta \text{ (in radians)} \approx \tan\delta \approx \sin\delta = \cos\theta$$

In a perfect cable, the angle would be nearly zero. An increasing angle indicates an increase in the resistive current through the insulation. The greater the angle, the worse the insulation or contamination is [2].

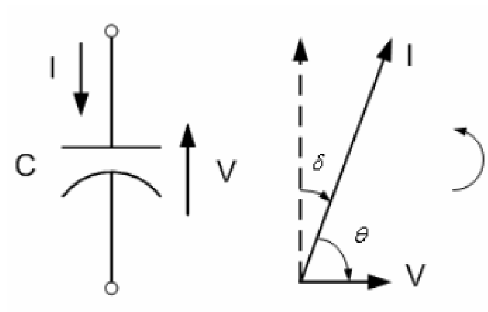

Fig. 1: Capacitor and phasor diagram, I (current) lead V (voltage) at θ^0 and δ is loss angle

1) Parallel Model

To model an insulator, parallel combination of Rp and Cp can be used to show the tan δ phenomena (Fig. 2).

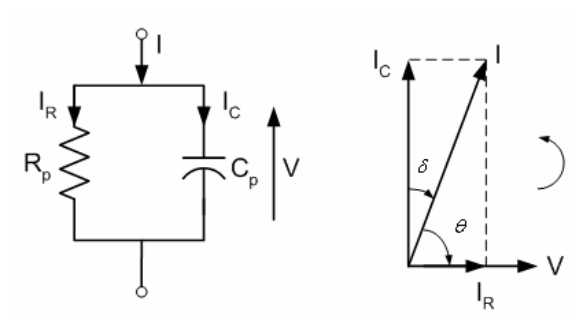

Fig. 2: Parallel RpCp model equivalent circuit and phasor diagram

$$\tan\delta = \frac{|I_R|}{|I_C|} \quad \text{…………..(1)}$$

$$\tan\delta = \frac{V/_{Rp}}{V/_{Xcp}} = \frac{V/_{Rp}}{V\omega Cp} \quad \text{…………..(2)}$$

therefore

$$\tan \delta = \frac{1}{\omega CpRp} \text{ …………(3)}$$

The parallel model has impedance, Z;

$$Z = \frac{Rp\left(\frac{1}{j\omega Cp}\right)}{Rp + \frac{1}{j\omega Cp}} \text{ ……………………(4)}$$

2) Series Model

The following is the series equivalent circuit model, RsCs (Fig. 3);

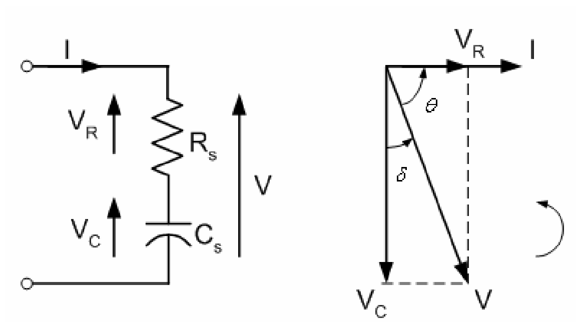

Fig. 3: Series RsCs model equivalent circuit and phasor diagram

The impedance, Z of parallel model;

$$Z = \frac{Rp\left(\frac{1}{j\omega Cp}\right)}{Rp + \frac{1}{j\omega Cp}} \text{ ……………………(5)}$$

