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Ionizing radiation as a component of energy balance in electrical discharges in air and mineral oil

Abstract

The paper presents the results of research concerning electrical discharges generating ionizing radiation in air and oil. Ionizing radiation is an important component of energy balance in electrical discharges. In energetics and all other engineering sciences, the energy balance shows the flow of energy for a given technological process. Within it, the energy needs of the process and its effect are collated.

Keywords: ionizing radiation, electrical discharges, scintillator, energy balance.

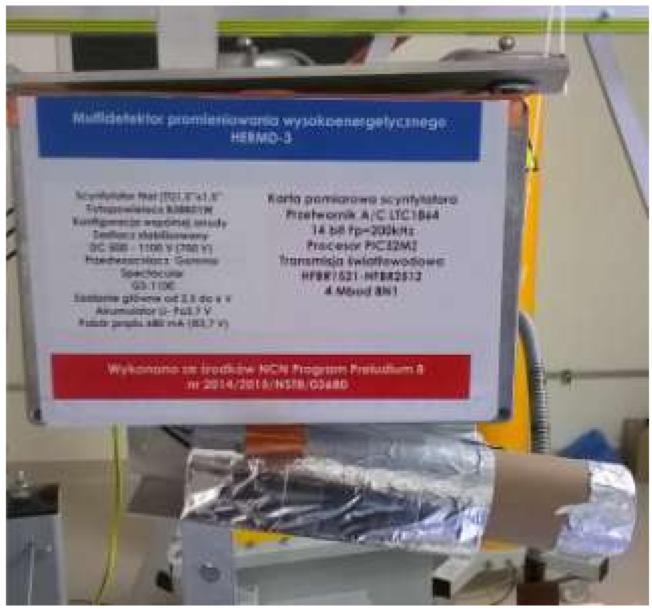
1. Ionizing radiation generated by electrical discharges

Electrical discharges, both partial and complete, generate many energy losses. Electrical energy is converted into a number of other forms, such as mechanical energy (sound), heat, light. Latest research indicates that energy losses in electrical discharges occur also due to the fact that ionized radiation is generated [1, 3, 15]. This happens both naturally, during a storm, and technologically, through partial and complete discharges within electrical insulation systems in equipment and power cables. The exact mechanism of this phenomenon is still a matter of debate. The Eindhoven University of Technology is one of the research centers dealing with this issue. An experiment conducted by Kochkin et al. [5-7] involved inducing discharges using a 1 MV Marx generator. Significant differences in the radiation generated depending on polarity of electrodes were observed. Another institute in which the phenomenon of high-energy radiation in electrical discharges has been investigated is the Florida Institute of Technology. Differences due to the polarity of electrodes were found here as well. 14 tests were conducted, during which X-radiation with energy between 30 keV to 150 keV was recorded [2]. Measurements made in the high voltage laboratory at the Institute of Power Engineering and Renewable Energy suggest that high-energy ionizing radiation is generated also during partial discharges. It is highly possible that detecting this type of radiation will assist in finding partial discharges. Developing a method of finding PD through radiation measurement would extend currently known methods, such as the electrical, optical and UHF methods or the acoustic method, which is also being developed at our Institute [4, 8, 9, 11-14].

2. Scintillation detector

To research the ionizing radiation from electrical discharges, a detector based on a NaI(Tl) scintillator was used. A 1.5" × 1.5" crystal placed next to a negative electrode converted X-radiation photons to scintillation flashes recorded by a photomultiplier. There was used a B38B01W photomultiplier powered by a Gamma Spectacular GS-1100 PRO high voltage preamplifier. The scintillation detector measuring card was based on a LTC1864 A/D converter and a PIC32MZ MCU. The data from the shielded memory card was transmitted to a computer via optical fiber cables, which prevented interferences which might have had an impact on the measurement results. The designed and built detector is shown in Figure 1. The entire test system was placed in a shielded cell suitable for researching high voltage energy discharges. The detector, on the other hand, was mounted on an arm capable of moving in a 3D space, which allowed the probe to be set precisely, anywhere near the electrodes or at a given distance. This enables tests encompassing not only the criterion of distance between the detector and the source of radiation, but also the angle at which the scintillation probe is set. The arm of the 3D system is controlled via a computer, and the control system is resistant to interferences from electromagnetic fields, both external as well as those generated during tests. The entire test system as well as research methodology have been described by the author in [10]. The tests presented in this paper were conducted in air at atmospheric pressure and in mineral oil.

