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Corona Discharges from Grounded Rods under High Ambient Electric Field and Lightning Activity

Marcelo Arcanjo, Joan Montanyà,
Michele Urbani, Pol Fontanes
Lightning Research Group (LRG)
Universitat Polytècnica de Catalunya
Terrassa (Barcelona), Spain.
marcelo.augusto.sousa@upc.edu

Victor Lorenzo, Enric Pons
R & D department
Dena Desarrollos S.L. (Ingesco)
Terrassa (Barcelona), Spain.

***Abstract*— We assess results of corona pulses detected under high background electric field in the laboratory and in the field in two different experimental sites. The first location is on the roof of a regular building, and the second is on a flat area. Due to the enhancement of the E-field caused by lightning strikes in the vicinity of a grounded rod with a sharp tip, we observed positive and negative pulses before or after the strikes. When lightning activity is far from the structure, but the electric field remains high, pulses are still observed.**

***Keywords*—corona discharges, electric field associated with lightning.**

I. INTRODUCTION

Many studies were conducted on the effects of the electric field enhancement below thunderclouds [1-6]. Irregularities on the surfaces of grounded structures can provide conditions for corona discharges that generates ions and form a space charge layer that decreases the magnitude of the electric field at the ground level [1].

Measurements of the corona current through a grounded needle under thundery weather reported an average current of a few microamperes [2, 3]. An electric field threshold is required for corona inception and the average current increases with the increase of the background electric field. The geometry of the system and weather conditions such as humidity and wind can significantly affect these parameters. The role of wind was studied in [4, 5], which indicated that higher wind speeds accelerate the ion removal from the structures and increase the corona current.

The measurements performed by [6] revealed the features of pulsating discharges from a grounded sharp rod, 30 milliseconds prior to a return stroke nearby. The amplitude of these pulses and their duration are different than the induced currents caused by approaching downward leaders [7], as well as induced currents in vertical conductors during return stroke currents [8]. In the laboratory, the corona current has been extensively studied. The first studies performed by [9, 10] reported the pulsating behavior of the current. As the applied electric field increases, the average current and pulse frequency also increases. However, amplitude and time durations seem to be constant for certain geometries [5, 11, 12].

The impacts of space charges on lightning strikes have been assessed by other works [13-16]. It was believed that the shielding of the electric field near grounded structures caused by the corona layer could delay the streamer inception from the structures [13]. However, the delay effect has been found not that severe since the shielding effect provided by glow corona discharges decreases rapidly in the lateral direction of the structures [14]. In upward lightning, [15] reported that self-initiated events were correlated with strong wind speeds that could remove space charges, creating conditions of high local electric field for the leader initiation. For wind turbines, observations reported in [16] indicate that moving structures are able to avoid the shielding effect caused by space charges and increase the probability of lightning strikes.

We performed in laboratory several experiments to characterize the corona current from a grounded sharp rod at atmospheric pressure. Although the phenomenon of corona discharges is well known, few studies have been conducted based on outdoor experiments. We measured corona pulses under stormy weather in two different experimental sites. In this work, we discuss the key features observed for the data obtained.

II. METHODOLOGY AND INSTRUMENTATION

In the laboratory, we measured the corona current using both a shunt resistor and a current transformer. Figure 1 shows the diagram of connections of the sensors in the setup.

A grounded conductive rod 30-cm high with a sharp tip is placed between two plates (with 1.4 meters and 2.0 meters of diameter) separated by 45 cm, leading to a gap distance of 15 cm. The high voltage power supply provides up to 20 kV DC at positive or negative polarity, and it is connected to the upper plate. This setup reproduces the conditions of sharp grounded

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structures subject to high electric fields when charged clouds are in the vicinities.

