Analysis of the Corona Currents in an Electrostatic Discharge System in Normal Atmospheric Pressure and Temperature

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Abstract: - In this paper, have been studied the corona current spectras in a needles to plane geometry of electrostatic discharge system (EDS) in normal atmospheric pressure and temperature. The air between electrodes becomes conductive when the electric field strength exceeds a limit value. Were made an optical analysis of corona (for the same voltage – 10 kV, for positive, negative and alternative supply of EDS electrodes) and an electrical analysis (through current spectra) for current corona (for different gap distances between electrodes - 2 to 5 cm, different polarity - positive, negative, and alternative, and voltage supply - 4 to 10kV). The currents spectras indicates that the positive current has the most harmonics and has a lot of noise than negative or alternative corona.

Key-Words: Corona currents, Electrostatic discharge system, Needles to plane geometry

1 Introduction

Atmospheric-pressure coronas are applied to various processes such as surface modification, materials separation, air purification, biological application and so on [1].

In normal condition air is very poor conductor, but the air can be ionized and it is possible to pass current under certain condition.

The current through the air is three types depending on current amplitude [2,3,4,5,6]:

- Townsend current that is a small current and there is not harm of plane and needle. This current occurs when voltage is not very high;
- glow current is approximate 1000 times greater then Townsend current and the surface electrodes may be affect. There is a glow between electrode and the glow shape depends on voltage and electrode polarity. Suddenly, the glow occurs the voltage between electrodes can be less then in the case of Townsend current;
- the arc (discharge) current occurs when the voltage increase after the glow is between electrodes. The arc current can be 100 times greater then glow current and the electrodes are seriously affect.

The arc resistance, in time, can be calculated as [2]:

$$R(t) = \frac{d}{\sqrt{2 \cdot a \cdot \int i(t)^2 \, dt}}, \qquad (1)$$

d is the arc length, a is an empirical constant and i(t) is the dicharge current in time. The light glow from a discharge is proportional with voltage between electrodes.

The air becomes conductive when the field strength exceeds a limit value that depends on the condition and composition of air and depends less on the electrode geometry [1,3,7,8].

If the direct current is replaced with an alternating current the discharge mechanism does not change if the mean free path of electron is much less than the gap distance and the air pressure is sufficiently high.

A corona discharge is a form of glow discharge. An increase voltage between electrodes also increase the corona current at a given fixed air gap dimension [6].

2 Theoretical analysis

To create corona discharge, it is used a typical circuit presented in fig.1. In high voltage experimental laboratory studies the electrodes may be: needle to needle, needle to plane geometry and so on.

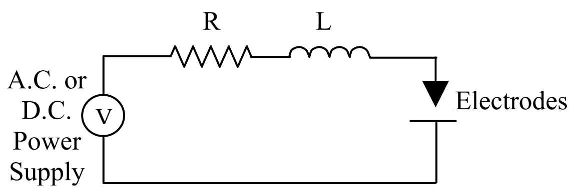


Fig.1. Typical circuit used for glow discharge studies

Between electrodes is the air discharge gap. The electrodes can act like an anode and a cathode (depends on polarity).

The corona discharge it is a way to generating electrons from solid surfaces by bombardment with energy particles created by high field strength between electrodes.

If V is voltage supply and V_g is voltage between electrodes, for circuit from fig.1:

$$V = R \cdot i + L\frac{di}{dt} + V_g \,. \quad (2)$$

In fig.2 the electric field strength (E) depends non-linear on gap length between electrodes for needle to plane geometry (x) [2,4].

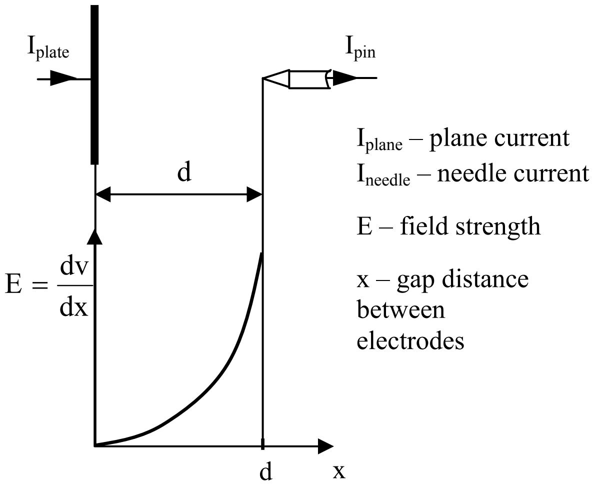


Fig.2. Needle to plane geometry and electric field strength depends on gap distance

$$E = \frac{dV}{dx}, \quad (3)$$

$$I_{plane} = I_{needle} = I_e + I_p \,. \quad (4)$$

I_{plane} and I_{needle} can be cathode or anode depends on supply type, I_e is current in air due electrons and I_p is current in air due positive gas ions.

