Optica Applicata, Vol. XIII, No. 2, 1983

Application of electro-optical method to measurements of discharges in dielectrics

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1. Introduction

For several years one of the major problems in the high voltage technology appears to be the presence of partial discharges (PD) in dielectric materials which accelerate aging of insulating systems and lead to their breakdown.

The initiation and the development of PD in dielectrics takes place in the gas volume either in the bulk of the material or at its interface with the gas phase. PD are common in many insulating systems with synthetic dielectrics, either liquids or solids.

The experimental data regarding changes of intensity of PD and the influence of various PD parameters on aging processes appear scanty and it is still necessary to study PD characteristics in correlation with other parameters such as dielectric geometry, applied voltage and time.

As there is no comprehensive description of the physical aspects of discharges in dielectrics some authors suppose that a more detailed understanding of the mechanism of PD development can be achieved only when more complex studies of PD will be performed employing different detection methods [1].

The measurements of light resulting from discharges were carried out a long time ago [2] but for dielectric applications they were performed in recent period only.

2. Measurements of light pulses parameters

The method of measurements of light emitted by PD is based upon some physical processes accompanied by an emission, mainly in the UV and the visible range of electromagnetic waves during re-excitation and recombination of gas atoms and molecules.

The PD phenomena, both of the surface and of the internal types, are physically very complex. Primary and secondary processes lead to the changes of the gas phase and of the gas-dielectric interface conditions, resulting in changes of PDs magnitude, which can be detected as an apparent charge by an electrical method or as a light pluse intensity by an electro-optical method.

Some data have confirmed the presence of a correlation between optical and electrical signals of PD, but the quantitative measurements have been carried out only recently, both for surface [4] and internal discharges [1].

An electro-optical instrument for measurements of light pulses related to PDs has been designed and constructed in the Institute of Theoretical Electrotechnique and Electric Metrology of the Technical University of Warsaw and is shown in Fig. 1. It was based on

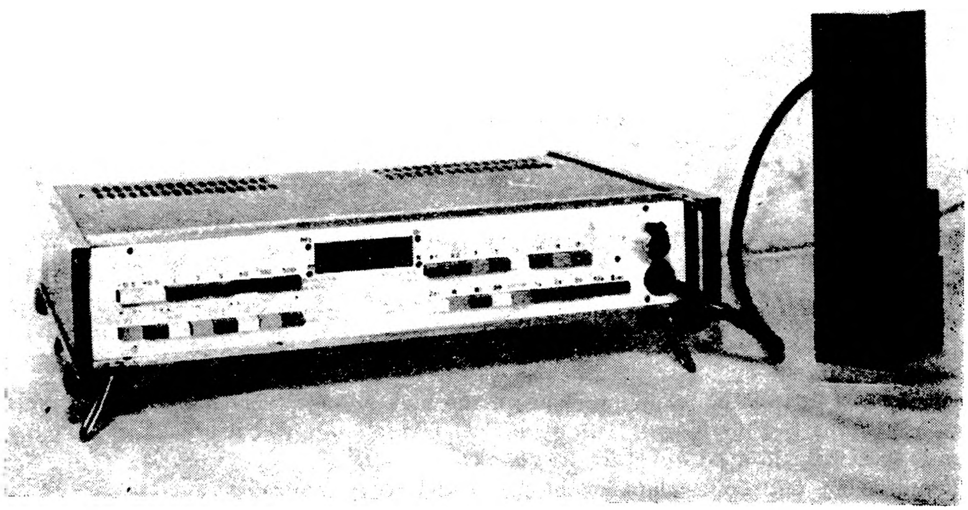

Fig. 1. Electro-optical instrument for the measurement of light pulse produced by PD

a digital photometer described by the authors in [5]. It consists of two main parts: the light detector and the display and control panel which are connected by a flexible cable. PDs light intensity is measured using a sensitive photomultiplier as a discharge detector fed by a stabilized power supply. A photomultiplier FEU-36 type has been used, with the wavelength range 320 to 460 nm, the gain of 10^7 at 1140 V, the anode sensitivity of 1000 A/lm and the luminous flux range of 10^{-7} lm. Dark current and noise signals were compensated using special potentiometer. This lowered the minimum detection level Φ min which can be measured to 10^{-11} lm.

