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Electric Field Sensor Calibration Using Horizontal Parallel Plates

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***Abstract*—This paper describes details of an electric field sensor calibrator. The electric field sensor (field mill) is used to measure the atmospheric electric field. This calibrator is a parallel plate capacitor capable of creating electric fields near the atmospheric condition of fair weather, ie, without clouds and also electric fields observed during storms. The details of this system and the methodologies for the calibration of the electric field sensors as well as a study of the electric field generated in the calibrator are presented. Results of measurements of the atmospheric electric field in different local conditions, fair weather and storms are also presented.**

Keywords— calibrator, electric field, electric field homogeneity, electric field measurements, "field mill", storm, fair weather

I. INTRODUCTION

Electrical field sensing devices are important for monitoring the local electric field intensity variations in fair weather and also in the presence of storm clouds. These sensors can emit warning of the possibility of lightning strikes in the region, which allows the taking of preventive and protective actions by the people located in the area of coverage of the sensor. The sensors are calibrated so that the data obtained are reliable, allowing the use of sensors in different types of applications. The calibration of the sensor is a crucial step for the development of an electronic device. Special care may be given to the instrumentation, montage of the experimental apparatus and standardization when exists.

The Laboratory of Atmospheric Sciences (LCA) of the Federal University of Mato Grosso do Sul (UFMS) developed a system to calibrate these electric field sensors. The description of the calibrator is the subject of the present work. The developed calibrator basically consists of a capacitor of parallel plates separated by a known distance d and applying a known potential difference (DDP). The intensity of the electric field (E) between the plates is determined by using the equation E = V / d. In the literature, there are studies that discuss such calibration systems [1,2,3] and also manuals of electric field sensors [4,5] comment briefly on their calibration by their manufacturers. The present system consists basically of a large capacitor of parallel plates, which has a much smaller aperture in the center of the upper plate than the area of the plate so that the electric field generated between the plates can be considered parallel (homogeneous / uniform). In this opening is placed the sensor to be calibrated, to measure the electric fields generated.

This paper presents a brief description of the electric field sensor and a detailed description of the operation of the calibrator and the calibration process of the electric field sensor. A figure is presented which illustrates the homogeneity of the electric field generated inside the calibrator as a function of the distance from the edge of the plates.

Calibration curves obtained are shown for a fixed distance between the calibrator plates. Results of measurements of electric field strength in different local weather conditions, fair weather and storms, are also presented. The calibration of the sensor is a crucial step for the development of an electronic device. Special care may be given to the instrumentation and montage of the experimental apparatus.

The contribution of this paper is to elucidate several aspects of the calibration process that are not included in the user´s guide of the manufacturers of sensors that are sold around the world. The calibration process is based on processes that are standardized for IEEE 1227^{TM} 1990 (R2010) [1].

Considering the number of variables to be analyzed about the capacitor dimensions and fringing effects, the importance of these analyzes, and some technical aspects of the arrangement of devices used in the calibration, the authors decided present these results in a future paper.

II. Methodology

A. Brief Description of Sensor

The intensity of the electric field can be determined by measuring the induced charge, current or voltage across a localized impedance between a sensor electrode and the earth between a sensor electrode and the earth [1,2,4,5].

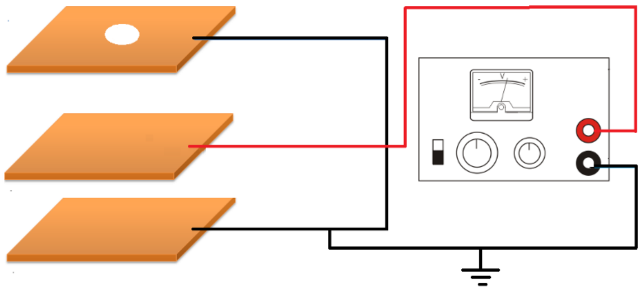
The sensor consists of a mechanical and an electronic part. The mechanical part is divided into a fixed part and a rotating part. In the fixed part, there are a set of eight sensors fixed on insulating supports, oriented vertically downwards. The rotating part consists of a pierced disc, with four holes attached to a grounded rotor (rotor) rotating at 100 Hz, which covers and exposes the sensor elements alternately to the local electric field. This movement causes induction of charge and subsequent discharge of the sensing elements, which generates an alternating voltage signal, which is filtered, amplified and rectified. The electric field signal is read by an AD converter, which is controlled by a microcontroller. This microcontroller also receives information from a GPS module, collecting the time, date, latitude, longitude and altitude information of the location of the sensor. Then, this information is sent to the computer through a protocol, where the data is processed and a graph of the local electric field strength is displayed as a function of time, which is made available on a web page.

