On-site experiments and electromagnetic modelling to characterize Corona discharges in VHF-band

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1. ABSTRACT

Corona discharges have been shown to disrupt aeronautical VHF communications after some research on broadband noises carried out by the Electromagnetics and Antennas research group of ENAC laboratory.

A stand-alone measurement device is set up and installed on a 25 m test tower to characterize corona discharges events.

The measurements show differences in behavior and coupling mode whether the discharges are positive or negative.

In addition to this experimental work, an electromagnetic modelling has been done using the experimental measurements in order to reproduce experimental results and retrieve the coupling mechanisms between the positive and negative discharges on the pylon.

2. INTRODUCTION

For decades, VHF communications have been disrupted at ground stations. Several sources of noise are known to interfere with VHF communications and most of them have been treated [1] [2] [3] [4] . Although solutions have been found for these problems, interference phenomena still exist, in particular in aeronautical VHF communications. These interferences have been attributed to corona discharges [5] i.e., partial electrostatic discharges which can occur at the top of pylons, where VHF communications antennas are installed on, during stormy weather. Yet, the sufficient intensity of the disturbance to interfere with a communication system is not known. It is therefore interesting to know if discharges appear in several places and at what intensity they shall cause interferences to communications.

The objective of this paper is to present an acquisition system on a test pylon that allows to study corona discharges in natural environment. With this experiment, it is possible to build up a numerical modeling of the problem to help having a better understanding of the couplings. This could lead to find solutions to protect VHF communication setups against these disturbances.

In this article, the first section presents the acquisition system that has been set up to measure corona events on a test pylon. Then, both positive and negative corona events are presented and analyzed. The modeling work is also presented. The source modeling is firstly explained, and the comparison between measurements and simulations is shown. Finally, the coupling levels between the antenna and the discharges are analyzed.

3. STUDY OF ELECTRICAL DISCHARGES ON A TEST PYLON

3.1 Installation of an acquisition system on a test pylon

Corona discharges mainly occur on elevated metallic structures. In order to record corona discharges signatures, an autonomous acquisition system has been designed to obtain a significant database to understand the diverse phenomena occurring on the 25 m high pylon located on the site of the Direction de la Technique et de l'Innovation (Technical and Innovation Department) that is attached to the Directorate General of Civil Aviation which can be seen on the Fig. 1.