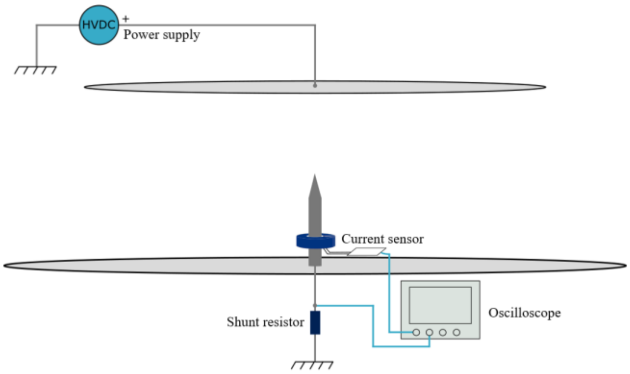

Fig. 1. Diagram of connections for the experiments in the laboratory.

We used a resistor in series with the grounding cable of the bottom plate with low inductance and low resistance to ensure that the shunt resistor would not affect the measurements. The current transformer is composed of a ferrite core with a secondary winding and a measuring circuit and does not affect the discharge circuit. For investigating one polarity of corona discharge, the opposite polarity was applied on the upper plate, in the setup described in Figure 1.

The shape of one single pulse is shown in Figures 2 (a) and (b), for respectively, -15 kV and +15 kV applied to the upper plate. The single pulse has a rising time of tens of nanoseconds and a duration of 200-300 nanoseconds. The current transformer presents a waveform representative of the measured discharges, and we applied a voltage ratio of 12 V/A for obtaining the equivalent current in amperes.

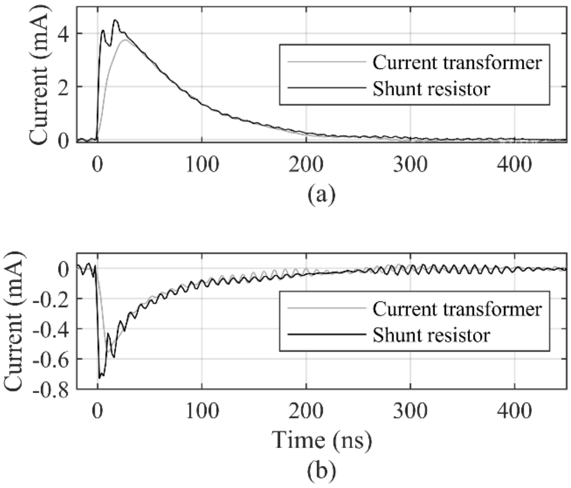

Fig. 2. Measurements obtained with the shunt resistor and the current transformer for (a) positive corona and (b) negative corona.

The waveform of a single corona pulse reveals some differences: First, in the recording shown in Figure 2, it is considered the same voltage applied (different polarity). The amplitude is higher for positive corona, with an average of 4.2 mA, while for negative, the average was 0.75 mA.

Pulses of positive discharges last longer than negative discharges. In a steady-state mode, when a DC voltage is applied, the frequency (number of pulses per second) of negative pulses is almost one order of magnitude higher than positive.

III. EXPERIMENTAL INVESTIGATION

For investigating the signatures of corona current from grounded rods, we used a conductive rod (about 1.5-meter-long) with a sharp tip placed over the ground surface. Fig. 3 shows the scheme of the installations. The current was measured using a shunt resistor and a current sensor. The resistor was placed in series with the grounding cable of the rod with low inductance and low resistance to ensure the quality of the measurements. The current sensor consisted of a ferrite core with a secondary winding and a measuring circuit and does not affect the discharge circuit.

The sensor provided detections that are correlated to the background electric field, measured by a 10-Hz electric field mill. The indications provided by the Field Mill consider the static component of the electric field. In this way, many lightning strikes happening within its sample rate cannot be perceived in the measurements individually. We also verified a lightning location network (Linet) to monitor the distances of lightning strikes to the sensor's site.