B. Detailed Description of the Electric Field Calibrator

A known uniform electric field can be generated by parallel plates since the spacing between them is small compared to the dimensions thereof. The desirable characteristics of an apparatus which generates the electric field for calibration are: a) The uniform field region must be large enough to reduce the uncertainty in the field strength value to an acceptable level in the probing region; b) The electric field is not significantly disturbed by nearby objects or by the operator performing calibration; and (c) The dimensions of the equipment shall be sufficiently large such that the sensor does not significantly disturb the charge distribution on the surface of the electrodes generating the field. A parallel plate calibrator can be used to generate a known electric field and also meet the above criteria [1,2,3].

The calibration system developed consists of a regular hexagonal wooden box placed horizontally, with two horizontal compartments. This calibrator is an adaptation to that of Campbell Scientific, Inc, also described in [3]. The measurement on the side of the hexagon is 59 cm. Inside this box were fixed metal plates in the form of a circular disc, constituting a capacitor of parallel plates in the horizontal. In the center of the top wooden plate and also the metal was made an opening for the insertion of the sensor to be calibrated. Fig. 1 illustrates this detail. The diameters are 17.0 cm and 14.5 cm respectively.

(a)



(b)

Fig. 1 a) Electrical field calibrator assembly details; b) Diagram of electrical connections.

The spacers of the plates are also made of wood. In the upper, intermediate and lower internal parts, polished stainless-steel discs are glued. Their diameter is 95.0 cm. These details can be seen in Fig. 1

Fig. 2 shows more details of the electric field sensor inserted in the calibrator for later calibration. Basically, the calibrator consists of a parallel plate capacitor.

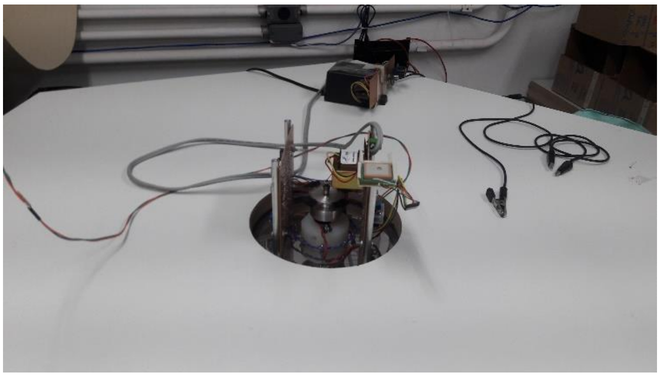


Fig. 2 - Installation of the electric field sensor for calibration purposes.

Details of the top plate are shown in Fig. 3, where the insertion cavity of the instrument to be calibrated can be observed.

Fig. 3 - Detail of the top plate of the electric field calibrator.

The metal discs of the upper and lower parts are connected to the ground and the intermediate to the positive of the DC power supply, thus generating a parallel (uniform) electric field between the plates, which depends on both: the distance between them and the applied DDP.

The calibration is done by applying a DDP between the plates with the sensor inserted in its position, the sensor elements being parallel and at the same level as the upper metal plate. The sensor case and the external plates are connected to the ground [1,3].

The calibration curve of the sensor is taken up by varying the DDP applied between the plates and recording the output voltage recorded by the sensor for each value of DDP applied. As the distance between the plates is fixed, for each value of DDP applied, it is known which is the intensity of the electric field to which the sensor is submitted. This variation of DDP is made so that the intensity of the electric field generated varies from -10 kV / m to +10 kV / m. In this way, a response curve is constructed for each sensor. Through the response curve, an equation is obtained that will be used to obtain the calibration of the sensor. The corrected equation is recorded in the sensor's internal programming.