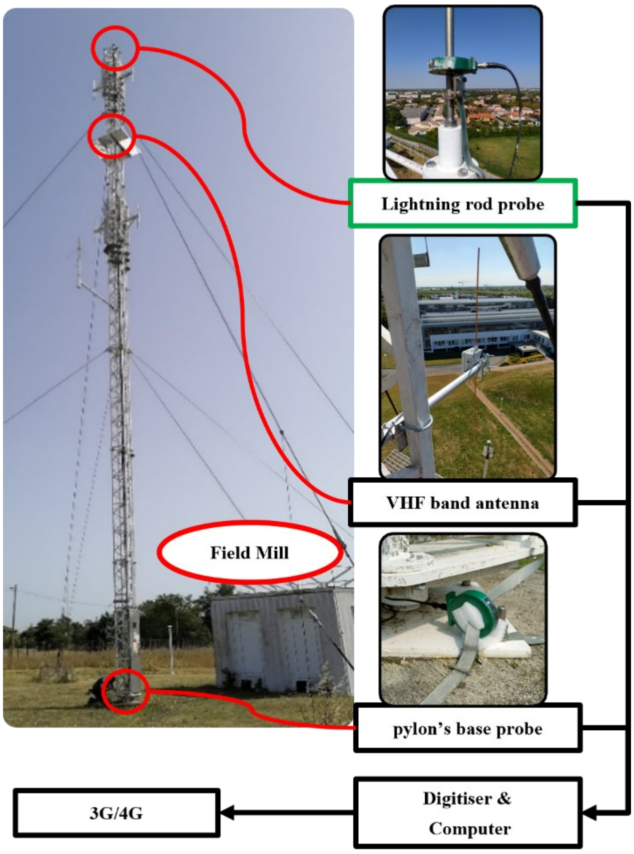

Fig. 1. Diagram and images of the acquisition system components

To measure these events, it was chosen to first instrument the lightning rod because the probability of measuring corona discharges is the highest due to the peak effect. A probe is also placed at the base of the pylon to measure all currents flowing on the pylon. The probe is not large enough to surround the entire pylon's base. So, it is placed around one of the ground cables. A calibration had to be carried out to know the distribution of the currents at the base of the pylon, as the probe measures between 10 and 15% of the total current.

These probes are analogical current transformers. For the lightning rod the conversion rate is 0.5 V/A and 0.1 V/A for the probe at the base of the tower. The measured current is positive when the electron flow is towards the ground.

In addition to the probes, an amplified VHF dipole antenna is also placed at a 20 m-height. It measures the noise in the relevant frequency band that is between 117 MHz and 137 MHz

Finally, a field mill is installed on the building next to the pylon to measure and correlate the ambient electrostatic field and to know the actual weather conditions.

These sensors are connected to a digitizer that is triggered by the lightning rod current and to stand-alone computers to retrieve the data remotely. The sampling time of the digitizer is 6.4 ns.

3.2 Analysis of corona effect on a test pylon

The acquisition system is able to record positive and negative current pulses combs at the current probe placed at the base of the lightning and on the antenna. In this section, these measurements are first analyzed to identify corona discharges. Then, the effect of these discharges on the antennas is studied.

3.2.1 Identification of corona effect on recordings

Here, two recordings are studied to illustrate a comb of positive pulses and a comb of negative pulses.

First, Fig. 2 shows the electrostatic field in kV/m as a function of time on 26 June 2021 between 21:15 and 23:15 measured by the field mill. The sampling time is 10 seconds for standard conditions. It increases to 1 second in stormy conditions. Stormy conditions correspond to a field higher than 1 kV/m. This measurement shows significant electrostatic field activity signifying an intense storm activity. The rapid variations of the field represent distant lightning strikes. The results presented here are those that took place at 21:52 (blue dot) for the negative pulses and at 22:13 (green dot) for the positive ones.

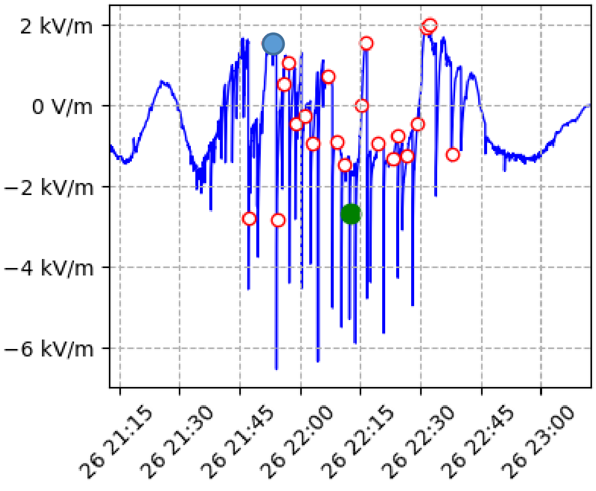

Fig. 2. Electrostatic field measurement on the 26.06.2021

Identification of positive discharges

The event that occurred at 22:13. is shown in Fig. 3 where there are two currents measured by the probes and the voltage measured by the antenna during 50 ms. The first observations are the activity at the lightning rod (top) and on the antenna (bottom). The current at the base of the pylon (middle) is not significant due to the low sensitivity of the probe.