The measuring and the control circuits were provided with calibration generator having the frequency range to 10 MHz which enabled varying the grating time from 0.1 μs up to 1 s. The range of sampling time available is from 10 ms to infinity. Data read-out uses 6 digits display indicator with holding time from 1 s up to 10 s. Analog output enables connections to oscilloscope or a recorder. Maintenance and operation of the system are enabled by potentiometers, push-button switches and luminous indicators showing measured functions. Optical and acoustic overflow indicators were also provided. The light pulse parameters that can be measured by the instrument (Fig. 2) are as follows:

– intensity of the first single pulse $|\Phi_i|$,
– mean intensity of the first pulses during time t_0, $|\Phi_a|$,
– mean flux of pulses $|\Phi|$,

- amount of light during time $t_0\,|Q|$, $Q = \int_0^{t_0} \Phi dt$,
- time lag of the first single pulse $|t_1|$,
- duration of the first single pulse $|T_1|$, $T_1 \geqslant 0.1$ μs,
- duration of all pulses during time to $|T_s|$,
- number of pulses during time $t_0\,|N|$.

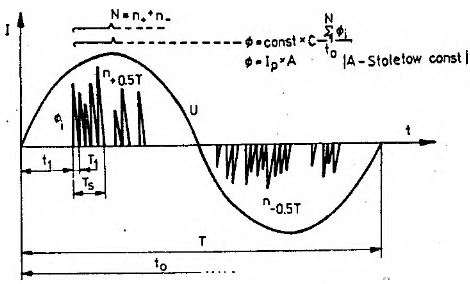

Fig. 2. Light pulse parameters of PD measured by the instrument

It was confirmed [1] that when PDs occurs light pulses magnitude can be related to charge pulses measured by electrical method.

Each single light pulse of PDs can be represented (on oscilloscope's display) as [1]:

$$\Phi_i = \frac{-en_i M}{C}$$

where e is the charge of electron, n_i number of electrons liberated from the photocathode of the photomultiplier, M is the multiplication factor equal to the overall gain of the photomultiplier, and C is the capacity of RC integrator circuit which forms the pulses.

Magnitude of Φ_i pulses is then proportional to the number of photons of PDs source and therefore can be a measure of PD intensity. The value of Φ_i can be expressed in units of charge $|pC|$ either as a product of electron charge and their number $|-en_i|$ or using a circuit calibrated with known charge pulses.

Other light pulse parameters can be also related to different PDs values (ionisation current, total charge, energy of discharge etc.) [1].

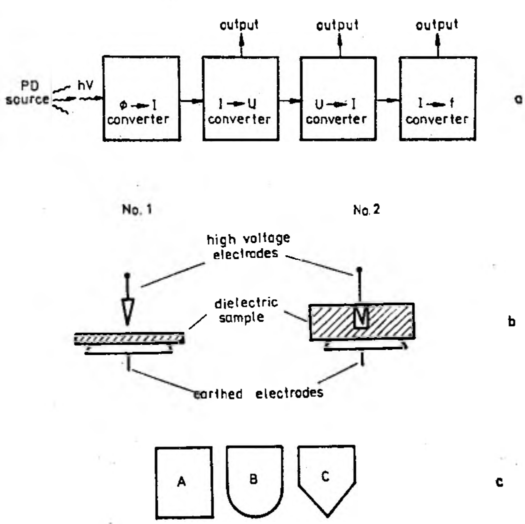

Fig. 3. Measurements of light pulses: a. principle of measurements, b. electrode's system, c. red electrodes for artificial void arrangement

The idea of PD measurements employing light detection has been developed in the Institute of High Voltages and it is based upon the arrangements described by the author [1].

Figure 3a shows the idea of the instrument used for discharge light measurements, and Fig. 3b gives the sketch of electrode's system which has been used for the measurements carried out in the laboratories of the Central Research Institute "Elektromontaż" and of the Institute of High Voltages.

A typical pin-plane arrangement was tested with a dielectric plate of 1 mm thick in series with a gap with a spacing of 1 mm (system No. 1). In artificial void arrangement (system No. 2) three different electrodes (*A*, *B*, *C*) were used as shown in Fig. 3c. The high voltage was applied to arrangement up to the level when no creep discharges appeared.

