

# The Planar Layered Two-Phase System Model of Frequency Response of Insulation System for Estimating Moisture in IOCT

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In the estimate of moisture content of the Inverted-type Oil-immersed Current Transformer (IOCT) insulation system, the interfacial polarization between oil-immersed paper and semi-conductive should be considered. The classical model functions of Frequency-domain Dielectric Spectroscopy (FDS) are no longer applicable. Therefore, the planar layered two-phase system model is applied in this paper. Firstly, the FDS of oil-immersed paper and semi-conductive paper with a certain moisture content are measured using Alpha-A broadband dielectric spectrometer. Then, the model functions of H-N and amendatory H-N considering DC conductance are used to explain the FDS of oil-immersed paper and semi-conductive paper, respectively. The two model functions are integrated into the planar layered two-phase system model. In the engineering, the quantitative evaluation of moisture content of IOCT insulation system can be obtained by comparing the on-site measurement data of FDS and the numerical relationship between the characteristic parameters and the moisture content.

**Index Terms**—Planar layered two-phase system model, moisture content, Frequency Domain Spectroscopy, inverted-type oil-immersed current transformer.

## I. INTRODUCTION

THE IOCT working outdoors is a series device used in high-speed railway traction network for measurement and protection purposes. In the process of the IOCT operation, the moisture content of insulation system will increase due to the insulation aging degradation and humid air invasion. Evaluation of moisture content in oil-paper insulated IOCT is an important issue. Water significantly accelerated ageing processes of cellulose and it is also a product of cellulose ageing. Therefore, knowledge about moisture content provides important information about the condition of the insulation and it is one of the parameters useful in predicting lifetime of the IOCT.

During the last decade several new techniques based on analysis of dielectric response of the insulation were introduced for estimating moisture content in transformer insulation paper [1]. Some of these modern diagnostic methods include the Recovery Voltage Measurement (RVM), Frequency Domain Spectroscopy (FDS) and Polarization and Depolarization Current Measurements (PDC) [2]. The FDS method is widely used because of its advantage such as nondestructive testing, strong anti-interference ability, low power supply voltage, etc. [3]. The dielectric relaxation processes are usually analyzed using the model function, and the commonly used are Debye, Cole-Cole, Davidson-Cole, and Havriliak-Negami model function. They are well applicable in a single material; however, they do not take into account the effect of interfacial polarization for the IOCT insulation system containing semi-conductive paper.

Then, a planar layered two-phase system model of FDS of IOCT insulation system which describes its dielectric behavior is parameterized, and this model take the interfacial polarization into account. All parameters of this model can be simulated and further determined using the already measured FDS of oil-immersed paper and semi-conductive paper with a certain moisture content. Based on the analysis of the fitting

parameters, the characteristic parameters that quantitatively describe the moisture content of the IOCT insulation system are elected, and the numerical relationship between the elected parameters and the moisture content is obtained. In the engineering, by comparing the on-site measurement data and numerical relationship, the quantitative evaluation of moisture content of IOCT insulation system can be realized.

## II. THE INTERFACIAL POLARIZATION MECHANISM

Interfacial polarization is mainly present in heterogeneous materials with phase interfaces. Fig. 1 is the mechanism of interfacial polarization.

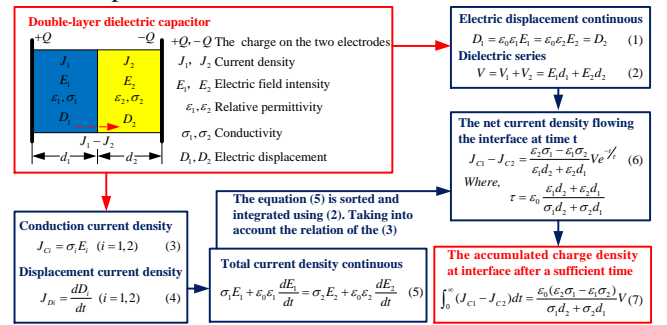


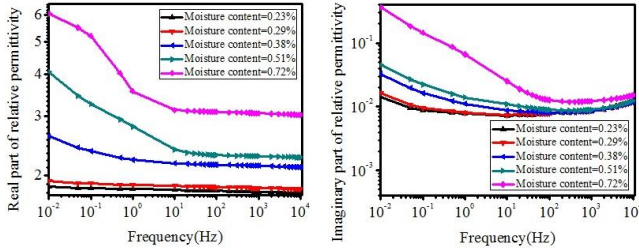
Fig. 1. The mechanism of interfacial polarization

It can be concluded that: as long as  $\epsilon_2 \sigma_1 \neq \epsilon_1 \sigma_2$ , there must be accumulation of charge at the phase interface leading to macroscopic polarization. The polarization of material is derived from the sum of all polarization contributions, but since the interfacial polarization occurs at the interface, it cannot be directly taken into account for the average polarization of each molecule. The main insulation system of IOCT used in traction network is consisted of oil-immersed insulation paper layer and inserted semi-conductive electrodes, therefore the interfacial polarization should be considered.