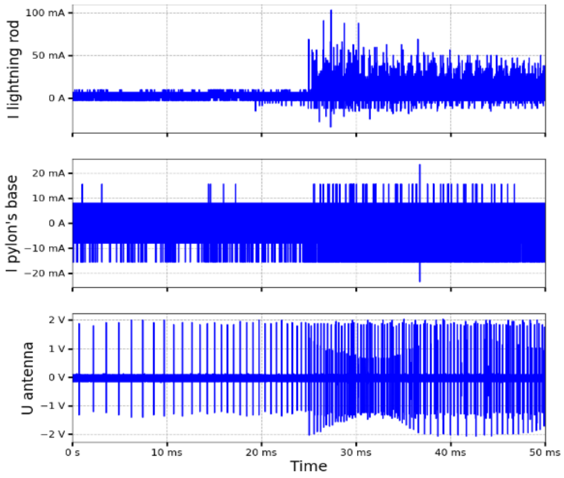

Fig. 3. Recording of positive discharges obtained by the acquisition system on 26.06.2021; top: lightning rod current, middle: pylon's base current, bottom: antenna voltage

Before 25 ms, there is no current on the lightning rod while there are bipolar voltage pulses on the antenna. The pulses reach an average peak of 2 V and -1.2 V. After 25 ms, another comb of pulses seems to superimpose to the others and show weaker positive and higher negative levels, at the antenna. Also, the current on the lightning rod is positive and reaches up to 100 mA. It contains many pulses of different intensities.

Fig. 4 shows a zoom of the current on the lightning rod. The current seems to be characteristic of a corona discharge. Indeed, a corona pulse is similar to a capacitive discharge and can be approximated with a biexponential law [6] . The current pulse lasts 300 ns and reaches up more than 50 mA.

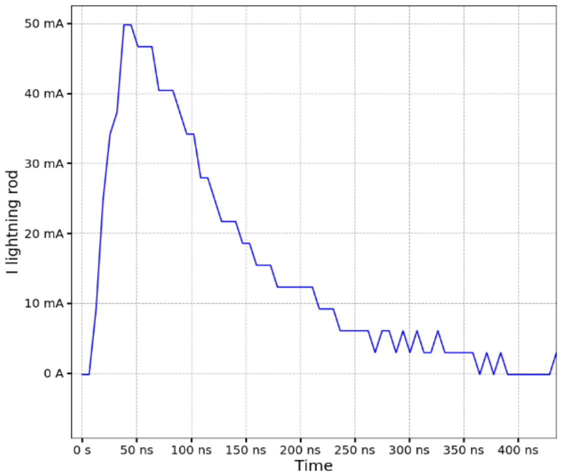

Fig. 4. Positive current pulse on the lightning rod of the event studied

The acquisition system measures corona events on the lightning rod and on the antenna. The comparison between measurements on Fig. 3 shows that there seems to be no correlation between the discharges on the lightning rod and on the antenna. Also, the activity on the antenna increases when the activity on the lightning rod starts at 25 ms. It seems that there is a little activity on the base current too. It is also clear that the corona discharges on the antenna interfere with the functioning of the antenna. Finally, it should now be investigated whether the lightning rod discharges can be correlated with the antenna signal by means of spectral analysis. It is also interesting to note that the corona discharges started to occur on the antenna first, even though it is located several meters below the lightning rod.

<u>Identification of negative discharges</u>

The following recorded event took place during the same storm as the one previously presented. It is represented by the blue dot in Fig. 2, when the electrostatic field is nearly at 2 kV/m. This event can be seen in Fig. 5 which shows the graph of the current on the lightning rod (top) and the voltage on the VHF dipole (bottom) as a function of time.

On this recording, we can see that there is no activity on the antenna but a permanent negative activity on the lightning rod. This activity corresponds to a comb of negative pulses of different intensity down to -35 mA.

