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COMMUNICATIONS

PARTIAL DISCHARGE MEASUREMENTS ON BÖNING MODEL

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Well-known *abc* circuit, Gemant-Phillipow three capacitors model, however proved for industrial purposes, is a too simplified representation of the actual behaviour of the dielectric. This can be better described with the aid of Böning model considering during the discharge processes also the charge movement along the surface of cavities. A laboratory model of this type has been constructed and both voltage across the cavity and number of discharges were measured and compared with the theoretical assumptions.

K e y w o r d s: apparent charge, Böning model, ignition voltage, partial discharge, remanent voltage, return voltage

1 INTRODUCTION

Not only the type of cavity but even the properties of volume parts in its vicinity can affect the partial discharge processes. During discharge in the cavity, the voltage drop both across the cavity and along its interface can be observed. Well-known Gemant-Phillipow three capacitive model does not take this fact into account. For that reason Böning has introduced an improved model of cavity in dielectric which containes as much as five capacitors. Analysis of Böning circuit and partial discharge measurements on the physical model are discussed below.

2 DESCRIPTION AND ANALYSIS OF BÖNING MODEL

The equivalent Böning circuit for internal discharges is shown in Fig. 1.

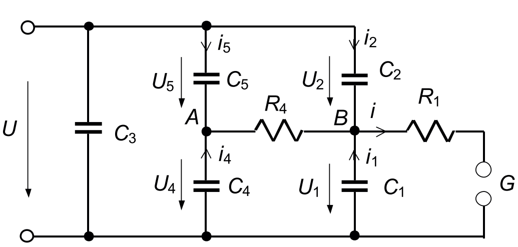

Fig. 1. Böning model – equivalent circuit of a cavity in dielectric.

The influence of close vicinity of the gas filled cavity is modelled by capacitor C_4 which is in parallel connected to capacitor C_1 modelling the gas filled cavity. Capacitor C_3 represents the sound part of the dielectric, C_2 represents the capacity of the dielectric in series with the gaseous cavity, C_5 represents the part of capacity of the dielectric. Resistor R_4 represents the resistivity of transverse discharge path between the solid dielectric and the surface of cavity, R_1 represents the resistivity of the discharge channel. Flashover gap G represents the discharge across the cavity. Since in the discharge phenomena there are many factors involved [1], these processes may be highly nonlinear.

2.1 Analysis of the model during discharge

Close before the partial discharge is going to occur ($t = 0$), the system is in a balance providing the current i_{AB} is zero and the following initial conditions can stated

$$U_1(0) = U_4(0) = U\ \frac{C_2 + C_5}{C_1 + C_4 + C_2 + C_5} = U_i,$$
$$U_2(0) = U_5(0) = U\ \frac{C_2 + C_5}{C_1 + C_4 + C_2 + C_5}, \tag{1}$$

where U_i is the *ignition voltage.*

To simplify calculations, it is possible to come out from the following assumptions

$$\begin{gathered} C_2, C_5 \ll C_3, \\ C_2 \ll C_1, \quad \text{and} \quad C_5 \ll C_4, \\ R_1 \ll R_4 \quad \text{and} \quad R_1C_1 \ll R_4C_4. \end{gathered} \tag{2}$$

Consequently currents i_5 and i_2 flowing to nodes A and B can be neglected and we get the equivalent circuit as shown in Fig. 2., with inital conditions given by (1)

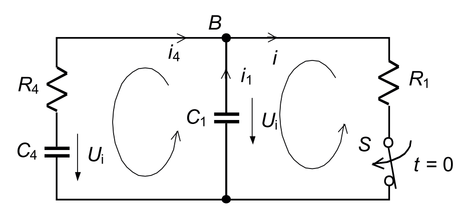

Fig. 2. Simplified circuit during the discharge, with initial conditions $U_1(0) = U_i$, $U_4(0) = U_i$.

