Determination of partial discharge inception level with pulsed X-ray

1 Introduction

Gases are widely used as insulation material in high voltage technology because of their excellent properties such as low loss factors and fast recovery after breakdown. Today, mainly sulfur hexafluoride (SF_6) is used in high voltage applications because of its high breakdown level compared to other gases. But the environmental impact of SF_6 is quite high. Therefore a reduction of the installed volume and potentially also a replacement is aspired. It requires a good knowledge of the properties and the behaviour of SF_6 to enhance the existing insulating systems and to achieve significant equipment size reduction.

For the breakdown of gases two necessary conditions must be fulfilled: i) the field strength must exceed the critical field strength in some part of the volume and ii) a free electron within this critical volume must exist. Charge carriers are mainly produced by ionization due to cosmic radiation [1]. The generation is a statistical process. Especially in inhomogeneous configurations at small voltages – when the critical volume is small – the statistical time lag – the time between the voltage application and first discharge – can be long [1].

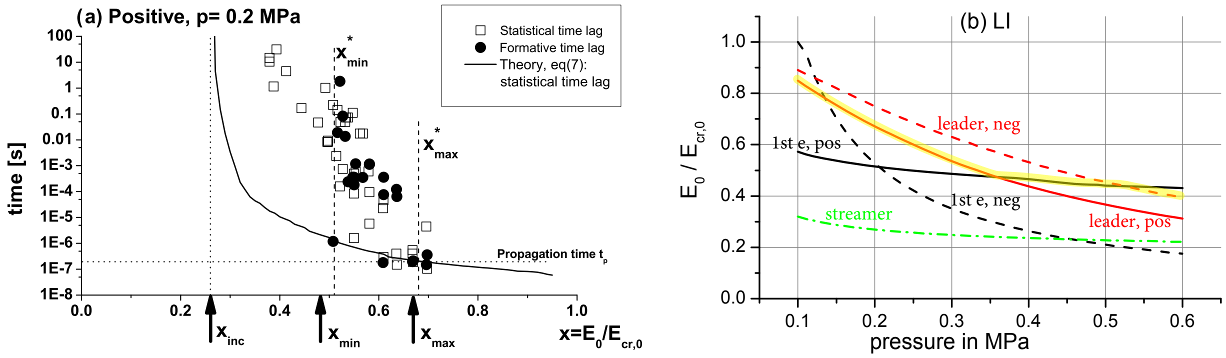
The electrical fields in gas insulated switchgears (GIS) are nearly homogeneous. Nevertheless, during installation process the surface of the compartments can be damaged or small conducting particles can remain. This causes local field enhancements and partial discharges. To prevent breakdown large safety margins are used. Therefore, it is of practical interest to know the inception mechanism and level for such small protrusions.

2 State of knowledge

In the 80s many experiments were done to describe discharges and breakdown in inhomogeneous fields, such as [2]. Recently, a model for inception and development of partial discharges in homogeneous fields with a small protrusion has been developed [3]. In this model the theoretical limits for discharge inception and delayed and immediate breakdown are described based on the theory of stepped leader breakdown.

In [4] the corresponding experimental data is presented (see figure 1(a) for a protrusion with positive voltage, 0.2 MPa SF_6). The comparison shows that the data and the model agree well. The theory predicts an exponentially decaying correlation between the overvoltage level and the statistical time lag: the Fowler-Nordheim equation for negative polarity at the high field electrode [5] and detachment of electrons from negative ions for positive polarity [4], respectively. This includes an increase of the time to the availability of a first electron at minimum inception level of partial discharges to infinity.

A comparison of the limiting mechanisms for discharge inception in different electrode configurations over a pressure range from 0.1 MPa to 0.6 MPa is described in [6]. The example of a protrusion stressed with lightning impulse (see figure 1(b)) shows that for pressures between 0.35 MPa and 0.5 MPa the availability of a first electron is the determining part of the discharge.



(a) Theoretical limits for partial discharge and breakdown together with experimental results [4, figure 6(a)]

(b) Limitation for breakdown (yellow line) for a protrusion stressed with ligthning impulse [6, figure 6(b)]

Figure 1: Pictures from literature showing the interesting points.

3 Proposed work

The sections 1 and 2 exhibit that it is of interest to determine the exact inception level of partial discharges in weakly inhomogeneous electrode configurations. As the natural production of first electrons due to detachment gives long statistical time lags in the voltage ranges of inception it is necessary to provide them artificially.

For artificial ionization often illumination with ultraviolet light, e.g. mercury-vapor lamps, is used. This method has two disadvantages: the high energetic radiation in the low UV-range cannot pass fused quartz and adequate ionization is not possible inside a gas compartment. Secondly, those lamps provide a permanent irradiation. This influences the composition of the charge carrier density in the gas continuously during the experiment.

Therefore we propose to use a pulsed X-ray source. This source produces very short X-ray pulses in the range of 50 ns. With this method sufficient free electrons are produced within the critical volume. Due to the short duration of the pulses the further development of discharges is not influenced. In addition, the radiation penetrates the aluminum shielding of the test vessel quite good.