The current at a gap distance x from cathode is given by [5]:

$$I = I_e \cdot e^{\alpha \cdot x}, \quad (5)$$

α is the first Townsend coefficient and represents the number of collisions made by an electron when traveling 1 cm. For distance d the current becomes:

$$I_{plane} = I_{needle} = I_e \cdot e^{\alpha \cdot d} \,. \quad (6)$$

From (4) and (6) results:

$$I_p = I_e \cdot \left(e^{\alpha \cdot d} - 1\right). \quad (7)$$

The charges between discharge electrodes are influenced by the charge at the electrodes at high voltage between electrodes. The local electric field E(x) depends on both the electrodes charges and charges between electrodes [7,9].

The critical electrons concentration N_{cr} in an avalanche that initiation a streamer in a non-uniform fields is [5]:

$$N_{cr} = e^{\int_0^d \alpha dx} \,. \quad (8)$$

The ionization region, for needle-plane geometry, is nearly the needle electrode, where the electric field has the biggest values.

For relationship between corona current and the voltage, for needles to plane type is calculated with [1]:

$$I = \frac{2 \cdot \pi \cdot K \cdot \varepsilon}{d\left[F(\delta / d)\right]^{-2}} \cdot \left(V - V_0\right)^2, \quad (9)$$

I is the discharge current, K is the charge carrier mobility, ε is the permittivity of the medium, F(δ/d) represents functions in terms of the ratio between radius of needles curvature δ and d is distance between the needles and plane electrode. From (8) results the current is proportional with the square of the difference between the applied voltage and the onset corona voltage.

The current from an electric circuit may be compute with:

$$I = \int JdA = \int \rho \cdot K \cdot EdA, \quad (10)$$

J is the current density, dA is the elementar surface, ρ is the charge density and E is the strength of electric field.

The gap current grows as a result of ionization by electron impact in the gas and electron emission at the cathode by positive ion impact.

The breakdown voltage for a uniform field gap is a function depends on air pressure p and the electrode separation d for a particular gas and electrode material (Paschen's low):

$$V_b = F(p, d) \,. \quad (11)$$

In a needle-plane geometry the field is non-uniform and the gas ionization vary across the gap (fig.2).

3 Experimental results

The electronic devices used in high voltage experiments often time are problems and risky.

A solution to studies the corona glow is to use photography. If the corona light emission is slight (not very high voltage) it is necessary long exposure time (several minutes) and the recording image depends on sensitivity of film (when is used film photography).

Another solution is to use digital oscilloscope that provides high sensitivity in large spectrum frequency compares with photography. An important issue is to protect the high costly digital oscilloscope to get corona current.

With a high-speed data acquisition card (DAC) the field of high-voltage technique has gained a useful tool. The DAC has important advantages over the use of analogue oscilloscopes. The signals record in a wide range of digital forms and with powerful software it is possible to analysis the high-voltage data [10,11,12]. A DAC, in contrast with anallogue oscilloscope, is able to record and store only instantaneous values of the signal rounded to integer number and sampled at finite period of time. The signal is reconstructing in time with the values contained in the recorder's memory.

The electrostatic discharge system (EDS) used in experiments is shown in fig.3 and the main components in fig.4. The discharge wire is ISODYN B5 type used in plate-type electrostatic precipitators. The electrodes length is 208mm and the distance between two successive needles is 50 mm.

Fig.3. Electrostatic discharge system used in experiments

An array needles electrod is used to provide an interraction between materials and electric charge generated by corona when the voltage is kept to a resonable level. Usually, the array needles electrode is supplied with high voltage, in normal atmospheric pressure and temperature, and generates high noise level.