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Provided $R_1 << R_4$, as anticipated in (2), voltages $\hat{u}_1$ and $\hat{u}_4$ can be evaluated

$$\begin{aligned}\hat{u}_1 &= U_i\left[1-\frac{1+\frac{1}{sT_4}}{(1+\frac{1}{sT_4})(1+sT_1)+\frac{R_1}{R_4}}\right]\\ &\doteq U_i\frac{s}{s+1/T_1},\\ \hat{u}_4 &= U_i\left[1-\frac{\frac{1}{sT_4}}{(1+\frac{1}{sT_4})(1+\frac{1}{sT_1})+\frac{R_1}{R_4}}\right]\\ &\doteq U_i\frac{s}{s+1/T_4},\end{aligned}\tag{3}$$

leading in domain to

$$U_1(t)=U_i\,e^{-\frac{t}{T_1}},\quad U_4(t)=U_i\,e^{-\frac{t}{T_4}},\tag{4}$$

where $T_1 = R_1C_1$ and $T_4 = R_4C_4$.

If the duration of the partial discharge Δt is supposed to be limited $\Delta t \in < 0, t_s >$, voltages across C_1 and C_4 (immediately after extinguishing the discharge in time t_s) can be expressed as

$$U_1(t_s)=U_i\,e^{-\frac{t_s}{T_1}}=U_r,\quad U_4(t_s)=U_i\,e^{-\frac{t_s}{T_4}},\tag{5}$$

where U_r we call the *remanent voltage.*

2.2 Analysis of the model after discharge

In time $t = t_s$ the process of discharging is finished and circuit switch S (see Fig. 2) is opened. Voltages across capacitors C_1 and C_4 are as (6) and capacitor C_1 starts to charge again (through C_4 and R_4). Considering (2), currents i_2 and i_5 can be neglected and it is possible to suppose that $U_4(t_s) \gg U_r \approx 0$.

When analysing the voltage across C_1 in time $t \geq t_s$, it is possible to come out from equivalent circuit shown in Fig. 3 with the following initial conditions: $t = t_s$, $U_4 = U_4(t_s)$ a $U_1 = U_r = 0$.

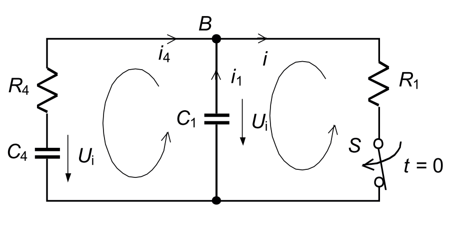

Fig. 3. Simplified circuit after the discharge

After finishing the partial discharge the voltage across capacitor C_1 is

$$\hat{u}_1=\frac{U_4(t_s)}{1+\frac{C_1}{C_4}}\cdot\frac{1}{1+s\,\left(\frac{R_4C_4}{1+C_4/C_1}\right)},\tag{6}$$

what in time domain gives

$$U_1(t)=U_R\left(1-e^{-\frac{t-t_s}{T}}\right),\tag{7}$$

where $T=\frac{R_4C_4}{1+C_4/C_1}$ and $U_R=\frac{U_4(t_s)}{1+C_1/C_4}$ is defined as the *return voltage.*

2.3 Behaviour of the voltage across cavity during the discharge

Voltage U_1 across capacitor C_1 (that models the cavity), behaves during the partial discharge process as follows (see Fig. 4a):

- in time $t \in \langle 0, t_s\rangle$ it drops from the ignition voltage U_i to the remanent voltage U_r with the time constant of $T_1 = R_1C_1$; in simplified case the remanent voltage $U_r = 0$,
- in time $t > t_s$, it rises from the value of $U_r = 0$ to a steady value of return voltage U_R with the time constant of $T=\frac{R_4C_4}{1+C_4/C_1}$.