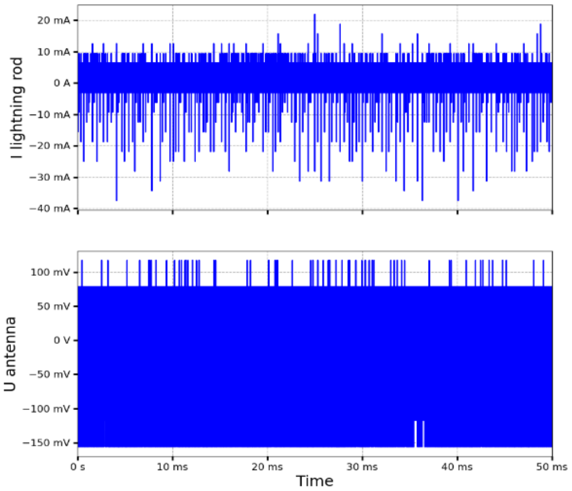

Fig. 5. Recording of negatives discharges obtained by the acquisition system on 26.06.2021; top: lightning rod current, bottom: antenna voltage

Fig. 6 shows a zoom on a current pulse measured on the lightning conductor. This shows a bi-exponential pulse with resonance after the rise of the pulse. This pulse lasts less than 100 ns, with 10 ns for the rise, and reaches up -30 mA.

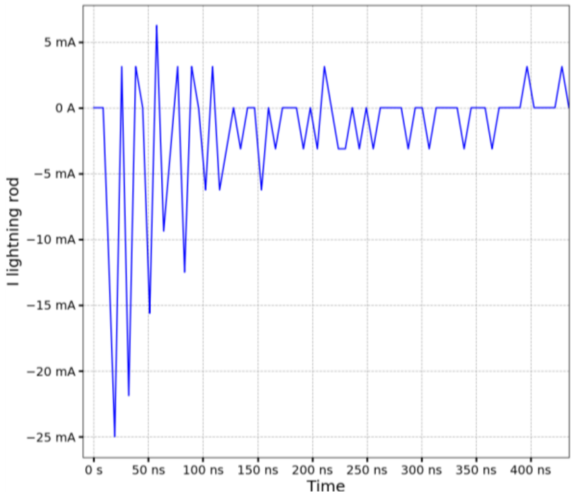

Fig. 6. Negative current pulse on the lightning rod of the event studied

There is a difference in the behavior of positive and negative pulses. The activity on the pylon is more intense when positive pulses are present at the 1st order.

Also, there is a resonance on negative pulses. This is probably due to the faster rise time than for positive pulses. As the sampling time (6,4 ns) is too low to analyze the resonance frequency of the pulse, it is not possible to check whether this resonance corresponds to the lightning rod resonance.

4. NUMERICAL SIMULATIONS OF CORONA DISCHARGE ON TEST PYLON

4.1 Reproduction of a current pulse with an RLC circuit in aperiodic regime

The current pulses follow a bi-exponential law. They can be modelled by a RLC type source circuit. This circuit must have an aperiodic regime.

To model the RLC source, a wire is placed above the lightning rod to radiate. This element replaces plasma of the discharge and has a capacitance. Between the lightning rod and the radiating element, there is the voltage source. In order to have a RLC source, the R and L components are added to the source.

The Nelder-Mead optimization method is used to retrieve values of R, L, C and V corresponding to the characteristics of the pulse (rise and fall time, maximum amplitude) measured in the natural environment.

4.2 Simulation of a discharge model on a 25 m high pylon

The pylon is modelled as a wire structure using a 3D software GiD. The source is placed above the lightning rod and a capacitance modelled by a wire.

For the simulation, the ground is considered as a PEC. A first simulation is performed with a simple source. The source has no RLC components and a voltage of one volt. This simulation is used to measure the capacity of the wire. The simulation code used for the simulation has been developed by ONERA [7]

The optimization method is used to find the other components L, R and V. The voltage must be adjusted at the end because the measurement is carried out at the base of the lightning conductor. In Fig. 7, the theoretical current resulting from using the optimization method to find the characteristic values of the RLC circuit and the measurement used are shown. There is also the simulated current using the RLC source on the 25 m tower. This result shows that the optimization method matches with the measurement.