The equation of the response curve is of the type:

$$E = aV + b \tag{1}$$

where the intensity of the electric field E is equal to a constant which multiplies the output voltage V of the amplifier of the sensor, plus a constant b which depends on the constructive (geometrical and electronic) characteristics of the sensor.

The power supply consists of a voltage transformer and an input voltage regulator, allowing to control the variation in the output voltage of the transformer, which goes to a voltage rectifier source. A digital multimeter (Politerm Mark, model POL-78, 4.1 / 2 digits) is used to read the DC output voltage that is applied between the metal plates.

Through the power supply, different voltages are applied on the plates and consequently resulting in different applied electric fields. The sensor response reading is made after approximately 20 seconds of voltage application, or the time required for stabilization to take place. This procedure is performed after each voltage variation applied.

III. RESULTS AND DISCUSSION

A known uniform electric field can be generated between parallel plates since the spacing between them is small compared to the dimensions of the plates. According to the literature [1], in this case, the onset of electric field uniformity due to the edge effect starts at 0.1% of the distance between the plates, from the edge.

The uniformity of the electric field between the plates for a given distance between them can be evaluated by the ratio of the distance x measured from the edge of the plate to the center by the distance d between them. For a ratio $x/d \geq 0.5$ the electric field E/E_1 is almost uniform [1]. The ratio E/E_1 is the normalized electric field where, E is the value measured as a function of position and E_1 is the field value measured at the center of the calibrator, and x/d is the normalized distance, where x is the distance measured from the edge of the disk and d, the distance between the metal disks of the sensor and the plate of the calibrator.

In our case, d = 2.5 cm and x = 47.5 cm, where d << x. Measurements of the electric field strength were performed as a function of the sensor x position. Fig. 4 shows the normalized electric field E/E1 versus x/d. Negative values for x/d mean that the sensor is out of the calibrator.

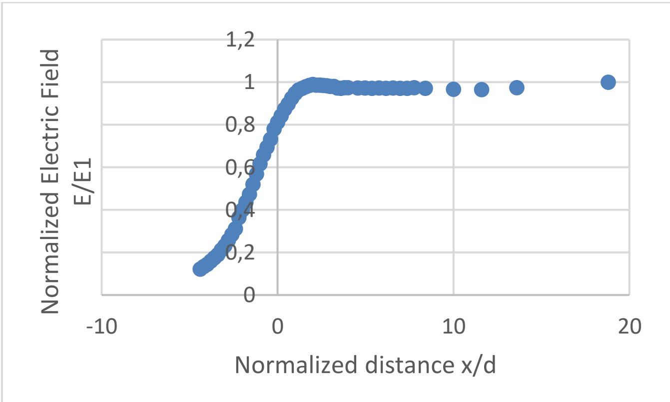


Fig. 4 - Electric field normalized as a function of the normalized distance for the electric field calibrator.

It can be seen in Fig. 4 that from a distance d from the edge of the disk, the electric field is almost uniform. This shows that the homogeneity of the electric field produced by the calibrator in question occurs from a small distance d from the edge of the disk, which reflects in an optimal system to carry out electric field calibrations. The homogeneity of the electric field generated in the parallel plate calibrator is verified. If we compare this result with the literature [1], we note that in this case, the homogeneity of the electric field occurs from x / d ≥ 1. This may be related to the fact that we use a capacitor of circular parallel plates.

Several electric field sensors were calibrated using the calibration system described herein. The response curves were obtained by applying an electric field between + 10kV / m and -10kV / m for the calibration of the sensors. In Fig. 5 a typical response curve of the electric field sensor is presented to the applied electric field.

After the sensor response curve is obtained, it is recorded in the sensor's internal programming. For the final calibration, the sensor is subjected to a zero electric field, ie the calibrator plates are shorted and grounded, for correcting the value of b in equation 1. After this, final calibration, a fixed (known) electric field value is applied in the calibrator for several hours and then the mean value is calculated to verify if the read value should be very close to the applied field.