All this process lasts only a few microseconds. At macroscopic observations of voltage relaxations U_1 across capacitor C_1, this fast transient response is reflected in the presence of return voltage $U_R > 0$ (see Fig. 4b). That is the difference between Böning model and Gemant-Phillipow model, where $U_R = 0$ (see Fig. 4c).

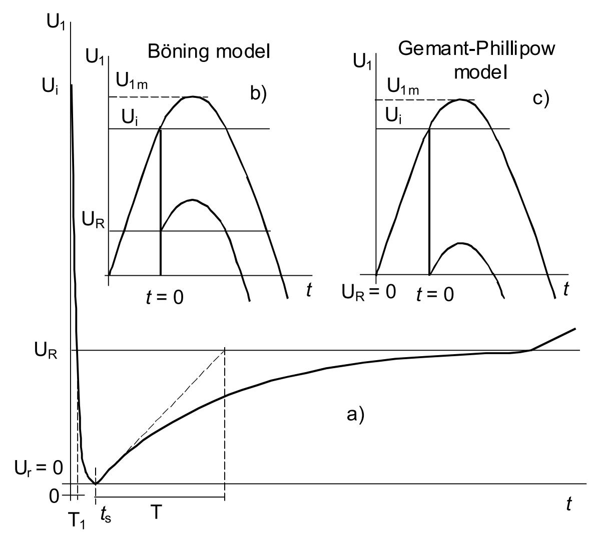

Fig. 4. Voltage U_1 across the capacitor C_1 during partial discharge.

The ratio of the return to ignition voltage

$$p=\frac{U_R}{U_i}=\frac{e^{-t_s/T_4}}{1+\frac{C_1}{C_4}}.\tag{8}$$

can be simplified considering if t_s/T_4 is small enough, giving

$$p=\frac{1}{1+\frac{C_1}{C_4}}.\tag{9}$$

Böning gives the relation between p and the number of discharges n in a one cycle of testing voltage as follows [2]

$$n=4\cdot\frac{\frac{U_{1m}}{U_i}-1}{1-p},\tag{10}$$

where U_{1m} is maximum value of the voltage U_1 across the capacitor C_1 and U_i is ignition voltage of the cavity.

3 PARTIAL DISCHARGES MEASURED ON THE PHYSICAL MODEL

To verify theoretical assumptions with practical measurements, the physical model of cavity in solid insulation, created from real capacitors and resistors, has been constructed, see Fig. 5.

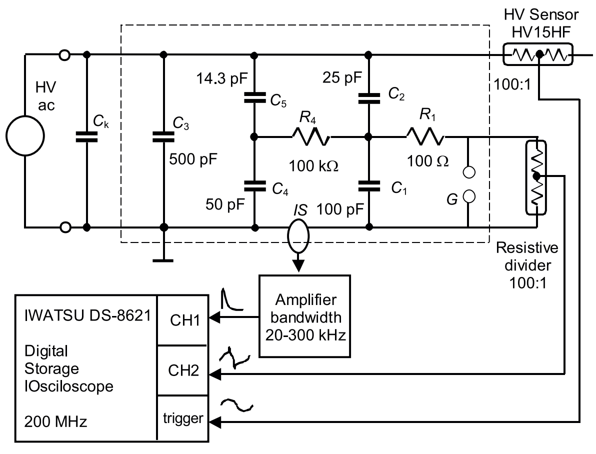

Fig. 5. Partial discharge sensing on Böning model.

Partial discharge signal was sensed using inductive sensor IS. After processing of the signal by amplifier, it was recorded into the internal memory of the digital storage oscilloscope. Signal from the resistive voltage divider (division ratio 100 : 1), parallely connected to to the flashover sphere gap G and capacitor C_1 (signal of voltage relaxations across the cavity), was recorded into the oscilloscope as well. Moreover, high voltage signal was sensed by high voltage sensor HV15HF (division ratio 1 000 : 1) and it was connected to the trigger of the oscilloscope. Testing voltage was increasing from 3 kV to 6 kV with the voltage step of 500 V. Distance between spheres of the flashover gap was 0,05 mm.