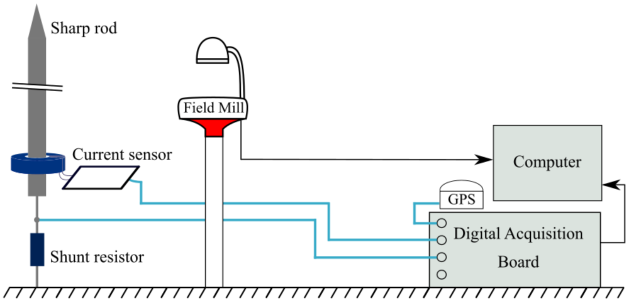

Fig. 3. Scheme of the setups for measuring corona discharges.

The first setup was installed over a typical roof of a building in Terrassa, Spain, and the second installation was performed in the Observatori de l'Ebre, in Roquetes, Spain. In this installation, the sensor's tip is 2 m above the ground level. Fig. 4 shows a picture of the installation of the sensor and the electric field mill, in both setups, separated by around 1 meter.

Fig. 4. Sharp grounded rod installed in the two setups: rooftop (left) and flat-ground (right).

At the beginning of the operation, both the shunt resistor and the current transformer were used for measuring currents through the rod. Fig. 5 shows the typical pulse recorded from the experiment, using an 8-bits digitizer in the rooftop setup. The signals were matched with the volt ratio of the current sensor obtained for discharges produced in the laboratory (12 V/A). The shape of one positive pulse presents a fast rise time (in the order of tens of nanoseconds) and decay of hundreds of nanoseconds, similarly to what is reported for laboratory experiments [5-6, 11-12].

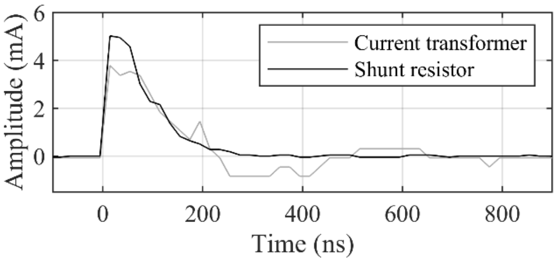

Fig. 5. Typical detection of pulse performed in the field comparing the current sensor and the shunt resistor.

The data obtained in the field allowed us to confirm several characteristics of the corona discharges. Pulses of positive discharges last longer than negative discharges. Their average amplitude is higher than negative pulses at the same E-field level (but opposite polarity). Conversely, their pulse frequency (number of pulses counted per second, over a nearly constant electric field) is lower.

For the following days of operation, the shunt resistor was removed from the sensor. Hence, only signals from the current sensor were recorded.

A. *Rooftop experiment*

For this setup, due to the buffer constraints of the digitizer and the sampling rate (50 MS/s) needed for recording the pulses, it was not possible to perform long-time acquisitions. In this work, all electric field waveforms are presented according to the atmospheric electricity sign convention [17].

Fig. 6(a) depicts a recording of the Field mill for an interval of 3 hours, on May 21st, 2019, when a thunderstorm approached the region of Terrassa. Fig. 6(b) shows a detailed portion of 20 minutes of electric field intensification. The increase in the background electric field started at 13:20 (UTC) and, at 13:22, when the electric field reached about -7 kV/m, the system started to detect a large number of positive pulses, for around 2 minutes. The only lightning activity in the vicinities was registered at 13:30, as it can be seen from a small step in the FM. According to the lightning detection network (Linet), it corresponded to an intracloud discharge 11 km far from the sensor.

