

# Influence of supply frequency on dissipation factor measurement and stator insulation diagnosis

Cyrille CAIRONI  
C.E.J.C.A.N.  
Nancy, FRANCE  
Cyrille.caironi@neuf.fr

Bernhard FRUTH  
QUARTZTEQ  
Zurich, SWITZERLAND  
bernhard.fruth@quartzelec.com

Detlef HUMMES  
A.U.K.  
Safat, KUWAIT  
dhummes@auk.edu.kw

**Abstract**—This paper deals with influence of the supply frequency for dissipation factor measurements, mainly for tests under power frequency and low frequency. After a theoretical reminder, we present some experiments on single coils and stators of high voltage motors. Finally, we discuss the results and the desirability of choosing one or the other of these methods.

**Keywords**—dielectric; tangent delta; frequency; measurement; electrical insulation diagnostics.

## I. INTRODUCTION

Dissipation factor, or  $\tan \delta$ , is currently used for the insulation diagnostics. While the  $\tan \delta$  measurements are mainly performed at power frequency, some methods based on the frequency steps [1] and very low frequency have been developed.

The methods using very low frequency have some advantages in term of portability, power requirement, etc. but it is interesting to see the impact of the frequency on the quality of measurement and, subsequently, of the diagnostic.

This paper presents the influence of the supply frequency on tangent delta measurement. The paragraph II reminds the theoretical bases. The paragraph III presents some experiments, firstly on single coil and secondly on a stator of high voltage motor. Test are performed at 0.1 Hz and 50 Hz. The analysis of the result presents some difference, especially on the sensitivity at relaxation phenomena. These differences are discussed and we can define some interests on insulation diagnostic.

## II. THEORITICAL REMINDER

Dielectric losses are currently measured and used for electrical machines diagnostics. To perform the dielectric loss measurement, the stator is considered as a capacitor and the theory supporting these measurements is based on the complex permittivity. Of course, this capacitor is imperfect.

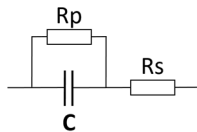


Fig. 1: Real capacitor model (without  $L_s$ )

It is schematized by the capacitance with a resistance in parallel, both in series with a resistance and an inductance, in case (fig. 1).

The real part of impedance is due to the series and parallel resistances  $R_s$  and  $R_p$ .  $R_s$  becomes important at high frequency when  $R_p$  has a dominating effect essentially at low frequency.

$R_p$  is the picture of the losses due to the dielectric polarization, the dielectric resistance, and leakage current and, also, charge redistribution phenomena. All these phenomena are involved at low frequency especially at industrial frequencies and lower. De facto we currently use the model within resistance in parallel which excludes  $R_s$  (1).

$$\underline{I} = j\omega \underline{\epsilon} C \underline{U} = \underline{I}_{R_p} + j \underline{I}_C \quad (1)$$

Due to the phenomena of relaxation and losses, the insulating materials permittivity is complex (2)

$$\underline{\epsilon} = \epsilon_0 (\epsilon_r' - j \epsilon_r'') \quad (2)$$

In this arrangement,  $\epsilon_r'$  is the component which defines the capacitive current (3) and  $\epsilon_r''$  is the component which defines the current  $I_{R_p}$  corresponding at the active losses in phase with the voltage (4).

$$\epsilon_r' = \frac{I_C}{j\omega C U} \quad (3)$$

$$\epsilon_r'' = \frac{I_{R_p}}{\omega C U} \quad (4)$$

The tangent delta, or dissipation factor is defined as (5):

$$\tan \delta = \frac{I_{R_p}}{I_C} = \frac{\epsilon_r''}{\epsilon_r'} = \frac{1}{\omega C R_p} \quad (5)$$