This can be rearranged to give;

$$Z = \frac{Rp}{1+\omega^2 Cp^2 Rp^2} + \frac{1}{j\omega}\,\frac{1}{1/\omega^2 Cp^2 Rp^2} \text{ …….(6)}$$

and this is also the impedance of the equivalent series equivalent circuit shown in Figure 1.2 if;

$$Rs = \frac{Rp}{1+\omega^2 Cp^2 Rp^2} \text{ ………………….(7)}$$

and

$$Cs = Cp + \frac{1}{\omega^2 Cp^2 Rp^2} \text{ ………………..(8)}$$

For this series equivalent circuit (Figure 1.2),

$$\tan \delta = \frac{|Vp|}{|Vc|} \text{ ……………………(9)}$$

$$\tan \delta = \frac{IRs}{IXCs} = \frac{IRs}{I\frac{1}{\omega Cs}} \text{ ………………(10)}$$

therefore

$$\tan \delta = \omega CsRs \text{ ………………(11)}$$

B. Principle of Measurement of Tan δ

Measurement of capacitance (C) and dissipation factor (tan δ) are often made using A.C. bridges. Fig. 4 shows the general form of A.C. bridge.

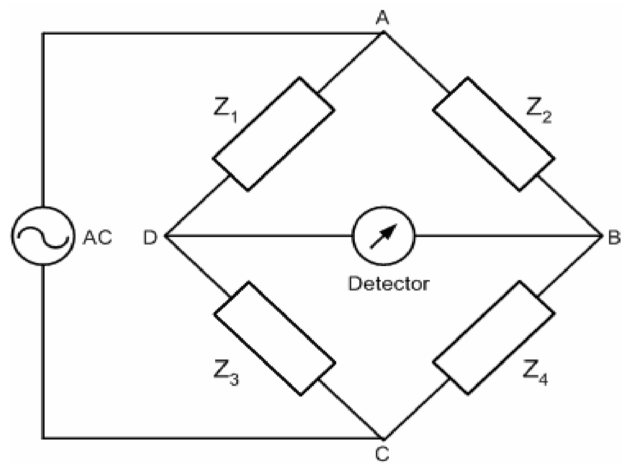

Fig. 4: General A.C. bridge circuit

The bridge circuit is balanced when the detector has zero voltages across it (and zero current through it). At balance condition;

$$V_{DB} = 0 \text{ ………………..(12)}$$

Therefore $V_{DC} = V_{BC}$ ………………(13)

and $$V_{AC}\frac{Z_3}{Z_1 + Z_{Z3}} = V_{AC}\frac{Z_4}{Z_2 + Z_4} \text{ ……………..(14)}$$

giving $$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4} \text{ or } Z_1 Z_4 = Z_2 Z_3 \text{ …………(15)}$$

Because the Z's are generally complex components, each of these equations requires both real and imaginary parts to be equal. Consequently there are always two separate conditions that must be fulfilled for balanced A.C. bridge.

C. General Principle of Schering Bridge

The circuit of the Schering bridge is shown in Fig. 5. The unknown is represented by C and r in series. Thus $Z_1 = r + 1/j\omega C$, and the unknown has loss tangent, tan δ = ωCr. C_2 is a standard capacitor. Often an air capacitor is used in this position, being loss free. To balance the bridge it is necessary to have two variable components.

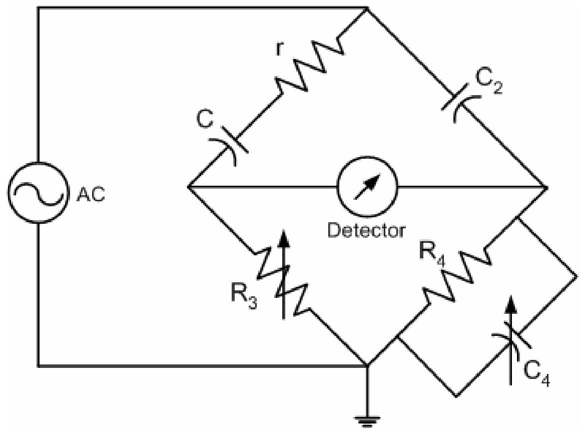

Fig. 5: Schering Bridge

Normally one of these is C_4 and the other one is either R_3 or R_4. Balance occurs when (refer Fig. 4),

$$Z_1Z_4 = Z_2Z_3$$

that is when,

$$r - (j/\omega C)\,\frac{R_4\frac{1}{j\omega C_4}}{R_4 + \frac{1}{j\omega C_4}} = \frac{R_3}{j\omega C_2} \quad \ldots\ldots\ldots\ldots(16)$$

