Some Problems of the Partial Discharge Burning Time

Nikolay V. Kinsht[a] and Marat A. Katz
Electrophysics and Power Lab, the Institute of Automation and Control Processes
Far East Branch of Russian Academy of Science, Vladivostok, Russia

[a]E-mail : kin@dvo.ru

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The problem of the partial discharge (PD) extinction is investigated. The transient process takes place in a small spherical inclusion which is located in the dielectric. Both the losses caused by polarization and ohmic losses as the dielectric parameters are taken into account. From the inclusion standpoint the dielectric is considered as an active two-pole element (equivalent generator) and inclusion represents by own current-voltage curve. PD extinction voltage was shown to depend on the polarization loss tangent.

Keywords : Dielectric inclusion, Partial discharge extinction, Transient, Current-voltage curve

1. INTRODUCTION STATEMENT OF A PROBLEM

We have continuous homogeneous imperfect dielectric in which there are polarizing and ohmic losses. There is a small spherical inclusion in the dielectric. The dielectric is influenced by the external homogeneous electric field E_e, resulting in electrostatic intensity E inside inclusion. The rupture (partial discharge - PD) takes place inside the inclusion at the moment when intensity achieves the value $E_r < E$. The process has relaxation character. The PD process was studied by many researchers in detail[1]; there appeared the necessity to reveal some new interrelations between parameters of the process. At the same time, any evidence concerning the extinction voltage is not distinct enough. It is noticed only, that the value of it makes (0.1 ... 0.9) from the PD firing voltage, or, in recalculation for the period the burning PD makes (2.3 ... 0.1)τ, i.e. a disorder in this matter ranges up to 23 times. We shall attempt to take into account both the characteristics of the imperfect dielectric and the nonlinear current-voltage curve of the PD.

To solve the above mentioned problem we apply circuit and electromagnetic field theories.

The analysis of a problem it is made in the electrostatic approximation.

2. MODEL OF THE IMPERFECT DIELECTRIC

Dielectric space around of inclusion is simulated by the rectangular uniform three-dimensional grid, one of it's axes being directed along external field E_e (Fig. 1). The size of a grid cell is defined by radius of inclusion a. Let's accept that the element of grid model $Y(s)$ has the minimal equivalent circuit with the lumped parameters (Fig. 2), taking into account the losses caused by polarization (R_1) and ohmic losses (R_2) separately.

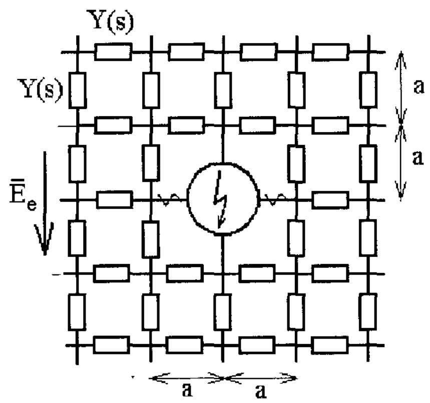

Fig. 1. The grid model of the dielectric with inclusion.

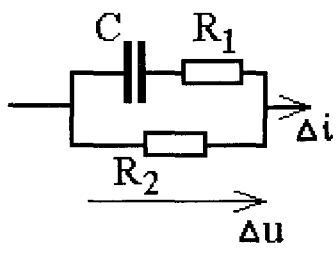

Fig. 2. The element of the grid model.

Passing on to Laplace transform we shall write down relationships:

$\Delta i\ (s) = \Delta u(s)\ Y(s),$

$Y(s) = [s\ C\ (R_1/R_2 + 1) + 1/R_2]]\ /(s\ C\ R_1 + 1).$

The table of symbols corresponds to Fig. 2.

As the element of grid model models elementary volume in length a and cross-section section a^2, we shall obtain:

$\Delta u = a\ E;\ \ \Delta i = a^2\ J,\ R_1 = 1/\gamma a;\ \ R_2 = \rho / a;\ \ C = a\ \varepsilon.$

Here they are symbolized as,

ε - dielectric permeability of dielectric,

γ - its specific conductivity,

J - current density,

E - intensity of the electric field,

ρ – specific resistance imperfect dielectric, reflecting presence of polarizing losses.