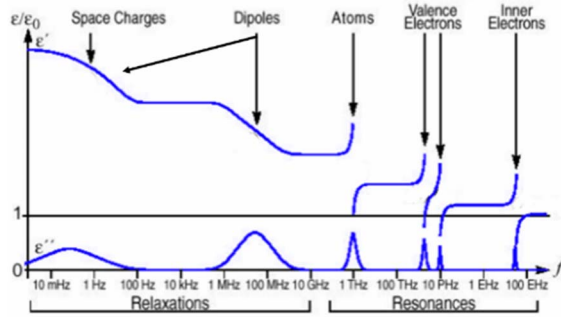


Fig. 2: effect of resonance and relaxation on permittivity (source [3])

Of course, we can see that the tangent delta is inversely proportional to the frequency. But the main interest of the low frequency is the physics of the material. The polarization and relaxation phenomena involved in dissipation of the insulation have different origins and each of them are approximately can be linked to frequency (fig. 2).

The electronic and ionic polarization have a high frequency level (around  $10^{15}$  Hz for electronic polarization) this type of polarization is not interesting for the machine diagnostic in first approach. On the other hand, the relaxation phenomena linked to dipoles, space charges and interface charges are very interesting.

These relaxation phenomena enable us to check precisely details like pollution and polymerization, which are visible at lower frequencies (less than 1 Hz) by  $\tan \delta$  analysis.

Furthermore, the temperature influence is a particularly important factor as presented on fig. 3 and fig. 4 [4] [5]. It could be an advantage but also a risk because a variation on the temperature has a bigger impact at low frequency (less than 1 Hz) than at industrial frequency.

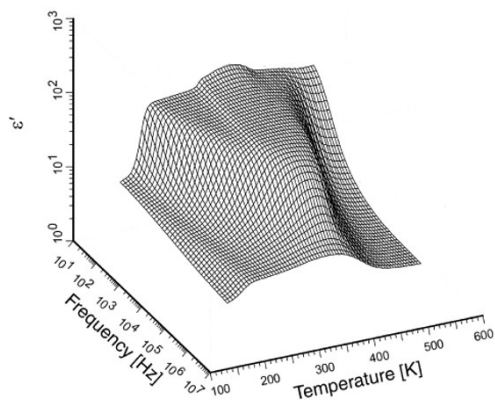


Fig. 3: Typical real part of the permittivity of porous glass versus frequency and temperature (source [4])

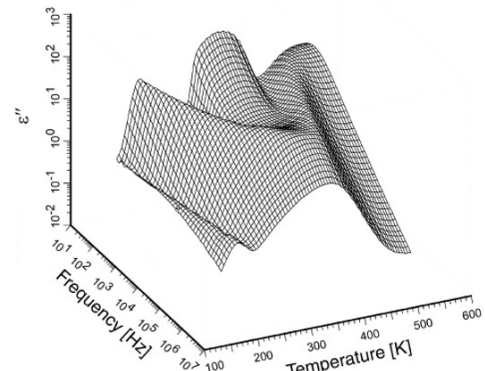


Fig. 4: Typical imaginary part of the permittivity of porous glass versus frequency and temperature (source [4])

### III. EXPERIMENTAL STUDIES

IEEE 433 [11] recommends to perform very low frequency tests at 0.1 Hz and the monitoring present on the market uses this frequency. The tests are therefore performed at frequency of 0.1 Hz and 50 Hz, in accordance to IEEE 433 and IEC 60034-27-3 [10].

#### A. Experiments on coils

$\tan \delta$  measurements were performed on sample coils (7 kV rated) in steps of 1 kV from 1 kV to 9 kV. Measurements were performed successively at 0.1 Hz and 50 Hz.

These tests show higher  $\tan \delta$  values with a 0.1 Hz frequency supply than with a 50 Hz supply (fig. 5). Therefore, these measurements confirm some explanations of the theoretical reminder, and, they are also in accordance to the related literature and different diagnostic methods proposed therein [1].

The difference of levels can be explained by a dielectric relaxation, which means a lowering of the dielectric losses with frequency, therefore 0.1 Hz is more sensitive than 50 Hz.