For the same voltage supply (10kV) was experimentally estabilish the limit of breakdown voltage for positive polarity (d= 18mm), negative polarity (d=10 mm) and alternative supply (d= 15 mm) in normal atmospheric-pressure and temperature (25 ^{0}C).

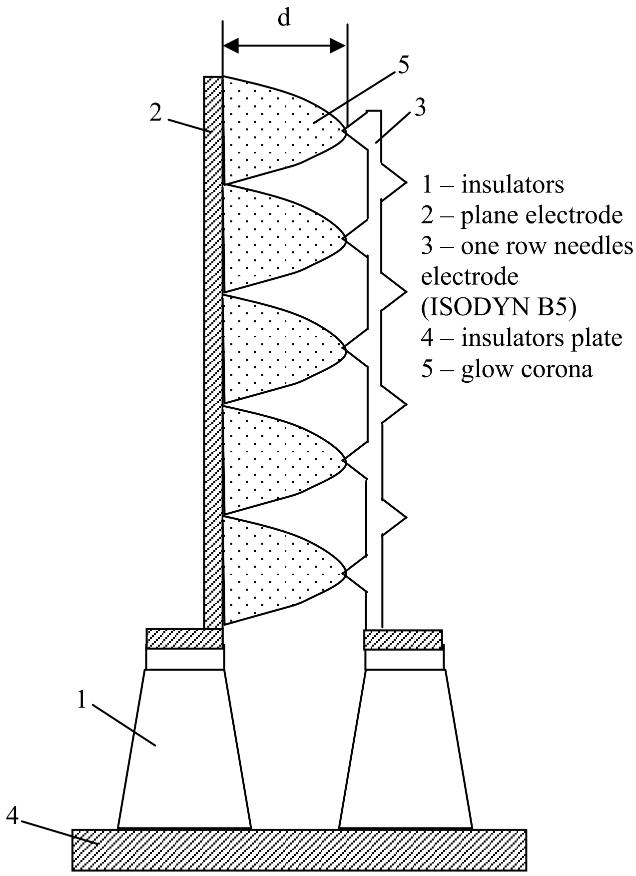


Fig.4. Electrostatic discharge system

Near the points needles, high electric field produce electron avalanche. Due the action of electric field the kinetics energy of electrons grows up. An energy exchange occurs (the ions are accelerated by the applied electric field) when ions collide with air molecule [13,14].

Negative corona in air (at normal pressure and temperature) can be followed by diffusive glow discharge, precedes the spark. Due the high electric field around the sharpened needles, the discharge emits light only in cathode area (needles) and the space between the electrodes occupied by negatively charged is dark (fig.5.b).

The negative corona has discrete tufts along discharge wires, distinguished from glow positive or alternative corona (fig.5.a,c). For negative corona, when the voltage increase the tufts become uniformly distributed along the discharge wires.

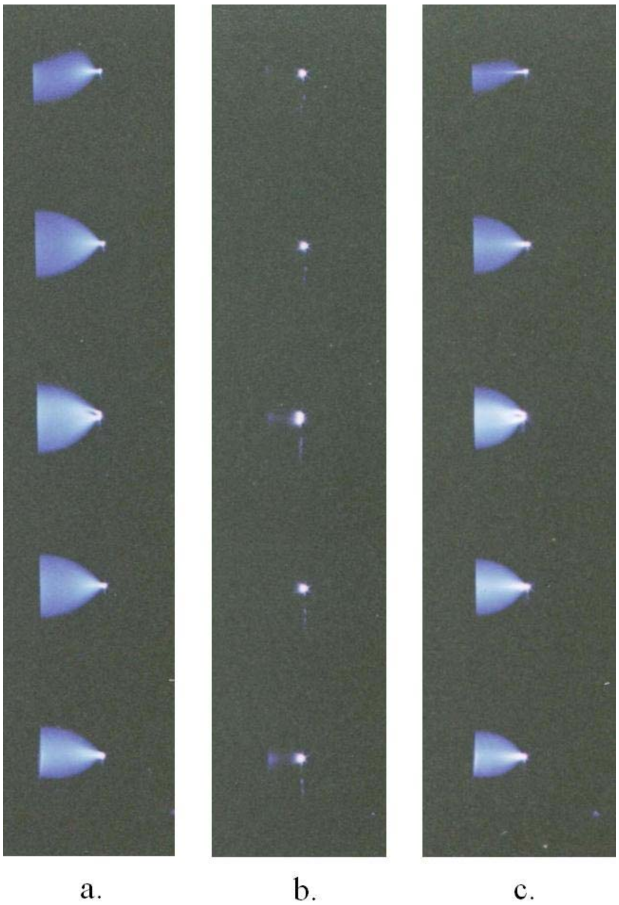


Fig.5. Corona discharge at V=10kV for EDS: a. positive (d=18mm), b. negative (d=10 mm), c. alternative supply (d=15 mm)