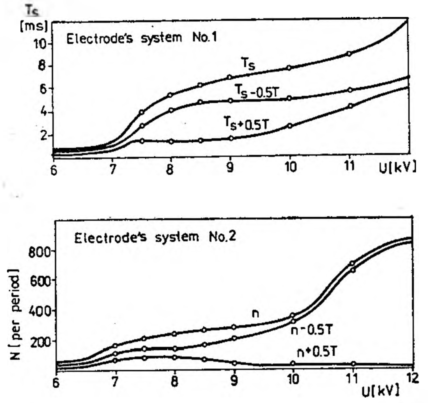

Fig. 4. Characteristics of the duration of pulses T_s and their frequency N as a function of applied voltage U

Measurements were performed at the ambient temperature of 17°C and a relative humidity of 70%. At each level the voltage was applied for 2 min. The measurements of light flux were carried out for the whole period of 2 min. and the measurements of time parameters of PD and their repetition rate for periods of 20 ms every 2 s.

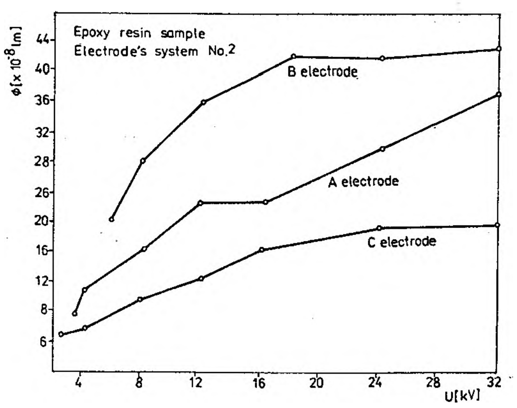

Fig. 5. Characteristics of light flux Φ as a function of applied voltage U

Some of the results are presented in Fig. 4–6 as a function of applied voltage U and time of voltage application t. Luminous flux Φ, duration time T_s and number of pulses N rise from initial voltage of discharges U_0 with different slope of the curves for both electrode configurations tested.

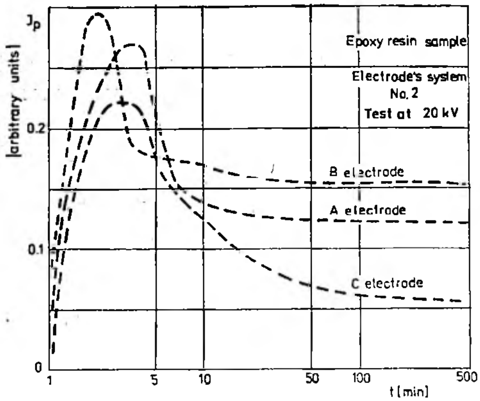

Fig. 6. Characteristics of photocurrent J_p as a function of voltage application time t

3. Applications

The above described electro-optical instrument can be used for many applications.

For the purpose of laboratory testing of dielectric materials it can be used for detailed analysis of PDs in gaseous, liquid and solid dielectrics. It should be added that for transparent solid dielectrics it can be used as an internal discharge detector which gives information straight from the PDs source. In insulating oils affected by PD light signal detected by the instrument it can be used to control the gasing processes and rate of degradation.

For detailed testing of PD in dielectric materials the system with a multichannel analyser and a computer has to be used, as shown in Fig. 7.

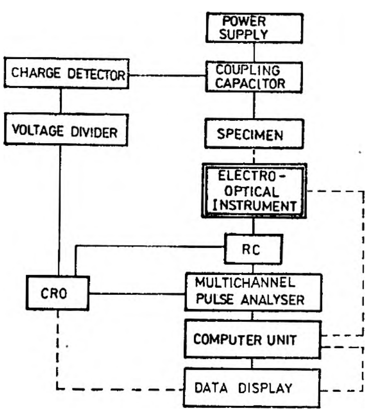

Fig. 7. Diagram of a system for a detailed testing of PD in dielectrics

As the object tested could be represented by any system with either emission or modulation of electromagnetic radiation at certain wavelength, the instrument can be used for testing of light modulators, optoelectronic measurements and others, in many photophysical and phototechnical laboratories.

Apart from laboratory applications the instrument can be used as PD detector in high-voltage transmission lines and apparatus for identification of corona and PD sources.

In high voltage technology and industry it can be employed for identification and selection of partially damaged and improperly constructed insulating parts, insulators, windings, weak terminals, etc.

4. Summary

Electrical discharges in different dielectric media can be detected by an electro-optical method and measured as a light pulse. The electro-optical instrument has been constructed and used for some measurements of discharges in pin-plane system in air.

Some results are presented. The instrument can be used to measure PDs appearing either on the surface or in the bulk of the transparent material. Other applications both in the laboratory testing or for industrial diagnostic technique are also possible.

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Received December 7, 1982