Now it is possible to pass on to point estimations of the electric field on the basis of dielectric parameters and receive a connection between a current density $J(s)$ and intensity of an electric field $E(s)$ for imperfect dielectric taking into consideration the account of both ohmic, and polarizing losses:

$\Gamma(s) = J(s)\ /\ E(s) =$

$= [s\ \varepsilon\ (\rho\ \gamma + 1) + \gamma]]\ /(s\ \varepsilon\ \rho + 1) = Y(s)\ /\ a$

We shall note, that actually $R_2 / R_1 \cong 10^6 \ldots 10^8$, and parameter R_2 does not affect quick-flow PD processes. So, for quick-flow PD processes the grid transforms to state shown in Fig. 3 and the formula for $\Gamma(s)$ changes:

$\Gamma_q(s) = [s\ \varepsilon\ (\rho\ \gamma + 1)\ /(s\ \varepsilon\ \rho + 1).$

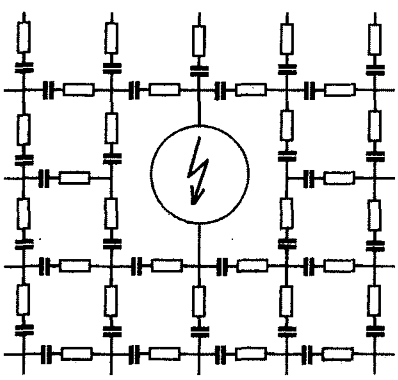

Fig. 3. Quick-flow grid.

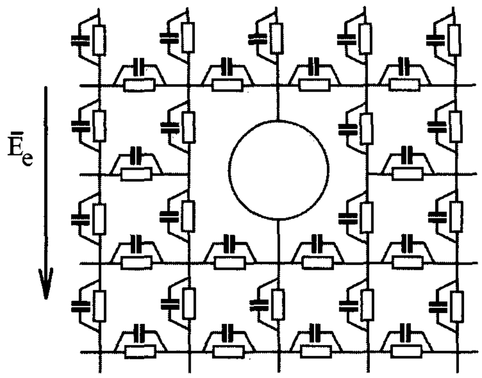

Fig. 4. Grid for insulation charge.

Now we switch to the description of the slow processes of the insulation charge; in conjunction the external field intensity E_e it creates the forced component of the potential distribution of the electric field. The time constant of an establishment of the forced mode is great enough. Resistors of grid R_2 and external field E_e also provide initial conditions to quick-flow PD processes through inclusion – the charges of the grid capacitors as shown on fig.4 and formula for $\Gamma(s)$ changes for the simplest tradition state:

$\Gamma_s(s) = s\ \varepsilon + \gamma.$

3. INCLUSION MODEL

The inclusion model in the grid is represented as a multipole element (to be more precise, in the three-dimensional grid - as a six-pole element). As is mentioned above the vertical grid axis is directed along an external field and the ideal discharge is considered to occurs along this axis. In view of axial symmetry of processes, it is possible to break off the horizontal connections of the six-pole element (marked on Fig. 1) and present inclusion by a two-pole element (as shows on Fig. 3, 4). Now it is possible to apply the theorem of the equivalent source to the analysis of processes. We shall pay attention that parameters of the equivalent source are invariant concerning the properties the inclusion as the two-pole element.

Now it is possible to apply Tevenen's theorem to the analysis of processes. We shall pay attention that parameters of the equivalent generator are invariant concerning properties of inclusion.

4. MEDIUM PARAMETERS AS AN EQUIVALENT SOURCE

We will turn to a matter on input impedance $Z_{eq}(s)$. Actually the question is of input impedance of the infinite

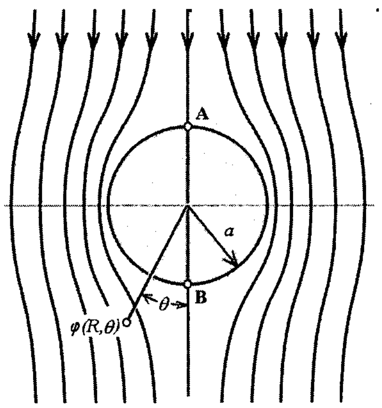

Fig. 5. The illustration of "open circuit" mode.