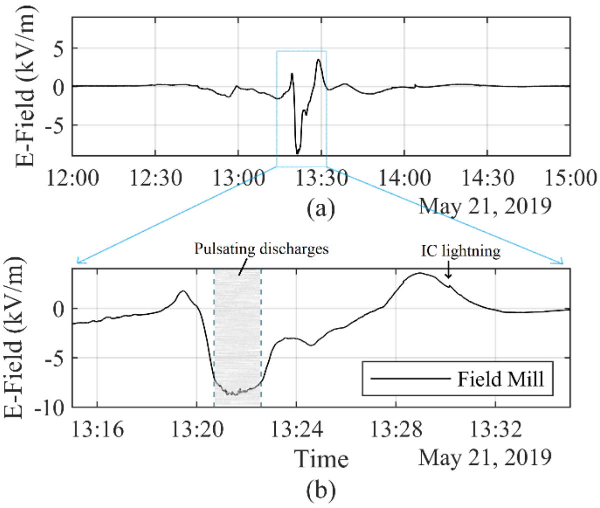

Fig. 6. Oscillation of the electric field over a 3-hour interval (a). Continuous detections of positive corona during a 2-minute depicted interval (b).

Fig. 7(a) depicts an interval of 10 minutes from the data of Aug 12th, 2019, in which several lightning strikes were observed. Since the field mill is a measurement of the quasi static electric field, the steps observed usually are related to all return strokes of a flash, or even different flashes that happened in a short time interval. Thus, the distances indicated by the arrows below the curve of the electric field are the distances to the nearest cloud-to-ground lightning strike detected by Linet.

Pulses were registered by the sensor at the instants shown by the dots. For the period shown in Fig. 7(a), they have negative polarity. One can note that all pulses exhibited were recorded after the step detected by the field mill, corresponding to periods of a few seconds of intense positive electric field.

A few hours later, on Aug 12th, 2019, more pulses were recorded, as seen in Fig. 7(b), in a time window of 20 minutes. One stepwise change in the electric field (labeled as ‘ND’) was not detected by Linet. Positive corona pulses were registered in high negative E-field, for several seconds before lightning strikes.

For the cases shown in Fig. 7(b), positive values of the E-field after the return strokes are probably not high enough for triggering negative pulses from the rod. However, in the event shown in Fig. 7(a), when the E-field is negative, one can see that it reaches similar values to the ones present in Fig. 7(b) (that led to positive corona detections), and positive corona was not detected in that specific interval. It is speculated that several other factors, such as humidity conditions, wind, and presence of water along the tip of the conductive rod can also affect the emergence of corona pulses from the rod, in such a way that establishing a E-field threshold for the discharges may not be consistent.

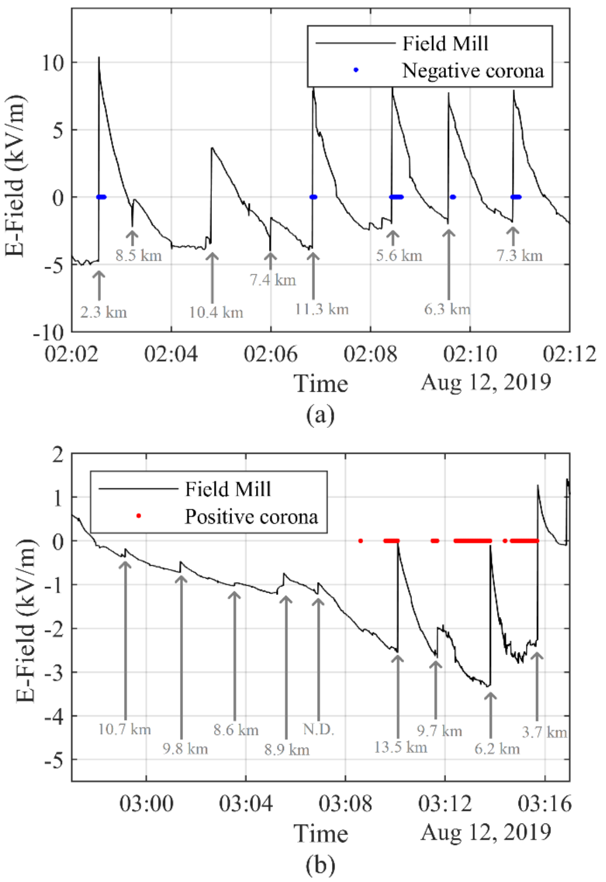

Fig. 7. E-field record leading to negative (a) and positive (b) discharges after and before nearby lightning strikes.

