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RELATIONSHIP BETWEEN PARTIAL DISCHARGE (PD) APPARENT CHARGE AND AREA SUBJECTED TO THE DISCHARGE IN AN ARRANGEMENT METAL-GASEOUS GAP - DIELECTRIC

1. Introduction

Studies of problems associated with partial discharges are of multidirectional character. In most cases the determination of the intensity is required and almost each quantity, describing the PD intensity, requires in turn precise calculation of the apparent charge. It follows from the theoretical considerations, based on a three-capacitance equivalent circuit, that the apparent charge is not affected by the instantaneous voltage and it should be constant for a given max. voltage, applied to an arrangement under investigation. However, for almost every real either model or practical system, contrary to theory, the apparent charges vary for individual partial discharges. To get a reliable picture it is in general necessary to measure a spectrum of the apparent charges [2].

The presented here studies try to explain what affects apparent charge level. The tested model consisted of an arrangement of metal - gaseous gap - dielectric and the measurements were limited to the first PD.

The selection of this metal - gaseous gap - dielectric arrangement was because of its wide practical application in finding quantities for the assessment of resistance of synthetic dielectrics to the PDs. For proper selection of such assessment indicators, a precise determination of the discharge intensity and through knowledge of its relation with the phenomena in a gaseous gap and on the dielectric is essential.

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2. Test circuit

The test circuit is illustrated in Fig. 1. It consists of a highvoltage hemispherical electrode, fixed to a micrometer screw for precise setting of the gap, and housed in a lightproof enclosure which also allows the internal pressure to be varied. The polypropylene foil samples had been washed with ethyl alcohol and then stored in a desiccator for 48 hours.

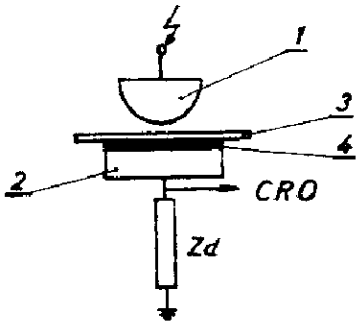

Fig.1. Arrangement of electrodes for PD tests
1-upper electrode, stainless steel, 8 mm dia, 2-lower, flat plate electrode, 40 mm dia, 3-polypropylene foil, 12 µm thick, 4-photographic film, 27 DIN, 0,22 mm thick, Z_d-detection impedance

The measurements were carried out in air of temperature of 18 to 20°C relative humidity of 40 to 50% and at pressures of 101,3 kPa and 50,6 kPa. For each measurement a new sample was prepared. D.c. voltage pulses of high steepness and positive and negative polarities were used. The application time was below 0,25 µs and the voltage was removed at the moment of occurance of the first PD.

The following quantities have been recorded:

- applied voltage
- apparent charge
- Lichtenberg's figure i.e. trace of a discharge on the insulation surface
- time lag of the PD inception i.e. time interval between the instant of the voltage application and the first PD.

Fig.2 illustrates the measuring circuit. The measurements were performed at three positive and three negative pulses for each of the following gaps: 0,2 mm, 0,4 mm and 0,6 mm and for each of the following two pressures: 101,3 kPa and 50,6 kPa.