Now, we apply the same method on the negative discharge. The rise time of this pulse is faster than the one before. The behavior of the discharge is higher in frequency. On Fig. 8, all three currents are shown. The peak of the theoretical current is lower than the simulated one. This is the result of a resonance. Even though the frequency resonance seems to be the same as the measurement, the resonance is not as strong. This result shows that this method is not enough to model negative discharges.

A simulation was performed only on the lightning conductor. A black curve is drawn on Fig. 9 This time, the oscillations of the simulated current have a larger amplitude. The simulation highlights the resonance of the lightning conductor.

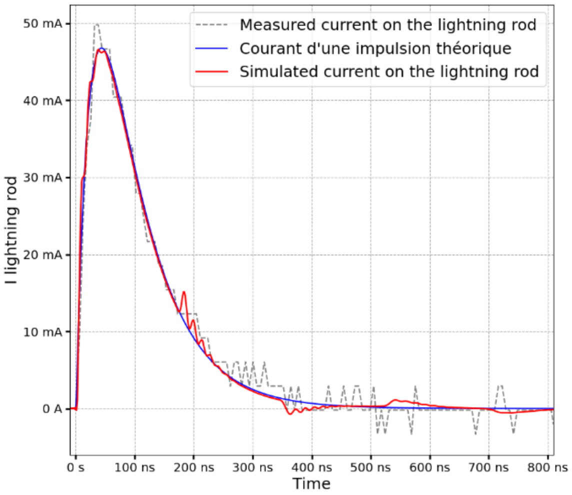

Fig. 7. Measured (grey), theoretical(blue) and simulated (red) current of a positive pulse

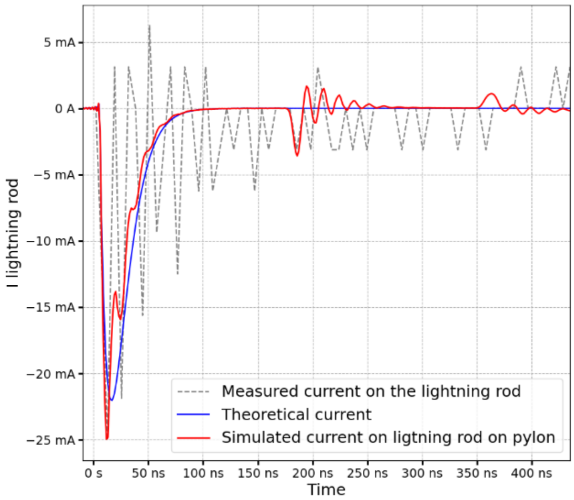

Fig. 8. Measured (grey), theoretical(blue) and simulated (red) current of a negative pulse

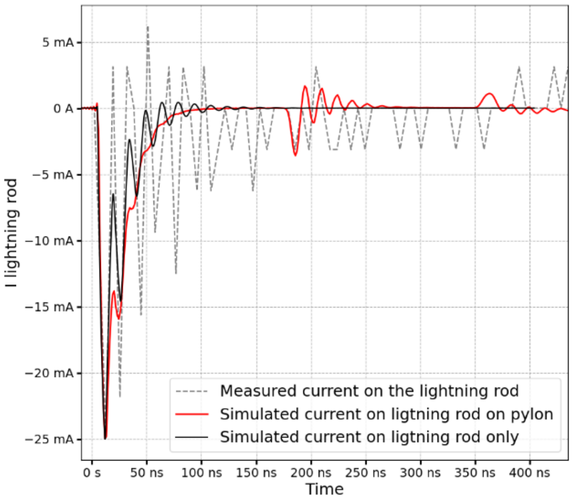

Fig. 9. Measured (grey) and simulated on lightning rod only (black) and on pylon (red) current of a negative pulse

By comparing the spectra of the different currents on Fig. 10, it is possible to see the resonance of the lightning conductor on the modeled tower.

