NEGATIVE DC CORONA INCEPTION ON LARGE ELECTRODES IN A LARGE AIR-GAP

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Abstract: Negative DC corona inception on large electrodes in a large air-gap has been experimentally investigated. In the study, both traditional corona detection methods and a UV camera were used for identifying the DC corona inception voltages. The very sensitive UV camera made it possible to detect the weak local corona on the large electrodes that is normally neglected by traditional detection methods. The weak local coronas generated extremely low PD levels, even lower than the background noise in some cases. With increasing the applied voltage, four types of corona were usually observed successively, i.e. UV-visible weak corona, audible corona, intermittent and continuous strong corona. Depending on the sensitivity of the detection method, it is clear that the value of the "corona inception voltage" will be different. For the case of large electrodes, the inception voltages of the weak corona visible by UV-camera are much lower than the inception voltage determined by traditional means.

1 INTRODUCTION

A large amount of research work has been carried out on corona discharges in atmospheric air, mostly with laboratory setups utilizing sharp needle/rod-plane air gaps [1, 2]. Consequently, much successful research has been performed on the corona problem related to coaxial cylinders of small sizes and transmission lines with large air spacing, but still with small electrode-diameters [3, 4]. In these study cases, corona-inception voltages are usually similar for AC and DC applications and the threshold level of corona-inception voltage can be well determined by the traditional criteria for the streamer inception or the empirical formulas derived from experimental results.

There are also a few published studies on DC corona inception on relatively large electrodes, such as big spheres and toroids together with long air-gaps. The results from those studies show that DC corona inceptions can occur at voltages below the threshold level in terms of the geometrical fields [5, 6]. The general characteristics of such electrode systems are that the fields tend to be quasi-homogeneous and there are large electrode surface areas with high E-fields. The corona inception becomes more sensitive to surface E-field disturbances, caused by surface micro-protrusion and/or surface contamination.

In previous studies, the standardized methodologies used for corona inception detection were usually monitoring the audible noise and visible light emission in a darkened laboratory as well as partial discharge (PD) measurement. In recent years, the use of UV cameras has become more common in this field [7-9] and this is one of the most sensitive methods. Corona with low pC levels, such as the first corona initiated by local surface disturbances, is difficult to detect using traditional PD measurements, but can be easily identified by using a UV camera.

This paper presents some results from a study on large electrodes under negative DC voltages, with a special attention paid to the weak local corona observed using a UV camera.

2 EXPERIMENTS

The negative DC corona inception tests were performed in a specially designed cage using toroids as electrodes, as shown in Figure 1.

Figure 1: Experimental set-up and UV-video camera for negative DC corona inception tests

In the tests, both traditional corona detection methods and UV camera were used for identifying the DC corona inception.

Three identical newly-manufactured aluminum toroids with an outer and inner diameter of 600 mm and 400 mm respectively, were used for the tests. The distance to the cage floor was kept constant at 1 m. An HVDC generator with rated voltage of 600 kV was used as a DC voltage source.

The diameter of the cage was 4 m and the height was 2.5 m. Both the circumference of the cage and the floor were made of perforated aluminum sheet metal. The cage was insulated and only connected to ground via a shunt for PD measurements.

The voltage pulses over the shunt impedance, created by the PD, were amplified and sampled with a digital oscilloscope. Three channels with different settings were used simultaneously in order to cover a wide range of PD, from the noise level to 10000 pC. The data were subsequently transferred to a computer for analysis. The system was calibrated with a 100 pC pulse and the background noise level was about 15 pC. From the sampled spectra, it was possible to extract PD values and the PD repetition rate.

The test electrode was cleaned with alcohol before the tests. The DC voltage was gradually increased to a voltage level, at which the first corona was observed by the UV camera. The voltage was kept at this level for observation and measurement of PD levels. The applied voltage was then increased to a new level, at which the DC corona behavior clearly changed. In this way, the continuous corona start voltage was found. The voltage-increasing steps were not equidistant, while the test time at each voltage level was the same, 5 minutes.

3 EXPERIMENTAL RESULTS

Negative DC corona inception tests were performed for all three toroids.

3.1 Behaviour of negative DC corona

An example of a typical test carried out on the 600 mm diameter toroid is described below.