B. *Flat-ground experiment*

The digitizer used in this setup allowed performing acquisitions at 33 MS/s in time intervals of 1 second. The grounded rod was placed 2 m above the ground level, in a flat area, with trees and shrubs, including some taller than the sensor. For this reason, during the campaign, we did not observe as many events as for the rooftop site.

Unlike the roof experiment, in which pulses were recorded continuously during periods of sufficiently high electric fields, the corona pulses obtained at this site were recorded only during fast variations in the electric field resulting from near lightning strikes. We also detected part of the atmospheric processes' signature in VHF due to the grounded rod behaving like an antenna. In this way, we considered only corona discharge pulses with similar features to those obtained in the laboratory, and higher amplitudes than the background noise.

Fig. 8(a) depicts a recording of the electric field for an interval of about 3 minutes, on Jan 21st, 2020, when lightning strikes were nearby the sensor's site. In Fig. 8(b) and (c), we show the current measurement obtained at the moment when the field mill reaches 7.1 kV/m. Due to the very different sampling rates of the two quantities, they are not displayed in the same figure. We indicate at time equals zero, a positive cloud-to-ground (CG) return stroke (RS) registered 4.2 km far from the sensor, with an estimated peak current of 12.5 kA. Negative current pulses start 70 milliseconds after the lightning strike and last for a short period (about 50 milliseconds). The pulse amplitude reaches approximately 4 mA and decreases until the pulses are indistinguishable from the VHF background noise.

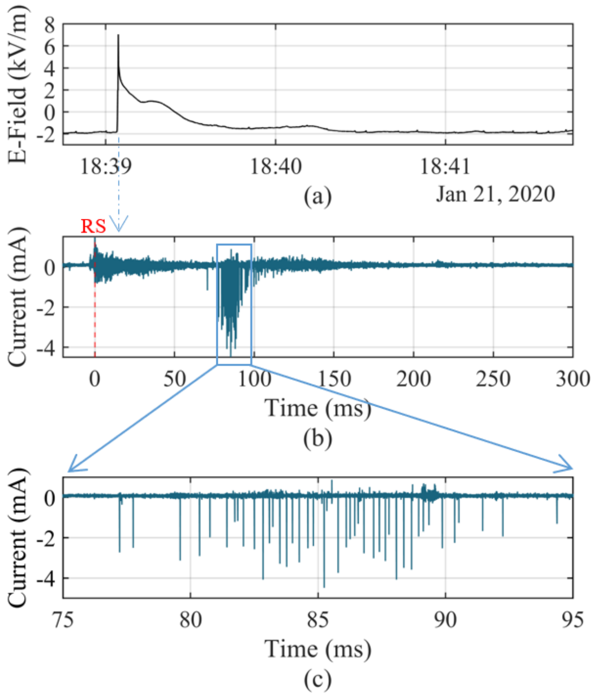

Fig. 8. E-field waveform of a positive CG lightning strike (a), that leads to negative corona pulses (b); enhanced view of negative pulses (c).

Fig. 9(a) shows a 3-minute field mill recording obtained on the same day. Three negative return strokes were detected in a wind farm at about 9.1 km away from the sensor. They exhibit a small VHF irradiated pulse measured by the current sensor, and together with our GPS allows for synchronization. The electric field reaches -5.2 kV/m and the return strokes have peak currents of -14.3, -9.1, and -4 kA, respectively. Several positive pulses with amplitudes greater than 10 mA start to be recorded 34 milliseconds after the first return stroke and cease after 150 milliseconds.

In Fig. 9(b), one can note that the highest concentration of pulses is observed after the third return stroke, and that decreases, as the interpulse interval increases and the electric field decreases. For the flat-ground setup, several events like the ones presented in Figures 8 and 9 were recorded.