a)



b)

Fig. 1. a) The scintillation detector consisting of a photomultiplier, b), measuring card and the photomultiplier power supply unit

3. Measurement of partial discharges

The tests began with detector calibration. Americium 241Am was the source of radiation. The number of scintillation counts per one-second measurement is shown in Figure 2.

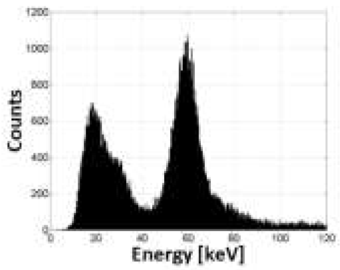


Fig. 2. Energy spectrum of americium 241Am recorded by the detector

The resulting image of americium corresponds to the spectra obtained from the detectors in nuclear laboratories. The first measurements in oil involved testing PD generated by a point-point spark gap configuration, with the distance between electrodes of 28 mm (Fig. 3). Next, argon bubbles were introduced to the configuration, with an appearance frequency of 15 Hz (Fig. 4).

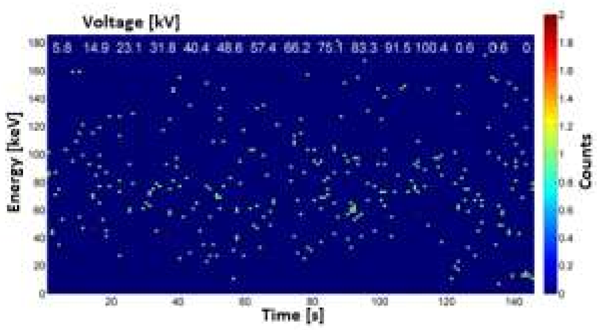


Fig. 3. Energy spectrum of PD in a point-point configuration. Electrodes were submerged in oil, the detector was placed above the oil surface. The distance between the electrodes was 28 mm

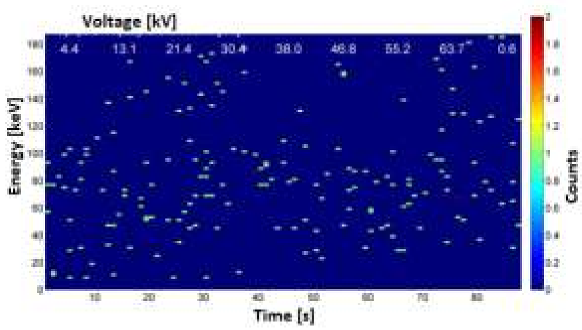


Fig. 4. Energy spectrum of PD in a point-point configuration with argon bubbles introduced. Electrodes were submerged in oil, the detector was placed above the oil surface. The distance between the electrodes was 28 mm

4. Streamer discharges

Figure 5 shows the sum of energies recorded by the scintillation detector during a complete discharge in a sphere-sphere electrode configuration with sphere diameters of 50 mm depending on the distance between the spheres. It is suggested that the scintillation energy comes from the X-radiation generated during discharges. From the proposed theories mentioned above it can be concluded that the recorded high-energy radiation comes from the excited or ionized molecules in the medium which are returning to their ground state.

Increase in the distance between electrodes increases the energy of the discharge, and therefore the ionizing energy in the medium.

