ELECTRIC FIELD DETECTOR FOR HUMAN PROTECTION

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Abstract: Electrical substations and high voltage overhead transmission lines are potential sources of accidents for linemen working in generation, transmission and distribution of electrical energy. For the mentioned reasons it becomes very important to develop warning systems to inform linemen about the proximity of high voltage sources. In the present paper advances of the design, development and characterization of an electric field warning device are presented.

INTRODUCTION

The human been is not able to perceive distant electrical currents or the presence of low electrical forces. This is one of reasons why many electrical accidents can not be prevented.

In Colombia the companies involved in the electrical sector are forced to take measures to prevent the occurrence of working accidents in the operation zone of their electrical networks.

For this reason, a research and development project to construct a portable device to warn the electrical workers on the proximity of high voltage sources, was financed by the electrical company EEC and the Colombian Research Institution COLCIENCIAS.

The developed device was an electric field sensor that generates a voltage signal proportional to the applied electric field. The signal was amplified and transformed into an acoustic and luminous alert with electronic instrumentation. This allows linemen to take the necessary preventive measures during their approach to high voltage sources. This is common during maintenance or repair activities in substations or overhead distribution lines.

Due to the fact that the objective of this project is to prevent accidents, save lives and understand the electromagnetic characteristics of the linemen working environment, it is necessary that the prototype fulfills reliability and robustness requirements. The electronic components should not be affected by high electric fields present in substations and transmission lines. Additionally, the prototype should be portable and have an ergonomic design.

SUBSTATIONS AND DISTRIBUTION LINES ELECTRIC FIELDS

A key component in the development of the present project is to know the electric field environment – electric field amplitudes – present in a typical medium voltage transmission line or substation. For this reason, the first step was to simulate a typical 13.2 kV distribution line to obtain the environmental electric field values.

Assuming the typical dimensions of the 13.2 kV distribution line shown in the Fig. 1, the electric field values at different heights were obtained by using the finite elements simulation program ANSYS ®.

The obtained results showed that the electric field underneath a distribution line varies between 30 V/m and 40 V/m at 1.5 m above the ground level (see Fig. 2). With this electric field threshold values the electric field sensor was designed.

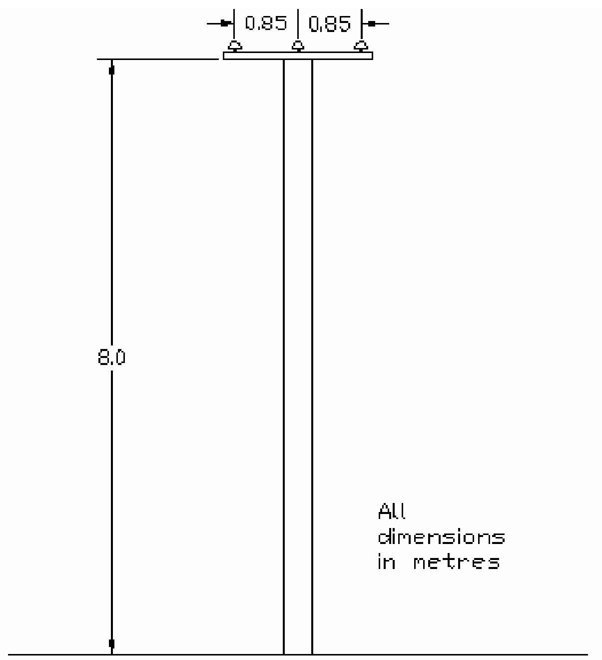

Fig 1. Typical dimensions for a 13.2 kV line.

ELECTRIC FIELD SENSOR

The designed sensor for detection the background electric field was a capacitive voltage divider which uses two different capacitors. The first capacitor is formed by two copper lines of 1 mm wide with a 1.5 mm separation. The second capacitor was formed by two 50 μm thick and 10 mm diameter copper discs, separated by a dielectric material: 1.5 mm thick fiber glass.

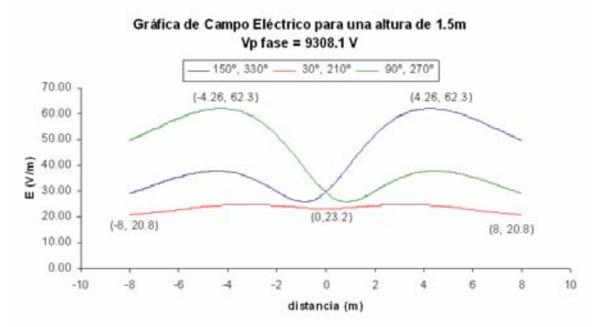

Fig. 2 Electric field values in the proximity of a line of 11.4 kV, according to the phase electrical angle.

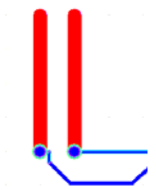

Fig. 3 Parallel-lines sensor. The sensor consists of two mounted copper lines placed on a fiber glass surface.