A particularity of the non-uniform fields is various luminous and audible discharges are appeared long before a breakdown occurs.

Under different polarity of the applied voltage there is visual difference (fig.5). For positive and alternative voltage (fig.5.a,c), corona has a uniform bluish-white sheath over the surfaces of the wire. For negative corona appears as glowing spots distributed on the wire (fig.5.b).

For normally pressure and temperature (25 ^{0}C), the breakdown under negative polarity occurs at higher voltage under positive or alternative voltage, for the same gap length. For the a.c. supplied (50Hz) needles-plane geometry the breakdown occurs during the positive half-cycle of the voltage.

For analyze corona currents it is necessary to distinguish between the impulse corona and the static corona (d.c. voltage or a.c. voltage, 50Hz) [15,16,17].

Under impulse voltage, because of transient ionization, the growth of discharge is difficult to analyze. When a high voltage pulse is applied to an array needles electrode turns up streamers. When the voltage increases the streamers grow (in length and in the number of branches).

In the static corona, ionization process has enough time to acumulate electric charge in space causing the distorsion of the electric field. If the gap increases the field distribution becomes more inhomogeneous and a filamentary discharge (streamers) occurs.

For positive polarity, the streamers become frequent when the voltage increase and the electric discharge is self-sustained and the glow turns on to the anode. The luminosity of glow increases for a further increase of voltage. The glow corona develops only in the presence of negative ions. If the voltage continuous increase the streamer becomes strength, and finally appear breakdown in the gap.

The breakdown under negative polarity occurs at higher voltage than under positive voltage for the same gap length, for normally pressure and temperature.

For negative needles electrod, for onset voltage, the current flow in regular pulses known like Trichel pulses. The Trichel pulses depend on needles radius, the gap length and the pressure. If the voltage increase the pulses does not change. The onset voltage depends on the gap length. A steady glow discharge is observed on the cathode. On increasing the voltage further, the glow continues until breakdown appears.

The breakdown appears during the positive half-cycle of the voltage, for the a.c. supply of array needles electrodes-plane electrode.

Many electrostatic precipitators have point coronas discharge wires (i.e. ISODYN B5 discharge wire) and corona discharge appears from each point [18].

A solution to minimize the high voltage risk is to use optical fibers to provide optical decoupling for data acquisition card [10,19].

A versatile solution is to measure the currents with DAC. A resistor was connected to the needles electrode and the current was determined from the voltage drop on the resistor.

The electric diagram for measure the corona current is shown in fig.6.