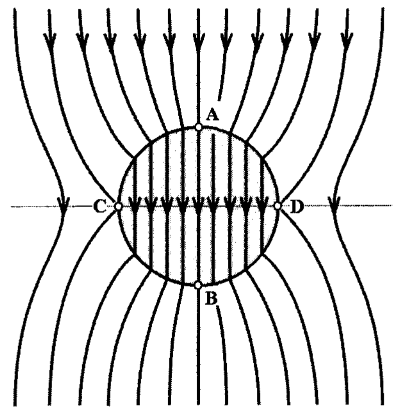

Fig. 6. The illustration of "short circuit" mode.

homogeneous medium which is external with respect to inclusion in which there was a PD. For this purpose we apply a method of open circuit and short circuit according to Tevenen's theorem and use the analysis of the homogeneous electric field E_e indignant of sphere of radius *a*.

Generally, dependence of potential $\varphi(R,\ \theta)$ from coordinates and specific conductivity of spherical inclusion γ_i and specific conductivity of an environment γ_e is given by expression[1]:

$$\varphi = \begin{cases} -\dfrac{3\gamma_e}{\gamma_i + 2\gamma_e}\ E_e\ R\cos\theta & R \le a \\ -\left[1 - \dfrac{a^3}{R^3}\left(\dfrac{\gamma_i - \gamma_e}{\gamma_i + 2\gamma_e}\right)\right] E_e\ R\cos\theta & R \ge a \end{cases}$$

Here it is considered, that environment possesses a generalized operational conductivity $\gamma_e = \Gamma(s)$

To mode of "open circuit" here corresponds value specific conductivity of a sphere material $\gamma_i = 0$, and the picture of lines of a current is represented in Fig. 5.

We shall receive the open circuit voltage as:

$$U_0(s) = \varphi_A - \varphi_B = 3a\ E_e(s)$$

On the other hand, to a mode of "short circuit" there corresponds indefinitely great value of specific conductivity of a material of sphere $\gamma_i = \infty$. The picture of lines of current will become, as shown in Fig. 6.

At short circuit intensity inside sphere is zero, also it is necessary to determine the total current flows through sphere (through surface CD as shown on Fig.6); for this purpose we shall take advantage of expression normal vector component (to a sphere surface) of the external intensity of the field (as shown on Fig.7):

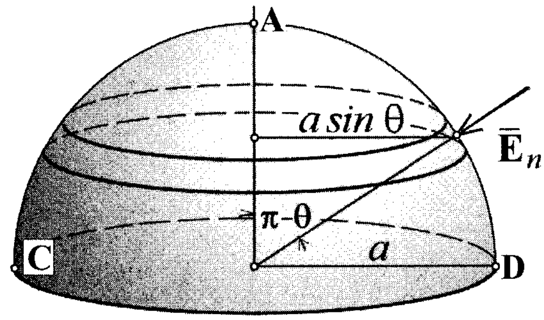

Fig. 7. The hemisphere for analysis of the inclusion "short-cut".

$$E_{ne}(s) = E_e\cos\theta\ (2a^3/R^3 + 1).$$

Operational current density on the surface:

$$J(s) = E_e(s)\ \Gamma(s) = 3\ E_e\cos\theta\ \Gamma(s).$$

Having allocated, for an any corner θ, an elementary spherical zone $ad\theta$ which have radius $a\sin\theta$ and having integrated on a hemisphere (for example, top hemisphere, as shows Fig. 5), we calculate the current of short circuit flows through inclusion:

$$I_s(s) = 3\ \pi\ a^2\ E_0(s)\ \Gamma(s).$$

Thus, input impedance of the equivalent source is calculated as:

$$Z_{eq}(s) = U_x(s)/I_\kappa(s) = (\pi\ a\ \Gamma(s))^{-1} =$$

$$= [s\ \varepsilon\ (\rho\ \gamma + 1) + \gamma]]\ /\ [\pi\ a\ (s\ \varepsilon\ \rho + 1)].$$

The voltage of an equivalent source at the moment of the discharge start in the inclusion will be equal to the voltage of discharge firing U_f.

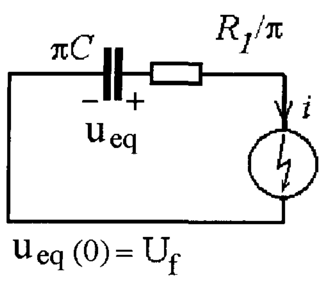

Fig. 8. Simplified circuit for transient analysis.