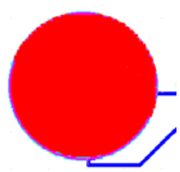

Fig. 4 Parallel-discs sensor. The sensor consists of two opposed copper plates placed on both faces of a fiber glass surface.

The parallel disc sensor simulation has shown that when the sensor is placed on 2 V/m background electric field, a 0.77 V/m electric field appears between the two sensor plates. This electric field reduction is consequence of the relatively high permittivity of the glass fiber placed between the two plates. The calculated parallel-discs sensor induced voltage was 1.09 mV. With this calculated induced voltage the disc sensor transformer ratio (effective length) this was: 0,545 mV/(V/m).

In spite of the same separation between electrodes 1.5 mm for both sensors, the obtained results were different. When a 1 V/m background electric field is applied to the parallel-discs sensor, a 4,84 V/m field appears between the electrodes. The induced potential difference between the electrodes of this sensor was 6.77 mV and its transformer ratio (effective length) was 6,77 mV/(V/m), approximately 12 times higher than the one of the parallel-lines sensor.

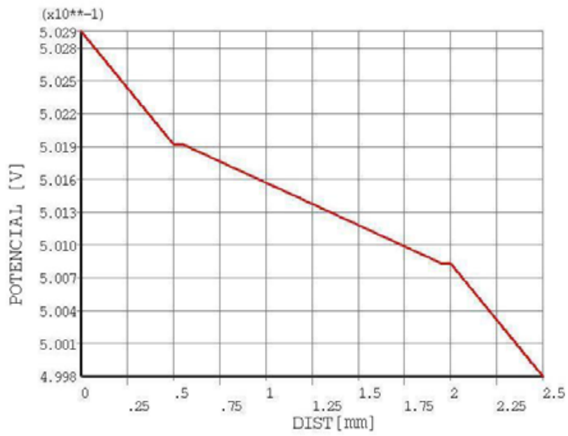

Fig. 5 Parallel-discs sensor potential distribution along the inter-electrode gap distance. As it can be seen, the observed potential difference which appears between the parallel-discs sensor was 1.09 mV.

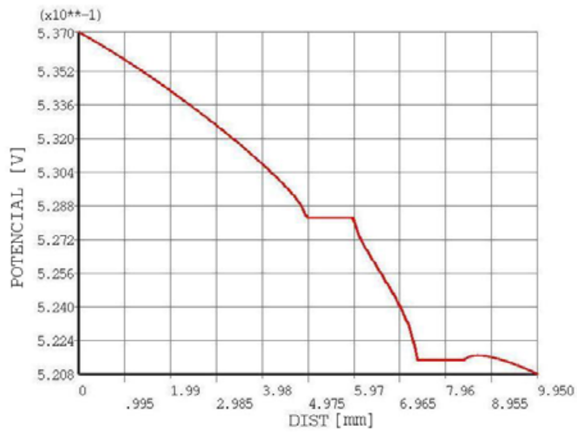

Fig. 6 Parallel-lines sensor potential distribution along the inter-electrode gap space. As it can be seen the observed potential difference which appears between the sensor lines electrodes was 6.77 mV.

The electric field was amplified mainly due to the fact that the parallel-lines sensor are perpendicular to the electric field lines, therefore more equipotential lines are compressed in the region between electrodes. This equipotential line compression causes an electric field enhancement in the interelectrode region and therefore, a large potential difference between both parallel-line electrodes.

According to the previous considerations it can be concluded that the parallel-lines sensor has larger sensitivity and it would be the most suitable for the application.

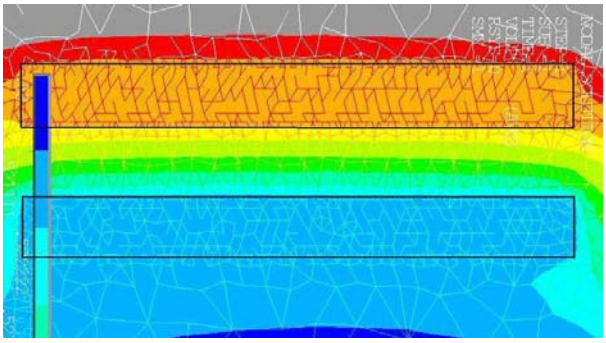

Fig. 7 Calculated equipotential lines in the interelectrode region of the parallel-lines sensor. The sensor electrodes are indicated by a black color box.

ELECTRONIC CIRCUIT

Due to the amplitude characteristics of the device measured signals, the use of op-amps with low offset level and low bias current was necessary. Additionally, due to the intended use of commercial batteries as voltage source, the amplifiers operation voltage should be limited to 4 volts.

Due to the sensor capacitive characteristic, the use of an instrumentation amplifier as signal conditioning stage and impedances adapter was necessary.

To guarantee that only 60 Hz signals will be measure, an active pass-band filter was placed to filter the instrumentation amplifier output.