## III. THE MEASUREMENT OF FDS

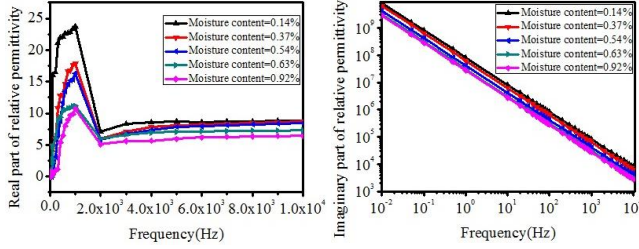
The FDS of Minsk oil-immersed paper and German semi-conductive paper were measured under different moisture

content, at 20 °C, using the Alpha-A broadband dielectric spectrometer. The measurement results are shown in Fig. 2-3.



(a) The real part (b) The imaginary part

Fig. 2. The FDS of Minsk oil-immersed paper



(a) The real part (b) The imaginary part

Fig. 3. The FDS of German semi-conductive paper

#### IV. THE PLANAR LAYERED TWO-PHASE SYSTEM MODEL OF THE IOCT INSULATION SYSTEM

The strong polarization observed in heterogeneous media is not only due to the dipolar polarization but to the macroscopic properties of charge accumulation at the boundaries between different materials. According to IOCT insulation system, there will be significant interfacial polarization at the interface between oil-immersed paper and semi-conductive paper. Therefore, it is not accurate enough to evaluate the insulating condition of the whole IOCT insulation system using only the measured FDS of oil-immersed insulation paper.

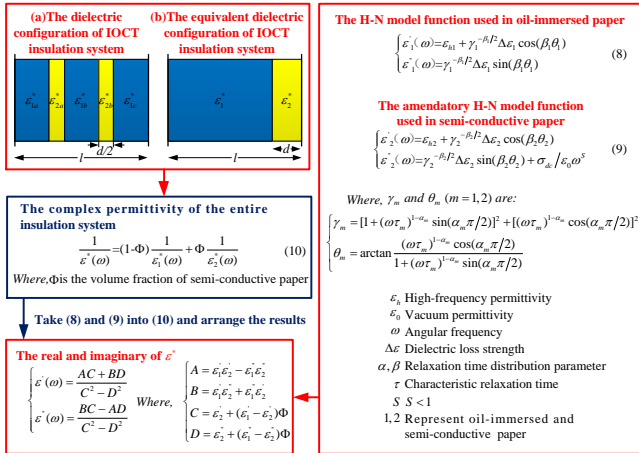


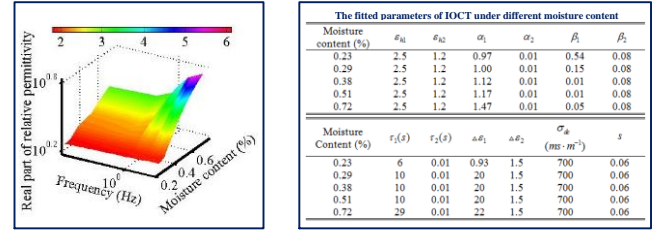
Fig. 4. The planar layered two-phase system model

Based on the experiment and theory, Haniai proved that the number of dielectric relaxation is not related to the number of the phases but the number of the phase boundaries in the heterogeneous dielectric model. In the IOCT insulation system, the oil-immersed paper with complex permittivity  $\epsilon_1^*$  is separated from two homogeneous semi-conductive papers with complex permittivity  $\epsilon_2^*$ , as shown in Fig. 4. (a). According to the M-W theory, the insulation-semiconductive-

insulation-semiconductive-insulation system can be equivalent to the dielectric configuration as shown in Fig. 4. (b).

The FDS of oil-immersed and semi-conductive paper are explained using the H-N and the amendatory H-N model functions considering the DC conductance, respectively, which are shown in Fig. 4.

Due to the Kramers-Kronig relationship between the real and imaginary parts of the relative complex permittivity, which contain the same information, the real part is studied and analyzed emphatically in this paper. The FDS of oil-immersed and semi-conductive paper with the same moisture content are obtained by the interpolation method, and the results are taken into the (10). Then the FDS of the IOCT insulation system is obtained, as shown in Fig. 5. (a)



(a) The FDS of the IOCT

(b) The parameters of the model

Fig. 5. The FDS of the IOCT insulation system and the fitted parameters

According to the FDS of the IOCT insulation system, the parameters of the planar layered two-phase system model under different moisture are fitted using the least square method. The results are shown in Fig. 5. (b)

The results show that the change of the parameters  $\alpha_1$  is the most obvious and regular, therefore, it can be chosen as the characteristic parameter to represent the moisture content  $m$  in the material. The fitted result is shown in (11).

$$\alpha_1 = 1.044m^{1.937} + 0.9175 \quad (11)$$

#### V. CONCLUSION

The FDS of the IOCT insulation system is explained using the planar layered two-phase system model. The characteristic parameter represent the humidity is chosen, and the numerical relationship between the characteristic parameter and the moisture content is obtained. In the engineering, the value of the characteristic parameter can be obtained by fitting of the on-site measurement of FDS using the planar layered two-phase system model. Then the results are compared with (11), the quantitative evaluation of the moisture content of the IOCT insulation system can be achieved. The more results and conclusions will be shown in full paper.

#### REFERENCES

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