Rearranging and separating into real and imaginary parts gives the balance condition,

$$r = R_3\frac{C_4}{C_2} \quad \text{and} \quad C = C_2\frac{R_4}{R_3}$$

Substituting in $\tan\delta = \omega Cr$ gives,

$$\tan\delta = \omega C_4 R_4 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(17)$$

S. Chattopadhyay et. al [3], have carried out the conventional Wagner - earth technique that may be used to minimise the effect of stray capacitance. But one disadvantage of this technique may be the requirement of several repeatations of bridge balance and Wagner Earth balance in each observation.

S. Kornhuber et. al [4] stated that for the evaluation of the equipment condition factors like the insulation integrity or thermal aging, various monitoring, analysis and diagnostic methods are available. In this paper, the classical method for determining the tan delta is the measurement by usage of the Schering Bridge, which is an AC-balanced bridge circuit.

J.B. Hodtium [5], this paper points out a method for analyzing the results obtained from dissipation factor tests of transformer insulation. Experimental data, obtained both from tests, extending over the past three years, and from tests of sample insulation, indicate a definite relation between resistance and capacitance, with varying conditions of temperature and moisture.

G. Eklund [6], investigated the frequency dependence of the dissipation factor for two types of capacitance standards. Results of this investigations shows the measured frequency dependence of the dissipation factor on the tested capacitors appear to be approximately linear.