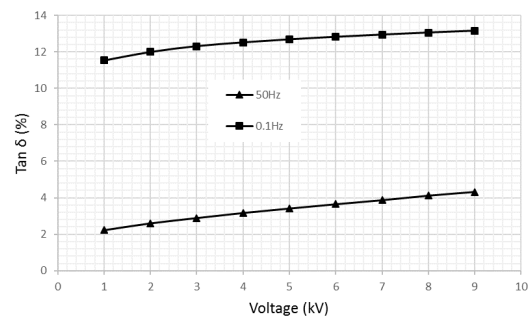


Fig. 5:  $\tan \delta$  versus voltage on single Coil

The underlying physical mechanism is usually related to the polymerization degree of the impregnating resin and interfacial polarization [5].

The voltage dependence of the losses of the sample is very similar for both frequencies. At this step, we could consider that the frequency just influences the level of  $\tan \delta$ . In fact, the influence is also on the behavior of the  $\tan \delta$  versus voltage.

### B. Experiments on stator

Measurements were performed on a 1.5 MW, 11 kV motor in accordance to IEC 60034-27-3 [10] and customer requirements.

Capacitance measurements at 50 Hz and 0.1 Hz have a similar behavior (fig. 06), on the other hand, the  $\tan \delta$  has a different shape at 50 Hz and 0.1 Hz (fig. 01)

As for a simple coil, the  $\tan \delta$  is higher at 0.1 Hz than at 50 Hz but of different shape (fig. 05). The measurement at 0.1 Hz shows a voltage dependence which is not present at 50 Hz.

This nonlinear voltage dependences of rotating machine insulation properties typically stem from partial discharges and currents in endwinding corona protection.

Evidence of the structural influence on the dielectric properties is shown in [5] as mechanical losses and dielectric losses largely coincide. This indicates the 0.1 HZ test method can provide information about e.g. brittleness, shrinkage and risk of resin cracking caused by post-polymerization

Partial discharges analysis, and especially PRPD, can complete the  $\tan \delta$  information. Of course, the  $\tan \delta$  and PRPD must be performed at the same frequency.

The patterns show solely the ionization phenomena and have to be analyzed in accordance with the  $\tan \delta$  measurements. Furthermore, the noise phenomena have shown more important using a power frequency supplies. Phenomena linked to the noise can be solved by numerical tools [7] especially in case of on-line PD monitoring.

Fig. 07 shows PRPD pattern at the network power supply and Fig. 08 shows PRPD pattern at 0.1 Hz. Despite differences, both patterns give similar information but the 0.1 Hz can be easily compared to the  $\tan \delta$ .