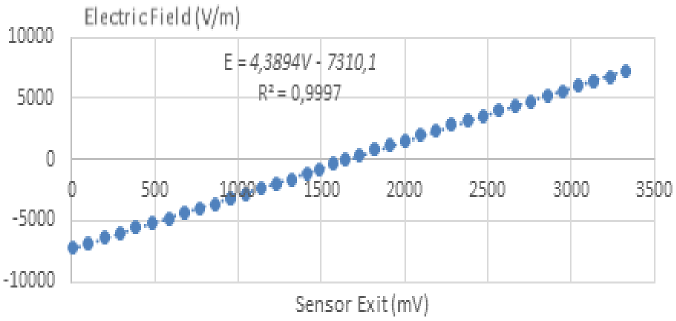


Fig. 5 - Typical response curve of the electric field sensor to the electric field applied in the calibrator (calibration curve).

The response curve can be obtained from the mean of several measurements without changing the experimental conditions [3]. Five calibrations were performed for the sensor. The response curve obtained by taking the mean values of the coefficients resulted in:

$$E = 4.4779V - 7235.96 \tag{2}$$

where E is the electric field strength read by the sensor and V is the sensor output voltage. The angular coefficient of the equation has a standard deviation of 0.0679 V / m and the linear coefficient, 161.54 V / m.

According to Fig. 5, it can be observed that the response of the sensor to the applied electric field presents a linear behavior and R^2 very close to one. The same behavior was observed for all calibrations performed.

The resolution of the sensor, ie the response of the same to the application of a constant electric field, shows a variation in the electric field strength measured in the case of the low field is ± 4 V / m around the mean value, as shown in Fig. 5 and for the high field is ± 70 V / m.

Fig. 6 shows the values read by the sensor for an applied electric field zero value. The read field strength has an average value of 46.87 V / m with a standard deviation of ± 0.65 V / m, within 2 hours. In this case, the value of 47 V / m shall be subtracted from the value of the linear coefficient b of the calibration curve. This completes the calibration process and the sensor is ready to be installed and send data to the site.

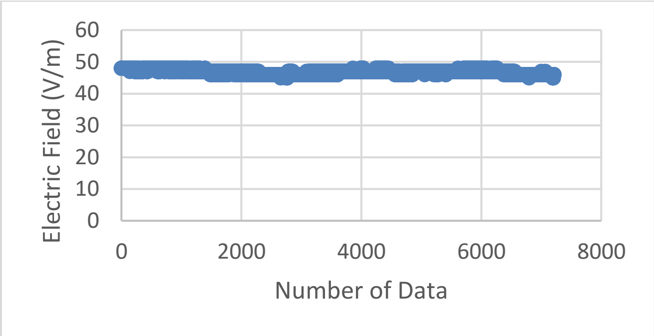


Fig. 6 - Measurements of the electric field sensor measured in the laboratory, for a zero-field applied in the interval of 2 h.

Fig. 7 shows measurement results of the electric field sensor for the case of a constant electric field applied for approximately 16 h. The mean value was 418.63 V / m with a standard deviation of ± 5.45 V / m. This shows the stability of the sensor.

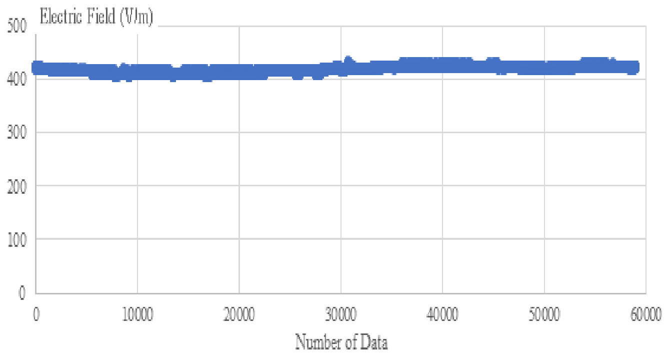


Fig. 7 - Electrical field measurement for the case of an applied constant electric field.