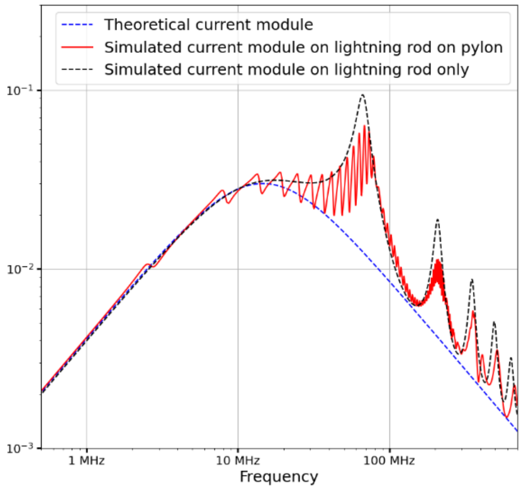

Fig. 10. Spectral of theorical (blue), lightning rod on pylon (red) and lightning rod only (black)

4.3 Study of the coupling between an antenna and a positive or negative pulse using simulation on a 25 m tower

After checking that the positive and negative discharge patterns are correct, it is necessary to look at the coupling levels with an antenna. On Fig. 11, the antenna voltage is shown for a negative discharge in blue and a positive discharge in red. The highest voltage is reached when the discharge is negative whereas the intensity of the source is higher for positive discharge.

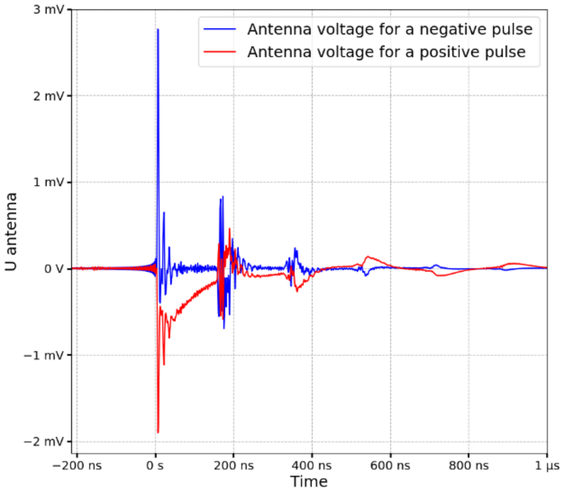

Fig. 11. Voltage of an antenna placed on the modeled pylon

Also, it is possible to see a resonance for both discharges that happens every 200 ns.

Finally, this simulation shows that the coupling between negative discharges on the lightning and rod and the antenna can be stronger with lower intensity. It means that a spectrum analysis of the measurement of the antenna is important to see if we can observe a correlation between the negative discharge on the lightning rod and the antenna.

5. CONCLUSION

An acquisition system has been designed with the objective of recording corona events. Positive and negative corona events have been identified. This type of instrumentation can be installed on other pylons such as larger operating pylons to compare discharge levels.

Corona discharges are capacitive discharges. Their current is approximated with a biexponential law. A RLC circuit source in aperiodic regime can reproduce this current. By using an optimization method, RLC components have been found to model a corona source on a pylon.

Simulations were used to retrieve the measurements for both positive and negative discharges. This method is good for positive discharges, but it has a lack of efficiency for reproducing the resonance that exists for negative discharges because of the rising time that is faster. This method still reveals the resonant frequency of the pulse current.

The simulations were used to compare the coupling levels produced by a corona source observed on an antenna located on the pylon in the VHF frequency band.

These results are necessary in order to use a simplified model to replace the classical discharge models with which it is difficult to perform simulations on large problems. Now, it is necessary to obtain new measurement with higher sampling step allowing to cover the frequency band which interests us.

Finally, simulation work on the elementary discharge can be performed to improve the discharge model.

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