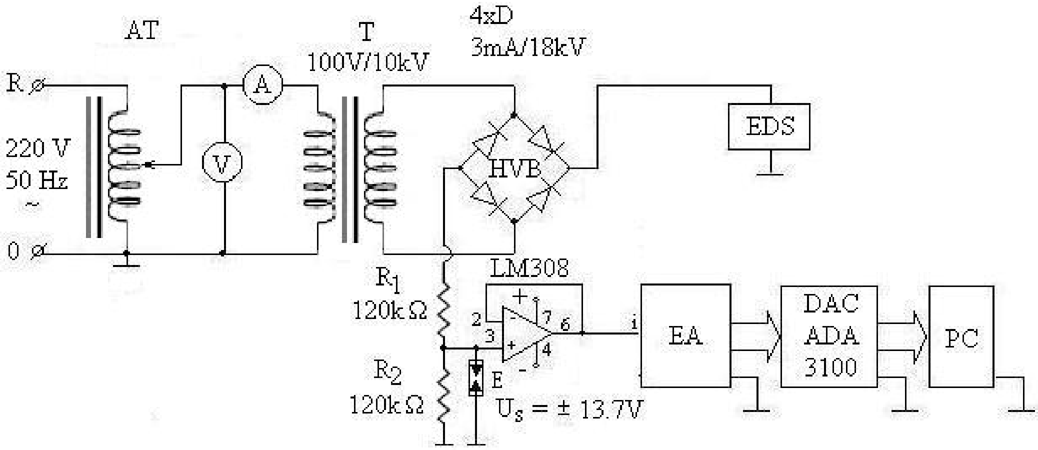


Fig.6. Electric diagram used in experiments

The electric system is powered from a regular power supply (a.c. 220 V, 50Hz) through an autotransformer (AT), a high voltage transformer (T), a high voltage rectifier bridge (HVB, connected in the same way for positive or negative measurements, and for alternative current measurements is missing) that supply the EDS. The input DAC (ADA3100, 50kHz sampling frequency) is connected to an operational amplifier through an electronic adaptor (EA that has insulating circuits) and is protected against high voltage shock through spark gap devices (protective spark gap E). The DAC is connected to a personal computer (PC). The voltage drop on resistance R_2 (120 kΩ) is applied to a precision operational amplifier (LM308) that is used as a signal follower. For operational amplifier the bandwidth of the amplification is 1 MHz.

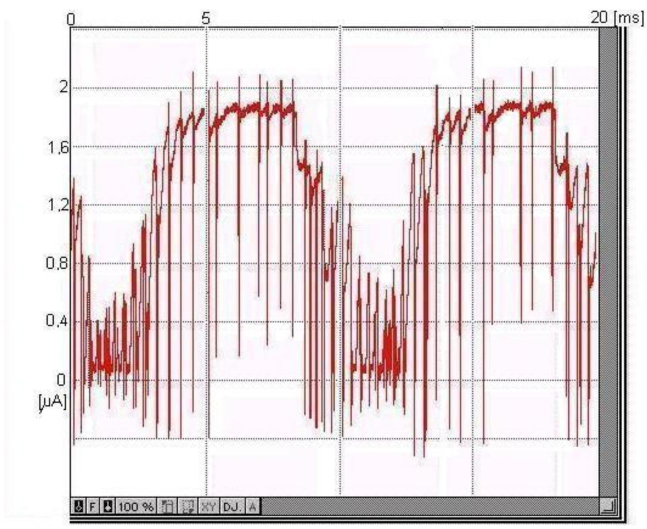
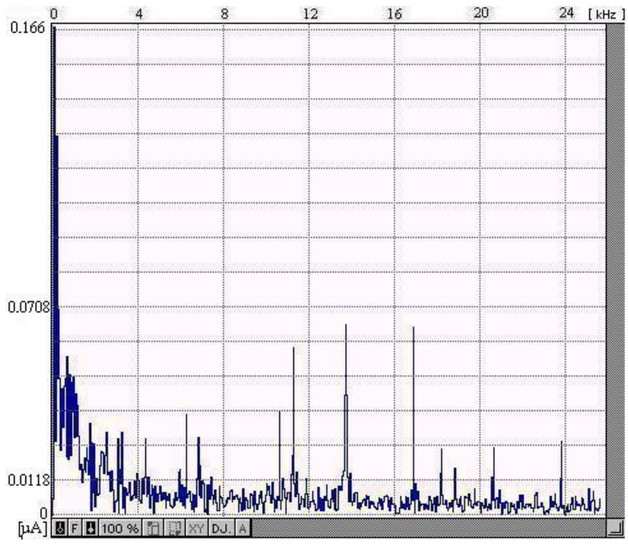


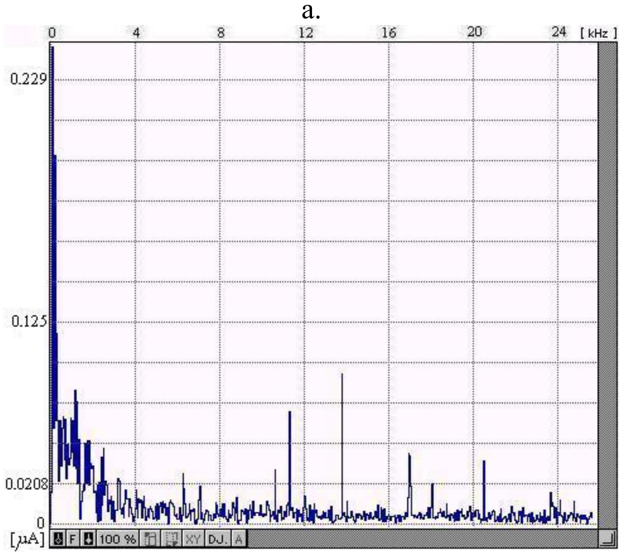
Fig.7. Positive corona: d=2cm, U=8kV

In this study, the current of ESD have been investigated as function of the amplitude and type of voltage (d.c. positive and negative, and a.c. voltage) and the air gap between the electrodes.