II. METHODOLOGY

A. Flow Chart

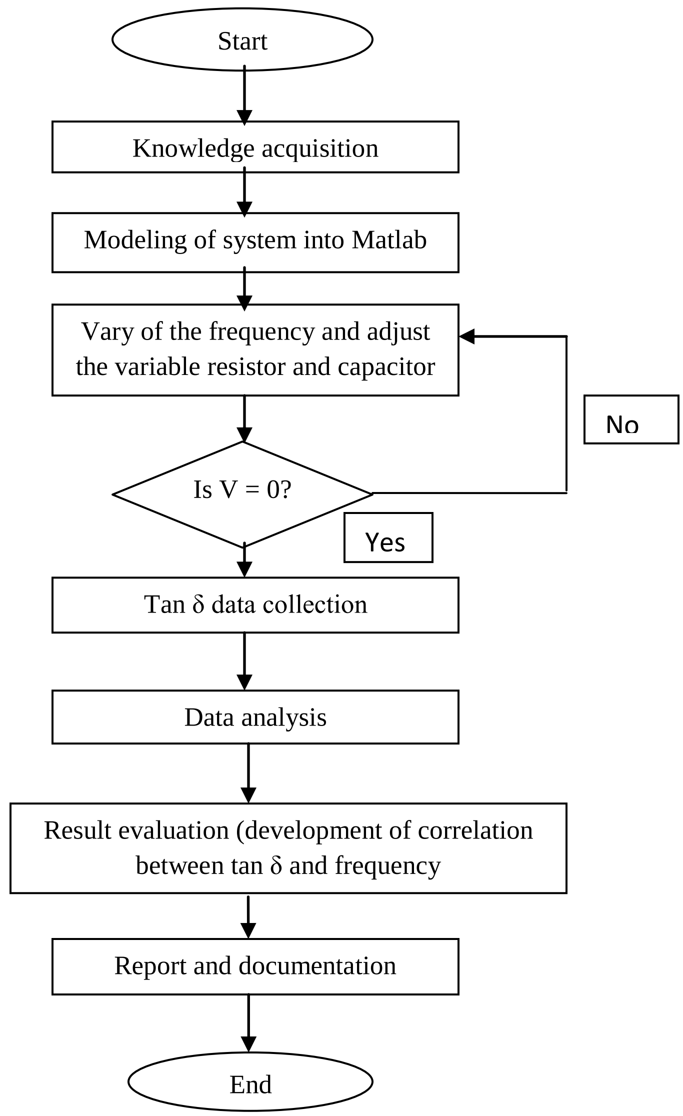

Figure 6: Schematic Diagram

B. Circuit and simulation description

1) Circuit of transformer and Schering Bridge

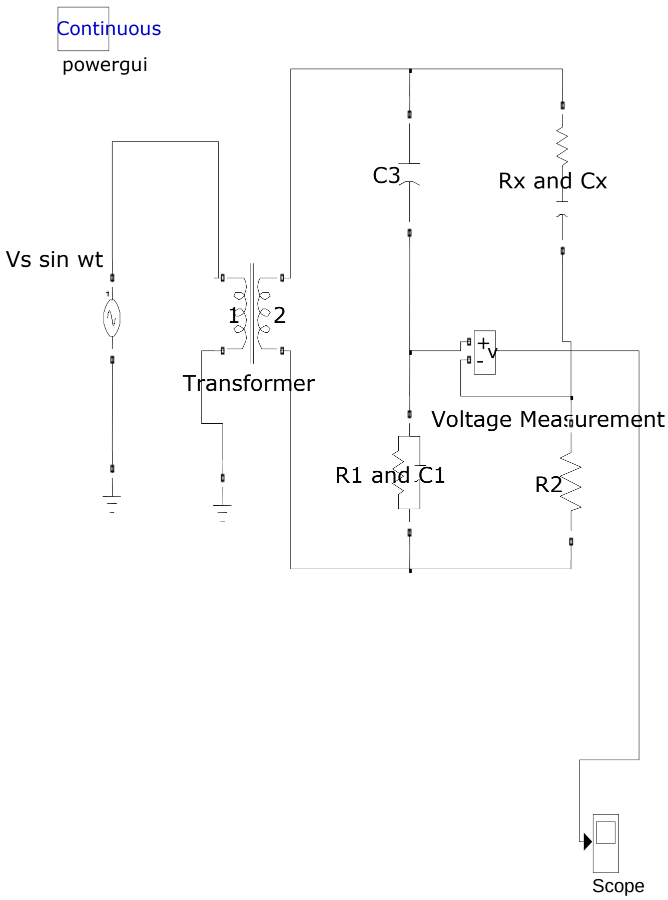

Fig. 7: Circuit model of two winding transformer

The simulation using MATLAB (Fig. 7) was conducted at 33/11 kV transformers. In the experiment, the bridge is divided into four different parts. It consists of two arms on the high voltage side, and two other different arms on the low voltage side. The first arm of the bridge consists of a sample like HV Transformer to measure its dielectric loss at fixed high voltage and varied frequency of 20, 30, 50, 80, 130, 230, 330 and 400 Hz. The bridge components of the network were the known fixed value of high voltage capacitor, variable capacitors, decade capacitors, decade resistors and potentiometers as a detector and measuring unit respectively.

1) The specification of the bridge components

R1, R2: Variable decade resistance box (1 k, 100, 10, 1 , 0.1 decades)

Cx, Rx: Transformer [6 MVA, 33/11 kV] equivalent series capacitance and resistance

C_1: Variable decade capacitor, (1, 0.1, 0.01,0.001 F decades)

Cs: Fixed standard loss free capacitors 0.5nF at 25kV DC

2) Bridge balancing

It was required to obtain maximum detector sensitivity to the bridge component being balanced, with attendant insensitivity to the corresponding quadrature component. At the balance condition of the bridge, $V_0 = 0$ as shown in Fig. 8 and 9.