3.1 Voltage relaxations – results

Partial discharge signals picked up from the inductive sensor IS and the voltage relaxations across the capacitor C_1 at the testing voltages of 3 kV, 4 kV, 5 kV and 6 kV are shown in Fig.6.

Signal of voltage relaxations across C_1 due to discharges between the sphere gap G is drawn by full line, signal of voltage across C_1 provided no partial discharge occurs is drawn by dashed line. U_{i+} is an *ignition voltage* of the flashover sphere gap in the positive half cycle and U_{i-} is an *ignition voltage* of the flashover sphere gap in the negative half cycle of the voltage U_1 (voltage across the capacitor C_1).

4 CONCLUSION

Obtained results have shown that physical model properly models voltage relaxations across the cavity and the number of partial discharges changes on dependence of the level of testing voltage as well.

From the results it is clear that Böning model explains the voltage relaxations across the cavity during partial

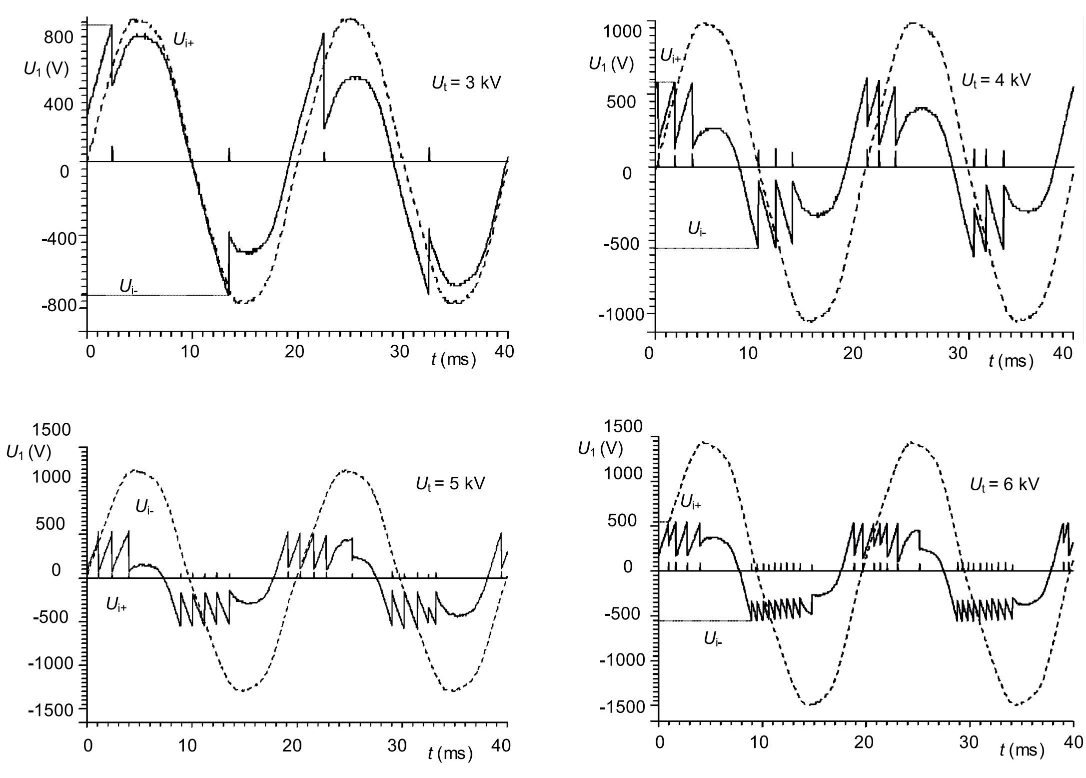

Fig. 6. Signals picked up at voltages of 3 to 6 kV.

discharge much better than simple 3-capacitive Gemant-Phillipow model because of considering return voltage U_R.

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