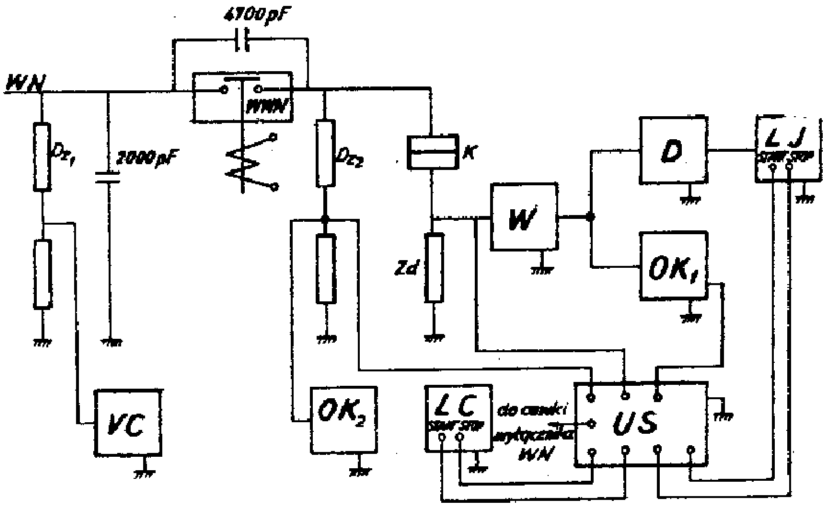

Fig 2. Test circuit
D_{z1}, D_{z2}- voltage dividers, VC-digital voltmeter OK_1, OK_2-oscillographs with memory, K-test module, WWN-H.V. circuit-breaker, Zd-detection impedance, W-amplifier, D-discriminator, LJ-voltage impulse counter, LC-time counter, US-control circuit

The applied voltage levels were so selected as to get the voltage across the air gap equal to 110%, 120% and 130% of the flash-over voltage from the Paschen curve. It was assumed that the tested arrangement represents a uniform field, an assumption quite acceptable, as the diameter of the high-voltage electrode, equal to 8 mm, considerably exceeded the applied gaps.

3. Test results

Average values from 12 tests have been listed in Tables 1 and 2. The results have been obtained by applying the Student's distribution for a confidence level of 95%. The diameters of the Lichtenberg figures have been measured with the ten fold magnification.

4. Interpretation of the test results

Basing on the simple formula for an apparent charge

$$Q_p = \Delta U_1 \cdot C_2$$

where: $\Delta U_1 = U_z - U_g$

and
U_z - PD inception voltage
U_g - PD extinction voltage
C_2 - capacitance in series with a gaseous void

it is possible to calculate the apparent charge value by substituting the measurement results.

The following assumptions have been made:

1. The arrangement under the test is of uniform field.
2. PD extinction voltage to PD inception voltage is 0,6 and is constant. Values of 0,6 to 0,8 are cited in literature [3].
3. Capacitance C_2, closing the PD circuit, can be determined from the diameter of Lichtenberg figure and the dielectric thickness.

The adopted formula is as follows:

$$Q = 38{,}4 \times K \times u_p \times D^2 \qquad \text{(pC)}$$

where:
K - coefficient due to distribution of capacitive voltage across the gaseous gap and a dielectric connected in series with it
u_p - applied voltage (kV)
D - diameter of the Lichtenberg figure

The calculated values of the apparent charge have been listed in Tables 1 and 2.

As our considerations have shown that the apparent charge depends on both the voltage and area covered by a surface discharge the $Q_p = f(U_p, D^2)$ measured and calculated for both polarities, is represented in Figs 3 and 4.

The comparison shows a pretty good conformity, except for a gap of 0,6 mm and a voltage of 4,49 kV, but in general, remembering our assumptions, and particularly constant ratio of the PD extinction voltage to the PD inception voltage and the fact that the circuit closing capacitance has been determined from the Lichtenberg's figure, the conformity must be considered as remarkably good.