The electric field sensor, after being calibrated as described above, is installed on the site to measure the local electric field strength. The records are sent in real time to a database, where they are processed, recorded and presented through a graph of the intensity of the electric field as a function of time in the site lca.ufms.br.

An example of both fair weather and storm recorded electrical field measurements are shown below. The recorded data are presented in graphs with a time interval of one hour, being updated every 30 seconds.

Examples of the measured atmospheric electric field during fair weather and during storms recorded by the calibrated sensors are shown in Figs. 8 and 9.

Fig. 8 shows a graph of the intensity of the typical electric field of fair weather as a function of time recorded by the sensor, whose value is approximately - 150 V / m.

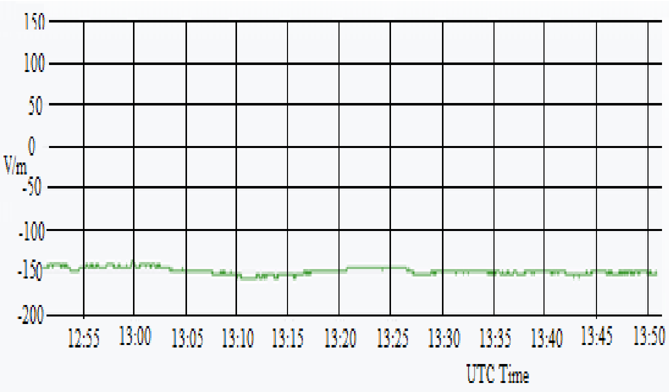


Fig. 8- Fair weather electric field of 05/13/2019, between 12:50 h and 13:50 h, in Campo Grande – MS.

Fig. 9 shows the intensity of the typical electric field recorded for a storm with many electric discharges. This low intensity in the recorded electric field may be due to the large distance between the storm cloud and the electric field sensor. One can also observe the oscillation during the end of the storm (EOSO) when the electric field returns to the fair weather values.

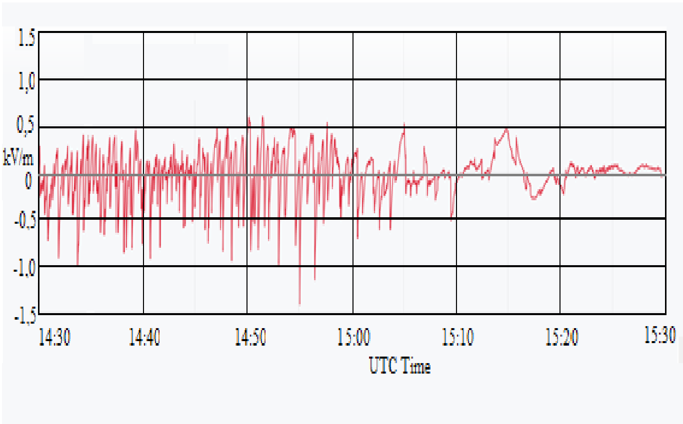


Fig. 9 - Shows part of the storm of 03/05/2019 between 14:30 and 15:30 h (and its end), in Campo Grande – MS.

All recorded data of the intensity of the Electric Field are presented in the graph in real time, covering the time interval of one hour, and updated every 30 seconds. This data is recorded and archived in a database for further processing and analysis.

IV. CONCLUSIONS

The use of a capacitor with the dimensions presented in this work was efficient for the calibration process of the Electric Field sensors.

The homogeneity of the electric field generated in the parallel plate calibrator is verified. If we compare this result with the literature [1], we note that in this case, the homogeneity of the electric field from the edge occurs from x / d = 1 and not for x / d = 0.5. This may be related to the fact that we use a circular parallel plate capacitor.

The resolution of the sensor, ie the response of the same to the application of a constant electric field, shows a variation in the electric field strength measured in the case of the low field is ± 4 V / m around the mean value, as shown in Fig. 5 and for the high field is ± 70 V / m.

The electric field in the most central region of the calibrator is uniform, since the distance between the plates is much smaller than the radius of the calibrator metal disk.

The response of the electric field sensor is linear in the calibration interval.

Typical electrical field records in fair weather and storm conditions were obtained, showing that the sensor has the capacity to represent these events well by measuring the electric fields.

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