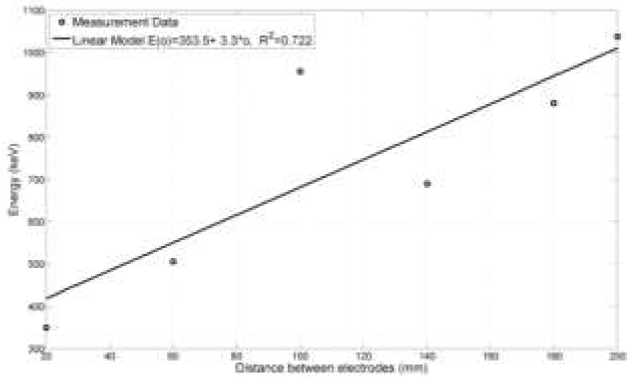


Fig. 5. Sum of scintillation energy depending on the distance between electrodes. Tested in air in a sphere-sphere configuration with sphere diameters of 50 mm

Figure 6 shows a time course of the scintillation spectrum, correlated with the voltage and current applied to one of the electrodes in order to induce a complete discharge. It is clear that the ionization occurs at the moment of insulation breakdown.

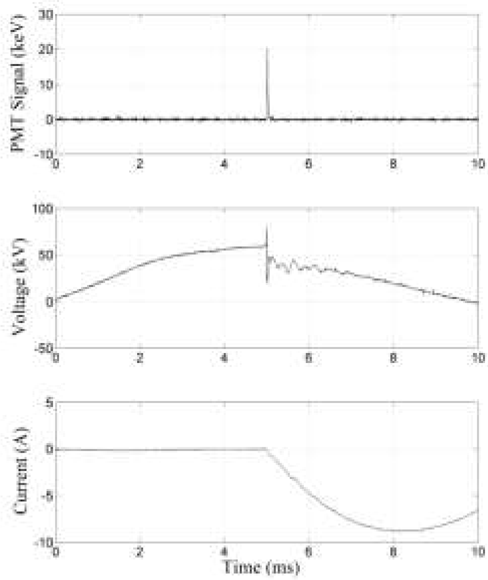


Fig. 6. Time courses of the signals from the photomultiplier and of the voltage and current in the primary winding of the transformer at the moment of breakdown in a sphere-sphere configuration with sphere diameters of 50 mm in air

Figure 7 shows a projection of the 3D diagram onto a 2D plane. It characterizes the probability density of recording an X-radiation photon with a given energy depending on the energy of the complete discharge wherein, as stated earlier, the energy of the discharge depends on the distance between electrodes. This dependence vividly suggests not only an increase in the energy of excitations of the molecules in the medium, but also an increase in the number of ionizing acts in the medium.

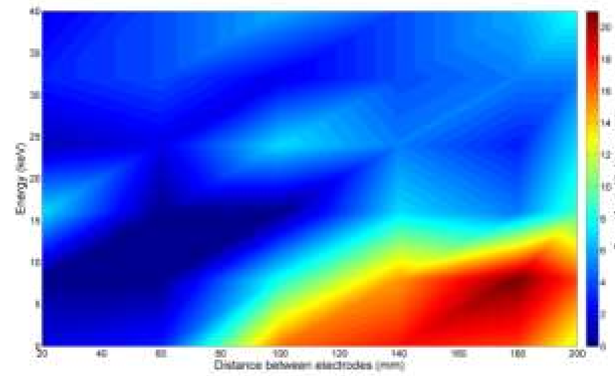


Fig. 7. Spectrum of scintillation energy. Tested in air in a sphere-sphere configuration with sphere diameters of 50 mm

5. Summary

Investigations of electrical discharges, regardless of medium or electrode configuration, does not provide a conclusive answer to the question of ionizing radiation being generated during partial discharges. Certain results presented on the images obtained during the research suggest the possibility of a low-energy bremsstrahlung, so weak, however, that it is difficult to record it by placing the detector next to the negative electrode. This low-energy radiation is short range; however, the recorded data could be the result of a disruption of the electromagnetic field which allowed the molecules to increase their range. Another possible explanation is a statistically possible spark arcing in just the gaseous inclusions. It does not constitute a complete breakdown in the configuration, but the energy released during arcing could have ionized gas molecules close to the detector. It is also worth noting that the second substance in which measurement was performed (oil) has considerable damping properties which could have influenced the recorded data. Compared to complete discharges generated in oil described in other papers, there is a visible difference due to the energy released during a given type of discharge; also, due to the fact that the energies in the latter case are higher, recording them in such a difficult medium produces more tangible results.

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6. References

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