Now it is possible to make calculation of the transient in the inclusion considered as a two-pole, the circuit represented on Fig. 8.

As already noted, at the description quick-flow process it is possible to exclude resistor R_2 from the further consideration; besides, taking into account that the capacitor C series connects with a source. For calculation of the PD current finally we shall use the circuit Fig. 7.

5. CURRENT-VOLTAGE CURVE (CVC) OF THE INCLUSION

To calculation of transient it is necessary to use nonlinear current-voltage curve of the PD. As is known, at a stage of maintenance of the discharge its CVC has hyperbolic character (a dotted line on Fig. 9).

During the first moment of breakdown the electric mode is set by point 2. It is a common point of the CVC and straight line 12. Line 12 is starting with a point (U_f, 0) on a plane CVC and having an inclination determined by resistance R_1, namely - $R_1 = \pi\, k\, tg\alpha$. Thus the voltage on burning PD U_b is small enough.

The piecewise-linear approximation of the PD CVC is made by three pieces of straight lines. The first piece 01 reflects PD absence up to firing. The second of them is piece 13 which are starting with a point (U_f, 0) on the voltage axis and directed on a tangent to hyperbolic CVC. The inclination corner of tangent sets differential (negative) resistance Rd of the burning PD. The third of them is piece 32, parallel to current axis, it distances from it on value U_b - the voltage on the PD burning.

PD process of the condenser of an equivalent two-pole can be represented by sliding of a voltage of the equivalent source U_{eq} downwards from value U_f and, accordingly, parallel moving of a loading straight line 12. This process will continue proceed, until the loading straight line does not reach the point of break 3 on the inclusion CVC. During this moment will take place PD extinction, the current will be step-wise stopped, the working point appears on piece 01, and the inclusion voltage will be step-wise increase to value U_{ex} and PD extinction voltage determined by limiting position of a loading straight line 32.

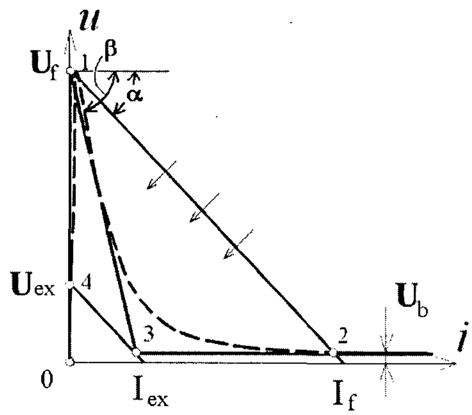

Fig. 9. The current-voltage curve of the inclusion for transient analysis.

6. TRANSIENT PROCESS OF THE PD BURNING

Thus, the discharging transient of the charged insulation through inclusion will be described by usual expressions.

It is easy to calculate transient time constant τ, PD current i, firing current of PD I_f , the voltage of the equivalent source u_{eq} , extinction current of PD I_{ex} , PD extinction voltage U_{ex} , PD time T_{PD}[2]. From what has been said it follows, that the extinction voltage obviously depends on a polarizing component of the dissipation factor:

$$tg\,\delta = \omega R_1 C = \omega\,\rho\varepsilon$$

Of special interest is to pay attention to the PD extinction voltage; it is the important parameter determining frequency of PD recurrence. The charge of insulation process begins with voltage U_{ex}, as the forced value of process acts $U_o=3aE_e$. The inclination voltage u_i is modified with rate, depends on low-frequency constant of time $\tau_2 = R_2C$:

$$u_i = U_{ex} + (U_0 - U_{ex})\,exp(- t/\tau_2),$$

and time of PD recurrence T shows as:

$$T = \tau_2\,ln[(U_0 - U_{ex})/(U_f - U_{ex})].$$

7. INTERRELATION OF PROCESS PARAMETERS

Thus, the logic chain of interrelation of process parameters is traced as shown: increasing of the polarizing losses (specific resistance ρ), increasing in the polarizing component of the tg δ, deceleration of the PD rate (increase in time constant τ), reduction current of PD firing I_f, increasing of PD extinction voltage U_{ex}, increasing frequency of PD recurrence.

The expressions obtained are most likely to have not settlement character, and on a formal basis show qualitative interrelations between process parameters.

ACKNOWLEDGMENTS

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