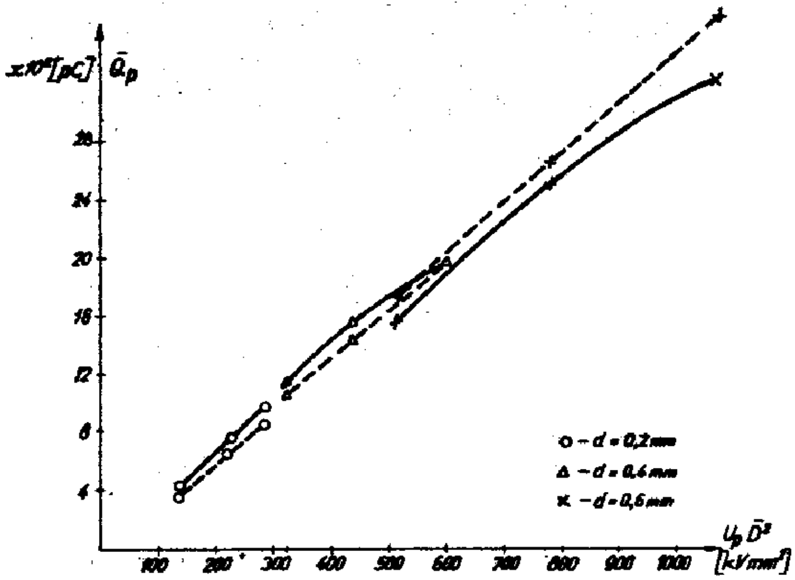

Fig.3. Apparent charge v. product of positive polarity voltage and squared diameter of Lichtenberg figure: Solid line - apparent charge measured values, Broken line - calculated values of apparent charge

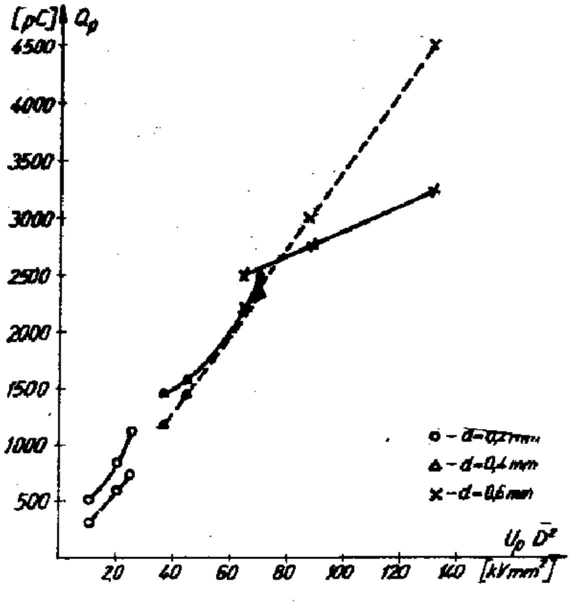

Fig.4. Apparent charge v. product of negative polarity voltage and squared diameter of Lichtenberg figure: Solid line - apparent charge measured values, Broken line - calculated values of apparent charge

If we conclude from our measurements that the PD apparent charge depends on the voltage and area covered by a surface discharge it will be interesting to find out which factor is of greater importance. It seems, that the comparison of the measurements at 101,3 kPa and 50,6 kPa may give us a right answer (see Tables 1 and 2). At a lower pressure, even the reduced applied voltages give apparent charges equal or higher than for a normal pressure.

Table 1

Results of measurements for positive test voltage

p kPa	d m	U_p kV	$\bar{D}$ mm	$\bar{Q}_p$ pC	$Q_{p\ cal}$ pC
101,3	0,2	2,12	8,1 ± 0,3	4278 ± 542	3895
		2,32	10,1 ± 0,6	7668 ± 647	6627
		2,51	10,7 ± 0,3	9938 ± 747	8046
	0,4	2,96	10,3 ± 0,2	11533 ± 417	10638
		3,23	11,7 ± 0,2	15666 ± 560	14414
		3,50	13,1 ± 0,3	19563 ± 1072	19580
	0,6	3,80	11,6 ± 0,4	15456 ± 1437	17487
		4,14	13,7 ± 0,3	25264 ± 513	26574
		4,49	15,4 ± 0,3	32378 ± 768	36417
50,6	0,4	1,83	14,5 ± 0,4	14280 ± 412	12543
		1,99	16,7 ± 0,3	20870 ± 1433	18092
		2,16	19,1 ± 0,5	31253 ± 1353	25688
	0,6	2,31	16,6 ± 0,5	20269 ± 1270	21769
		2,52	18,4 ± 0,3	30024 ± 955	29178
		2,73	19,6 ± 0,5	41793 ± 1543	35867

p-pressure, d-height of the gas gap, U_p-value of test voltage, $\bar{D}$-mean value of Lichtenberg figure diameter, $\bar{Q}_p$-PD apparent charge mean value. $Q_{p\ cal}$-calculated apparent charge

The diameters of the Lichtenberg figures are also greater at the reduced pressure. This fact indicates that the dielectric surface discharge is decisive for the PD apparent charge level. The measurements give us also another opportunity to check the formula for the apparent charge i.e. that the PD apparent charge depends on the applied voltage and the square of the diameter of the Lichtenberg figure. If this is true the ratios of the PD apparent charges at 101,3 kPa and 50,6 kPa will be approximately equal to corresponding ratios of the products of the applied voltages by the squared diameters of the Lichtenberg figure.