The applied voltage was in this case slowly increased to 396 kV, a stable weak corona was observed in the UV-camera as shown in Figure 2. The PD level of the corona discharge was estimated to 18 pC, a level that is close to the background electrical noise of the system. No audible PD noise from the weak corona was registered.

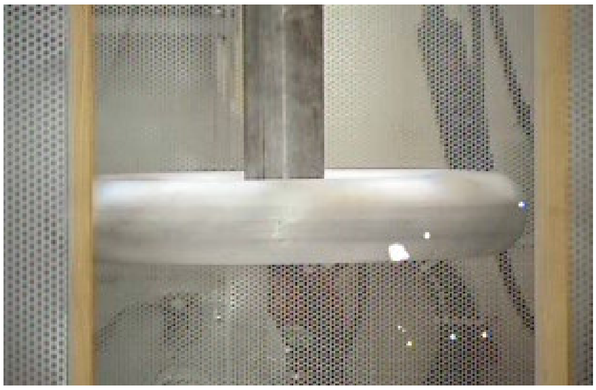

Figure 2: UV sensitive image of weak local corona under negative DC voltage of 396 kV (18 pC)

The size of the UV image of the weak corona was slightly increased, and a second weak corona appeared, as the applied voltage was further increased. The PD became audible as the voltage reached 420 kV. Figure 3 shows the UV images of negative DC corona at 431 kV. The PD level at that voltage had increased to about 194 pC.

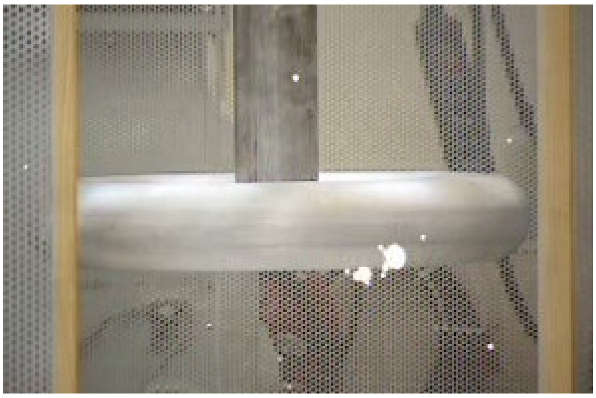

Figure 3: UV images of audible corona under negative DC voltage of 431 kV (194 pC)

As the applied voltage was increased, strong discharge was observed at 462 kV where the PD levels had grown to several thousands of pC. Initially, the discharges were intermittent and after a while became continuous when the applied voltage was further increased.

The UV images of continuous strong discharges at 470 kV is shown in Figure 4. From the UV-images, it can be seen that the stable weak coronas still existed. The continuous strong discharges consisted of a series of coronas with alternate strong and weaker “flashes”, as shown in Figure 4.

Figure 4: UV images of continuous strong discharges under negative DC voltage of 470 kV (up to 1000s pC)

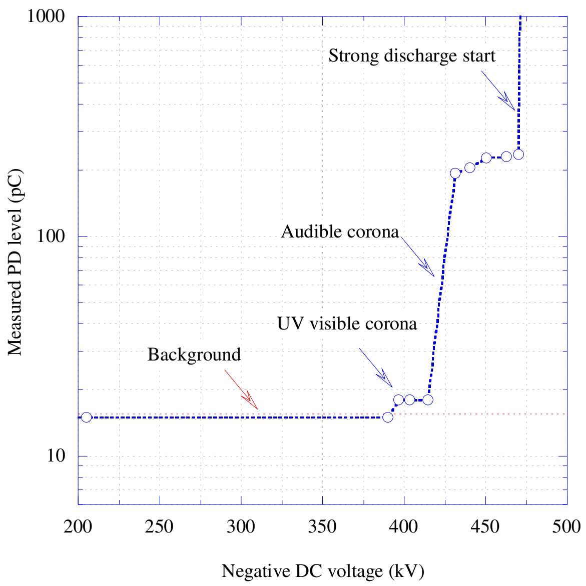

Figure 5: Measured PD level as a function of the applied negative DC voltage

Figure 5 shows the measured PD level as a function of the applied negative DC voltage in the above described test.

3.2 Test results observations

As in the above example, four types of corona were usually observed successively in all of the tests as the applied DC voltage was increased:

- UV-visible corona
- Audible corona
- Intermittent strong corona
- Continuous strong corona

With increasing DC voltage, the first observed corona was very weak and could only be detected by the UV camera. Such UV-visible coronas generated extremely low PD levels, which varied in the range 10-18 pC and most them were lower than the background noise.