The true RMS value of the filtered signal was transformed to a DC voltage using a true RMS detector. The output of this true RMS detector was compared with a voltage reference value to activate a sonorous and luminance alarm. This indicates that the measured electric field surpassed a 25 V/m threshold.

According to the performed simulations and measurements it was make sure that the sensor will always be activate under a 11.4 kV distribution line.

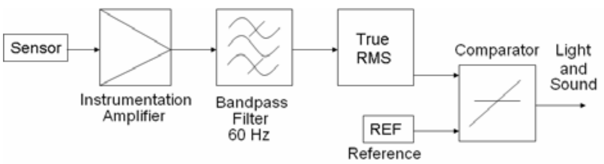

Fig. 8 Blocks diagram of the electric field sensor electronic circuit for the signal treatment.

LABORATORY TESTS

The device was tested under the application of a 60 Hz electric field.

The sensor was placed in an homogenous electric field produced by two 1m x 1m square metal plates separated 0.5 m, as it is shown in Fig. 9.

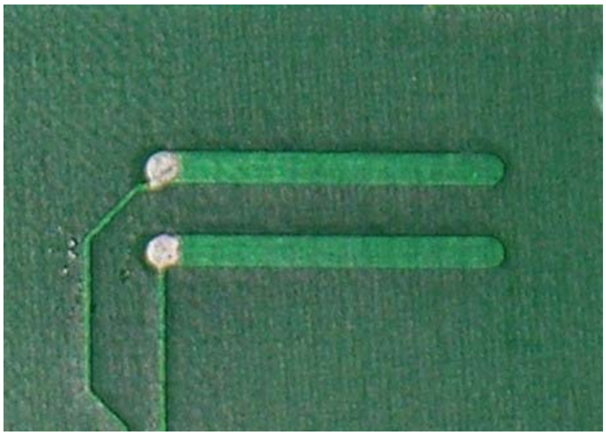

Fig. 8 Parallel-lines sensor printed on a printed board circuit

Fig. 9 Experimental assembly for the electric field simulation. The assembly consists in two aluminum plates of 1 m x 1 m separated 0.5 m.

Before the tests were performed, a simulation has shown that that the sensor does not modify the electric field distribution. The results obtained showed that the charge concentration on the metal plates was only modified on less than 0.5%, as it is shown in Fig. 10.

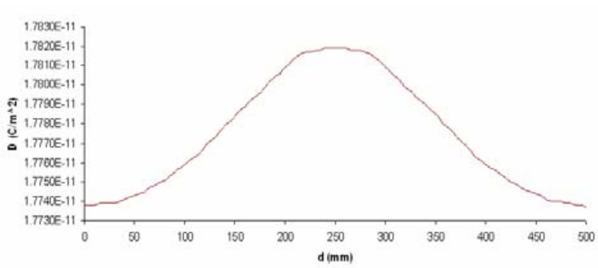

Fig. 10 Electric charge distribution on the plates. The electrical charge difference between the plates central area and the other zones was less than 0.5%.

Previously it was verified that there was no an important voltage induced by the assembly on the minicoaxial cable used to measure the sensor signal.

With the previously described assembly the sensor characteristic applied electric field to induced voltage was obtained. Fig. 11 shows the obtained voltage – electric field characteristic. The sensor response to the applied electric field was linear, with a correlation coefficient of 0,9873, for the applied electric field range of 0 V/m to 60 V/m.

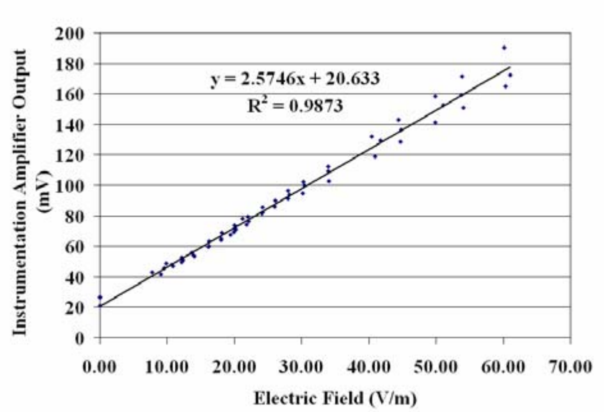

Fig. 11 Parallel-line sensor induced voltage (RMS) difference as a function of the 60 Hz applied electric field (RMS).

At the present moment electrical tests in different facilities, substations and distribution lines are performed. The results of these tests will determine the reliability and the routine viability of application of this equipment. Additionally, the final outer design of the device is under development.

CONCLUSIONS

The laboratory tests allow concluding that this type of sensors of electric field can be used as proximity alarm to energized objects. In special, the device can be used to determine the energize condition of a distant 13,2 kV distribution line.

Due to the linear response of the sensor, its use can be extended to 60 Hz electric field measurement.

ACKNOWLEDGMENTS

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