Table 2

Results of measurements for negative test voltage

p kPa	d mm	U_p kV	$\bar{D}$ mm	$\bar{Q}_p$ pC	$Q_{p\,cal}$ pC
101,3	0,2	2,12	2,3 ± 0,2	520 ± 92	314
		2,32	3,0 ± 0,1	825 ± 60	585
		2,51	3,2 ± 0,1	1118 ± 93	720
	0,4	2,96	3,5 ± 0,2	1462 ± 152	1184
		3,23	3,7 ± 0,1	1554 ± 114	1443
		3,50	4,5 ± 0,2	2494 ± 189	2313
	0,6	3,80	4,1 ± 0,1	2490 ± 54	2183
		4,14	4,6 ± 0,1	2737 ± 86	2994
		4,49	5,4 ± 0,1	3209 ± 72	4474
50,6	0,4	1,83	4,1 ± 0,2	1416 ± 147	1004
		1,99	4,7 ± 0,2	2076 ± 107	1434
		2,16	4,8 ± 0,5	2168 ± 292	1629
	0,6	2,31	5,4 ± 0,3	2460 ± 168	2302
		2,52	6,2 ± 0,3	2828 ± 126	3310
		2,73	6,9 ± 0,3	3098 ± 46	4442

Notations see Table 1

For example:

For a gap of 0,4 mm, a pressure of 101,3 kPa and a positive polarity of the applied voltage (Refer to Table 1) we have:

$$U_{p1} = 2{,}96 \text{ kV} \qquad \bar{D}_1 = 10{,}3 \text{ mm} \qquad \bar{Q}_{p1} = 11533 \text{ pC}$$

For a similar gap but at 50,6 kPa we have:

$$U_{p2} = 1{,}83 \text{ kV} \qquad \bar{D}_2 = 14{,}5 \text{ mm} \qquad \bar{Q}_{p2} = 14280 \text{ pC}$$

and consequently:

$$\frac{U_{p2} \times \bar{D}_2^2}{U_{p1} \times \bar{D}_1^2} = \frac{1{,}83 \times 14{,}5^2}{2{,}96 \times 10{,}3^2} = 1{,}22$$

$$\frac{Q_{p2}}{Q_{p1}} = \frac{14280}{11533} = 1{,}24$$

The so calculated ratios have been listed in Tables 3 and 4. Although there are small differences, the results have confirmed our original conclusion.

Table 3

Comparison of ratios of products of test voltages and square values of Lichtenberg figure diameters with ratios of apparent charge values by different pressures and positive test voltage

Lp	d mm	U_{p1} kV	U_{p2} kV	$\frac{U_{p2}\,\bar{D}_2^2}{U_{p1}\,\bar{D}_1^2}$	$\frac{\bar{Q}_{p2}}{\bar{Q}_{p1}}$
1	0,4	2,96	1,83	1,20	1,24
2		3,23	1,99	1,26	1,33
3		3,50	2,16	1,32	1,59
4	0,6	3,80	2,31	1,25	1,30
5		4,14	2,52	1,10	1,18
6		4,49	2,73	0,99	1,30

d-gas layer height, U_{p1}-voltage applied to the cell by pressure of 101,3 kPa, U_{p2}-voltage applied to the cell by pressure of 50,6 kPa, $\bar{D}_1$-mean value of Lichtenberg figure diameter for U_{p1}, $\bar{D}_2$-mean value of Lichtenberg figure diameter for U_{p2}, $\bar{Q}_{p1}$-mean value of apparent for U_{p1}, $\bar{Q}_{p2}$-mean value of apparent charge for U_{p2}, $\bar{D}_1, \bar{D}_2, \bar{Q}_p, \bar{Q}_{p2}$-see Table 1.