With further increase of the applied DC voltage, a low noise caused by DC corona became audible with the naked (unaided) ear, while the PD levels were in the range of 160-200 pC. Continually increasing applied voltage lead to intermittent and continuous strong discharges, successively. The PD levels were in those cases higher, sometimes much higher, than 1000 pC.

4 DISCUSSIONS

The definitions of “corona inception” are based on observation of phenomenon due to corona effects, such as visible or UV-visible light, audible noise, electric current etc. Therefore, to determine the “corona inception voltage” one has to consider the nature of corona on the test electrodes as well as which detection method that is used. The different types of corona generates different corona related phenomenon and the sensitivities of the phenomena-detecting methods varies between the techniques.

4.1 Negative DC weak corona

For extreme non-uniform fields, the negative DC corona appears in different states: first the onset streamer, the glow, and then the breakdown streamer as the applied voltage is increased. The corona surrounds usually the large-curvature part of the HV electrode.

For the large electrodes used in the present experiments, the weak corona is also a glow corona, initiated by local field disturbance, such as micro-protrusion and/or surface contamination. When increasing the applied voltage, i.e. the geometrical field on the HV electrode surface, the strong corona occur, however, it may be not at the same location as the week corona. There is also a large difference between the inception voltages for the weak and the strong corona.

The weak corona inception mechanism and its influence on the insulation system need to be further studied.

4.2 Corona inception detection

4.2.1 Visible and UV-visible coronas

A number of methods have been proposed to define corona inception voltage experimentally [10]. Visual observation with the unaided eye is one of the major traditional methods since there is a measurement standard that defines this procedure [11].

However, the corona discharge emits radiation in the 240nm-405nm spectral range [12] and the most intense emissions are the 298nm, 317nm, 337nm and 357nm lines [13]. Therefore, most of the optical energy emitted by corona is in the form of UV light and is invisible to the human eye, though relatively weak emission at about 400 nm might be observed under conditions of absolute darkness [14].

DC corona spectra have been studied and the results show that spectra of ultra-violet first appear, and then longer wavelength spectra occur as the applied voltage is gradually raised [15]. The peak of light intensity emitted from negative DC corona is at wavelengths of 336nm, 356nm and 379nm for various corona states, i.e. onset streamer, glow and breakdown streamer, respectively.

As a result, the weak corona on the large electrodes was always first observed by UV-camera as the applied DC was increased. The DC corona that occurred at higher voltage levels could then be detected by the traditional PD-detection methods.

Consequently, the inception voltages of the UV-visible weak corona are much lower than the inception levels determined by traditional means. The weak corona inception mechanism and the effects on the insulation should be worth further studies since it has been overseen in many experiments.

4.2.2 Audible corona

Audible noise is the result of the passage of electrons in sufficiently great saturation to momentarily displace the air molecules entirely. This produces a miniature vacuum and the resulting collapse and miniature thunderclap. The passage of electrons in such quantities constitutes a miniature arc [16]. Therefore, directly listening to the audible noise is a convenient method to detect the corona inception.

According to our experience, the lowest PD levels detected by naked (unaided) ear generally correspond to 50-200 pC, depending on the atmosphere condition, background noise, distance from the test object etc. Therefore, the corona inception voltages obtained by this method are of some uncertainty. Location of the corona is usually determined with the help of careful observation because the audible corona is also generally visible.

5 CONCLUSIONS

From the study, the following observations can be made:

(1) For large electrodes energized by negative DC voltages, the determined corona inception voltage depends on the corona-detection method. The first weak corona is usually observed by UV-camera at low voltages while the audible and visible DC corona, detected by traditional PD-detection methods, occurs at higher voltage levels.

(2) The weak corona is usually a localized stable corona and generates extremely low PD levels, often close to or even lower than the background electrical noise in such large systems. The influence of weak corona on the insulation system should be studied further.

(3) The weak corona is initiated by local E-field disturbances due to micro-defects and/or surface contaminations. Therefore, the weak corona is of poor reproducibility and the corona inception voltages are of large standard deviation.

(4) The audible corona and strong discharge are mainly caused by geometrical E-field. Many of the audible coronas and strong discharges originates therefore not from the same locations as the weak corona.

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