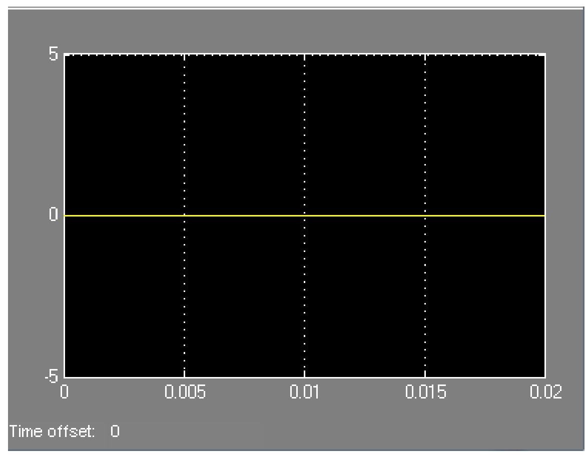

Fig. 8: Graph of V_0

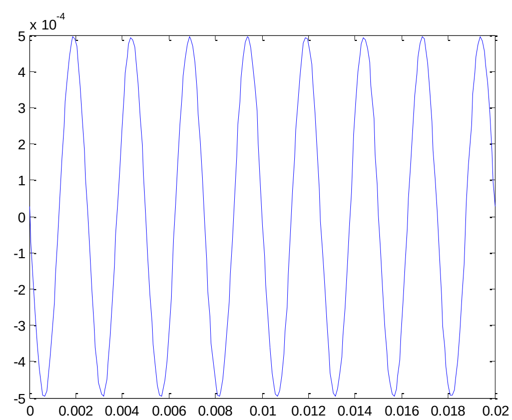

Fig. 9: Close up graph of V_0

III. RESULTS AND DISCUSSIONS

The experiment conducted on frequency ranging from 20Hz to 400Hz. Below is the graph plotted from the results obtained using series model to observe the effects of frequency.

TABLE I
SUMMARY INFORMATION OF TESTED TRANSFORMER

Min Tan δ when C_1 is varied (in rad)	Frequency (Hz)
0.00927	20
0.00864	30
0.00819	50
0.00699	80
0.00597	130
0.00447	230
0.00295	330
0.00203	400

TABLE II
AVERAGE TAN δ OVER MAX TAN δ OF TRANSFORMER INSULATION PERCENTAGE

Ave. Tan δ/Max tan δ (%)	Frequency (Hz)
13.51	20
12.65	30
11.93	50
10.75	80
9.04	130
7.55	230
5.20	330
3.12	400

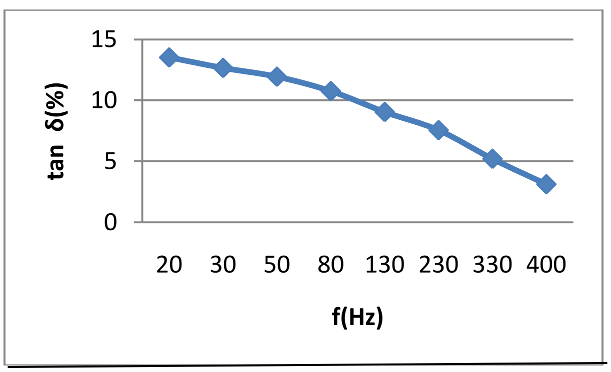

Figure 10: Tan δ vs frequency over the maximum tan δ insulation

The accuracy of the Schering Bridge depends on their component in the bridge balancing box at the low voltage side and of the functionality of the null instrument.
Since the projct is computer employed, 'rebalancing' could be carried out by manipulation of the data.To obtain optimum sensitivity the bridge arms impedances should be selected to be nearly identical, like all other bridge networks.
In this simulation, reference capacitance (0.5 nF at 25kV DC) is used as to ensure the reliability of the result.
All the values of tan δ, Rx and Cx are calculated using the formulae but all the characteristics of insulation are followed and minimum resistance for trnsformer insulation is 400 MΩ is used.

IV. CONCLUSION AND RECOMMENDATION

The value of tan δ was found to be decreasing as the frequency is varied in an increasing manner. This shows that the insulation tendency to get worse at higher frequency value. In the future, futher studies could be done by increasing the value of frequency to see the major effect of frequency on insulation condition.

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