The background of the proposed work is to use synergies between two different projects running independently at ETH Zurich. In one project (the main project of the applicant M. Koch) a setup is constructed to test the stepped leader model developed for SF_6 [3,4,6] also for other electronegative gases with less environmental impact than SF_6. In a second project, a pulsed X-ray source is used to study the inception mechanism of partial discharges in voids of solid insulation spacers [7]. The aim of this research proposal is to combine experimental facilities and experience from both projects to address an open question in literature which was not able to be answered previously.

4 Experimental Setup

The experimental setup provides a weakly inhomogeneous electrode configuration to examine partial discharges and breakdown in environmental benign gases. Figure 2 provides a

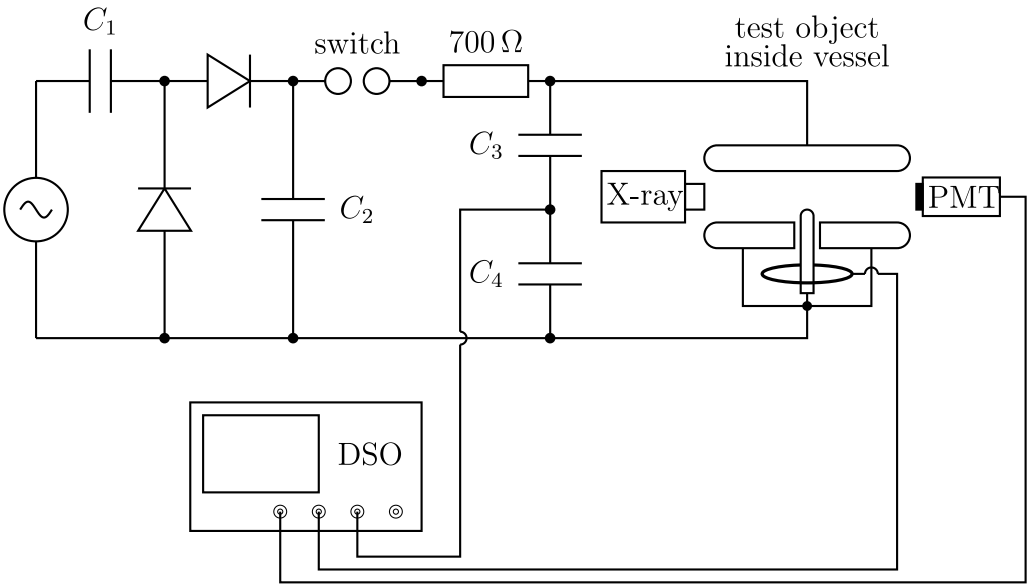


Figure 2: Experimental setup with X-ray source and photomultiplier tube (PMT); the test object is placed inside a pressure vessel (not shown in the picture)

schematic of the setup.

The voltage circuit consists of a high voltage step-up transformer and a two stage Grainacher cascade for doubling and rectifying the voltage. This source charges the capacitor C_2 with up to 200 kV. Depending on the polarity of the diodes the applied voltage is positive or negative. With a pneumatic switch the voltage can be applied to the test vessel. The resulting voltage form is a step voltage with a rise time of about 600 ns.

Inside the test vessel an electrode configuration is installed. The two plane electrodes are made of aluminum and have a gap distance of 15 mm. In the bottom electrode a needle is placed and isolated from the electrode. The needle has a spherical top curvature of 200 µm. The length of this protrusion above the plane electrode is 1 mm. The test vessel can be filled with a test gas with a pressure up to 0.6 MPa. For the experimental investigation of the discharge inception the compartment will be filled with sulfur hexafluoride (SF_6) with a pressure up to 0.2 MPa.

The discharges are simultaneously measured with a current probe (Pearson Model 2877) and a photomultiplier (Hamamatsu, H10721-110). The simultaneous measurement is done because the current probe has an upper edge frequency of 200 MHz. Partial discharges in SF_6 feature rise times down to 24 ns [8]. For better temporal discrimination of the phenomena the additional photomultiplier is used.

Additionally, the applied voltage is monitored with the capacitive voltage divider consisting of the capacitances C_3 and C_4. All signals are recorded with a wideband oscilloscope (RTO1024, 2GHz, 10GS/s). The experiment runs fully automatically.

For the determination of the inception level of the partial discharges a short pulse X-ray source will be borrowed from an other project. The Roentgen source has to be installed inside the experiment. For safety, the source has to be integrated into the existing safety circuit. An adequate trigger unit has to be provided. Additionally the experimenter needs to be protected from the Roentgen radiation. As discharges and breakdowns in sulfur hexafluoride produce strong electromagnetic interference fields a protection concept for the X-ray source is necessary.

5 Expected results and their possible impact

With the experiment described in section 4 the limit of discharge inception will be investigated. Because of the statistical behavior of discharge and breakdown events many experiments have to be performed and analyzed. It is expected that the resulting scattering plots (applied voltage vs. time to first discharge, analogous to figure 1(a)) will show a sharp inception of discharges at the level of electrical field indicated with x_{inc}. Further, it is expected that the statistical time lag will only depend on the time needed for triggering the X-ray source.

As described in sections 1 and 2 it is necessary to know the exact inception level of partial discharges. With this knowledge the safety of high voltage equipment can be increased. On the other hand the gas volume needed can be lowered. As a reduction of the use of SF_6 is recommended, this is a crucial point in the development of new generation gas insulated switchgear.

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