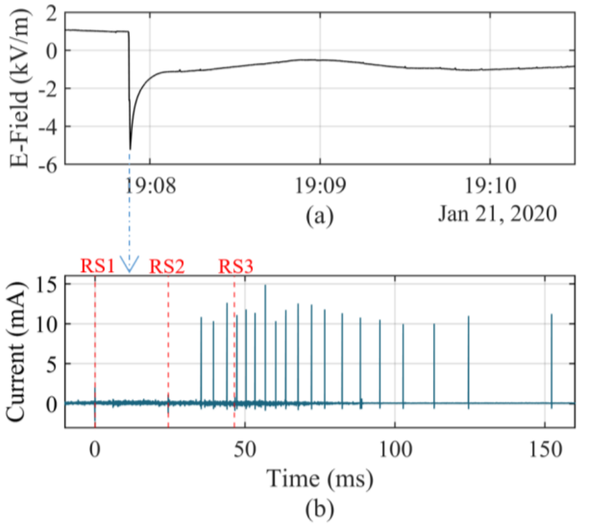

Fig. 9. E-field waveform of three negative CG lightning strikes (a) that lead to positive corona pulses from the grounded rod (b).

IV. DISCUSSION

From Fig. 8, the appreciable VHF content observed after the positive CG suggests that the movement of charges inside the cloud causes the emergence of negative corona pulses from the rod. The corona pulse polarity is not associated with the polarity lightning strike, depending only on the local electric field. We also observed positive pulses after positive strikes, which could be the precursors of negative upward leaders from grounded structures.

Table I shows the results of corona pulse parameters obtained in our setups, with their respective deviation. The rise time was determined as the time interval from 10% to 90% of the peak current. The charge per pulse was also calculated, but due to reflections on the decay of many measured waveforms, we do not present this data for the Rooftop setup.

TABLE I. CORONA PULSE PARAMETERS

Site	**Polarity**	**Rise time (ns)**	**Duration (ns)**	**Peak Current (mA)**	**Charge per pulse (nC)**
Rooftop	+	24 ± 2	364 ± 3	17.0 ± 3.6	--
	-	16 ± 4	320 ± 3	4.2 ± 1.9	--
Flat-ground	+	59 ± 9	516 ± 24	10.9 ± 1.6	2.3 ± 0.3
	-	44 ± 18	350 ± 49	2.7 ± 1.5	0.4 ± 0.2

The rise time observed for positive pulses (tens of nanoseconds) is significantly higher than for negative pulses in both setups, although their values are significantly different between the two setups. This is likely due to the different sampling rates and the actual bandwidth of the current sensors. The duration of the pulses is also higher (320 to 500 nanoseconds) for positive pulses.

The average peak currents obtained are about four times lower for negative pulses in both setups. The amplitude of negative pulses seems to be more variable than positive pulses, as indicated by the deviation. The noticeable difference of negative pulses' amplitude can be exemplified in Fig. 8, whereas this is not remarkable for positive pulses (as seen in Fig. 9).

Since positive pulses are in average longer, and higher than negative pulses, their charge per pulse is much greater (2.3 nC per pulse versus 0.4 nC).

V. FINAL REMARKS

Corona pulses of negative and positive discharges from sharp grounded rods were measured with an optimized current sensor in two different installations. We present waveforms and pulse parameters obtained from measured data.

We observed that the rooftop setup was more susceptible to register corona discharges than the flat-ground setup, presenting steady detections over several seconds. For other grounded structures, such as high towers and wind turbines, the enhancement of the local electric field plays an important role. Consequently, corona discharges are expected to be more recurrent for lower levels of background electric field.

With the results obtained, we confirm that pulsating corona discharges, in addition to forming during the approach of descending leaders, as shown in [6], can also occur before and after lightning strikes nearby, or when atmospheric activity it is very far, but the electric field is high enough.

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