Effect of the area of a dielectric subjected to a surface discharge can be seen by comparing the test results for the two polarities of the applied voltage.

Both, the apparent charges and the diameters are considerably higher for a positive polarity (Refer to Tables 1 and 2). As the applied voltage is identical for both polarities we can compare the ratios of the corresponding apparent charges with those of the squared diameters of the Lichtenberg figures.

For instance:

For a positive polarity and a pressure of 101,3 kPa:

$d = 0{,}4$ mm; $U_p = 3{,}23$ kV; $\bar{D}_+ = 11{,}7$ mm; $\bar{Q}_{p+} = 15666$ pC

For a negative polarity and a pressure of 101,3 kPa:

$d = 0{,}4$ mm; $U_p = 3{,}23$ kV; $\bar{D}_- = 3{,}7$ mm; $\bar{Q}_{p-} = 1554$ pC

$$\frac{\bar{D}_+^2}{\bar{D}_-^2} = \left(\frac{11{,}7}{3{,}7}\right)^2 = 10{,}0 \qquad \frac{\bar{Q}_{p+}}{\bar{Q}_{p-}} = \frac{15666}{1554} = 10{,}1$$

Table 4

Comparison of ratios of products of test voltages and square values of Lichtenberg figure diameters with ratios of apparent charge values by different pressures and negative test voltage

Lp	d mm	U_{p1} kV	U_{p2} kV	$\frac{U_{p2}\,\bar{D}_2^2}{U_{p1}\,\bar{D}_1^2}$	$\frac{\bar{Q}_{p2}}{\bar{Q}_{p1}}$
1		2,96	1,83	0,85	0,97
2	0,4	3,23	1,99	1,00	1,33
3		3,50	2,16	0,70	0,87
4		3,80	2,31	1,05	0,99
5	0,6	4,14	2,52	1,11	1
6		4,49	2,73	0,99	0,97

$\bar{D}_1$, $\bar{D}_2$, $\bar{Q}_{p1}$, $\bar{Q}_{p2}$ – see Table 2.

The so calculated values have been listed in Table 5.
It would be unwise to expect a similar conformity for all other cases, but nevertheless the results are quite satisfactory. The analysis of the Table 5 shows that lower values of the apparent charge at a negative polarity are due to a reduced area subjected to a surface discharge.

The above mentioned results, complete with the discussion, allow the following conclusions to be drawn up:

1. The apparent charge value depends on the PD voltage and on the area of a dielectric subjected to a surface discharge.

2. Area of a dielectric subjected to a surface discharge has a decisive effect on the apparent charge.

3. A surface discharge on a dielectric is primarily responsible for the distribution of the apparent charge amplitudes.

Table 5

Comparison of ratios of squared mean values of Lichtenberg figure diameter with ratios of mean values of apparent charge for both polarities of testing voltage

Lp	d mm	U_p kV	$\frac{\bar{D}_+^2}{\bar{D}_-^2}$	$\frac{\bar{Q}_{p+}}{\bar{Q}_{p-}}$
1	0,2	2,12	12,4	8,2
2		2,32	11,3	9,3
3		2,51	8,7	8,9
4	0,4	2,96	8,7	7,9
5		3,23	10,0	10,1
6		3,50	8,5	7,8
7	0,6	3,80	8,0	6,2
8		4,14	8,9	9,2
9		4,49	8,1	10,1

U_p -value of testing voltage, d-gas layer height, $\bar{D}_+$, $\bar{D}_-$ -mean values of Lichtenberg figure diameters for positive and negative test voltage respectively (see Table 1,2), $\bar{Q}_{p+}$, $\bar{Q}_{p-}$ -mean values of apparent charge for positive and negative test voltage respectively (see Table 1,2)

References

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