Fig. 6: VLF supply and measurement instrumentation on 11 kV Stator

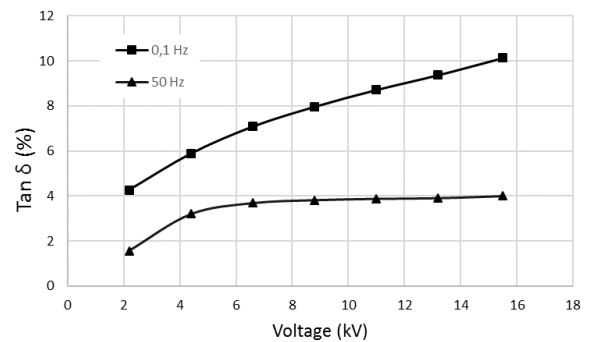


Fig. 7:  $\tan \delta$  versus voltage on 11 kV Stator

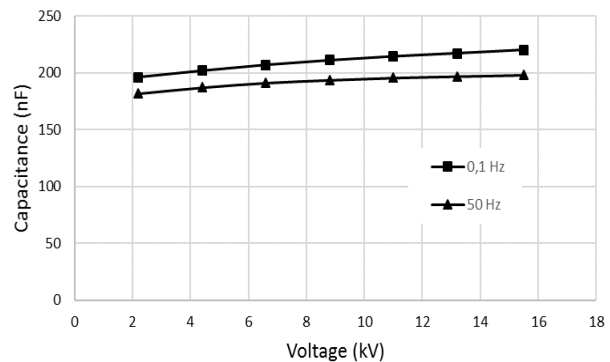


Fig. 8: capacitance versus voltage on 11 kV Stator

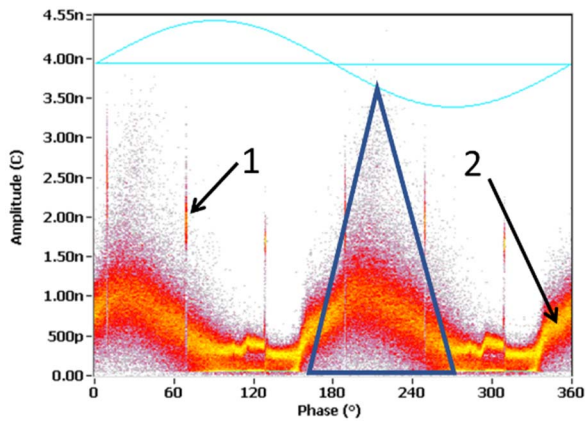


Fig. 9: PRPD at 50 Hz on 11 kV Stator (1) is commutation noise and (2) is saturation noise

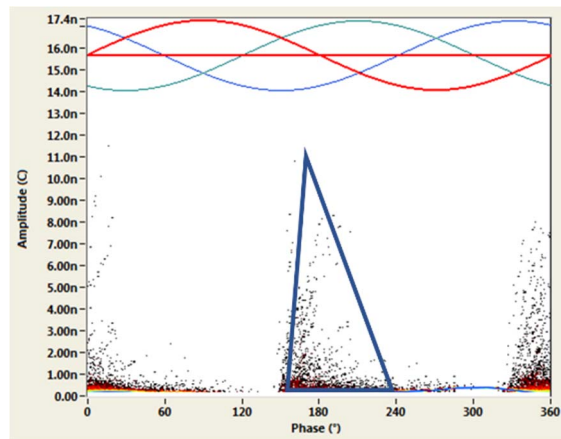


Fig. 10: PRPD at 0.1 Hz on 11 kV Stator

#### IV. EXTENSION TO THE STATOR INSULATION DIAGNOSTIC

The paragraph II confirms the theoretical reminder presented in paragraph I. Especially on complete stators,  $\tan \delta$  measurement allow to see some more phenomena at 0.1 Hz, being undetectable at 50 Hz.

In fact, the measurements at 0.1 Hz should be most efficient to the diagnostic phenomena linked to the complete insulation system [2]. Furthermore, this off-line monitoring procedure can be easily implemented and could be interesting to complement the on-line monitoring which is de facto happening at power frequency.

For example, the higher sensitivity to the structural properties of the composite material allows to more sensitively follow the resin post-polymerization.

#### V. CONCLUSION

This paper presents the influence of the supply frequency on the tangent delta measurement. It reminds the theoretical bases

before present two different cases: a coil and a stator. Measurement were performed on two frequency: 50 Hz (power frequency) and 0.1 Hz.

If similar diagnostic results, together with partial discharge measurements different defects can be detected or identified at low a power frequency.

The low frequency measurements present some advantages. Especially, the dielectric losses especially react more sensitive to structural changes;

However, while diagnostics can be improved using low frequencies, criteria must still be developed if the low frequency method should be used for acceptance testing. Indeed, most of the delta tangent delta criteria are established for power frequency tests and we have to perform further research in order to define reliable acceptance criteria.

On the practical side, the instruments used by the authors have proven easily transportable, insensitive to noise, and have very low power requirements in comparison to power frequency devices. So, that we feel that not only the enhanced diagnostic potential but also cost consideration which justify more research efforts in that field.

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