The voltage between electrodes was increase up to 10kV. The distance between electrodes was modifies between 2 to 5 cm.

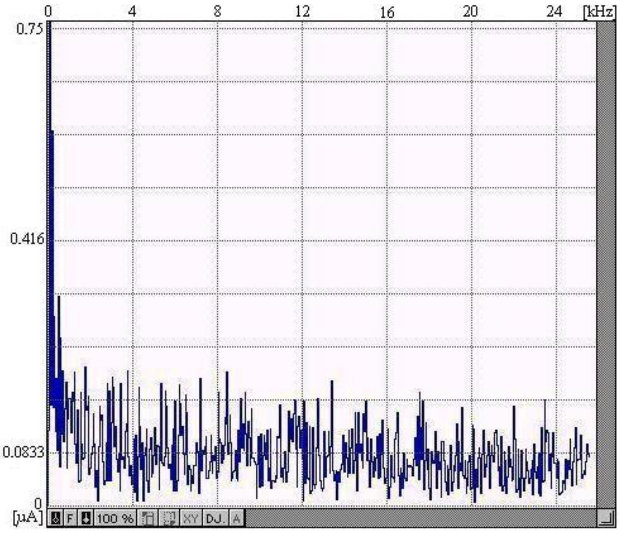


a.

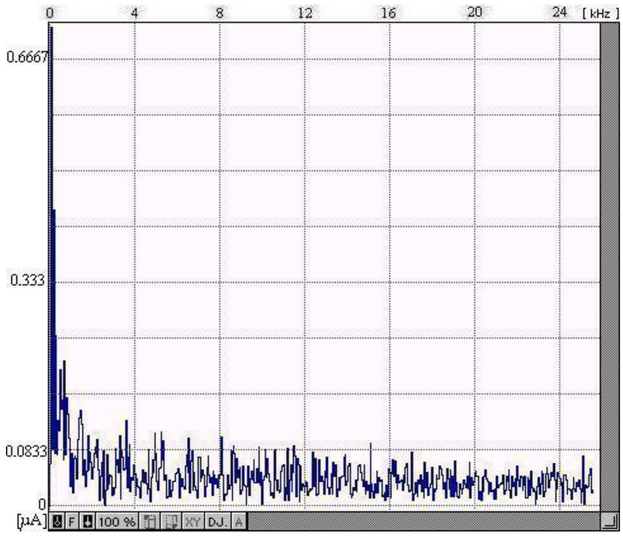


b.

Fig.8. Positive current spectra for:
a. d=2cm, U=4kV; b. d=2cm, U=6kV



c.



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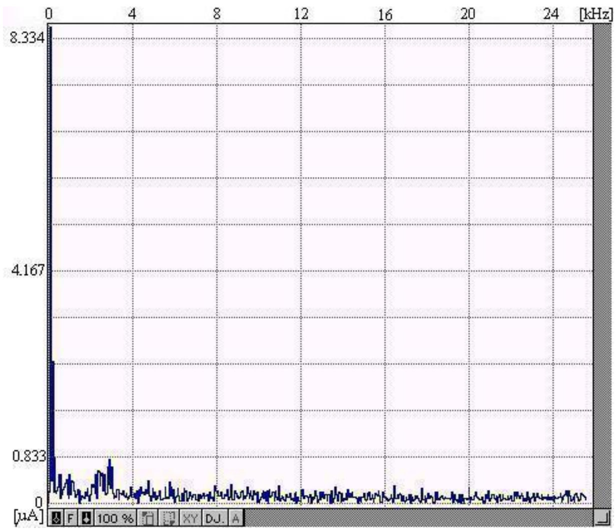
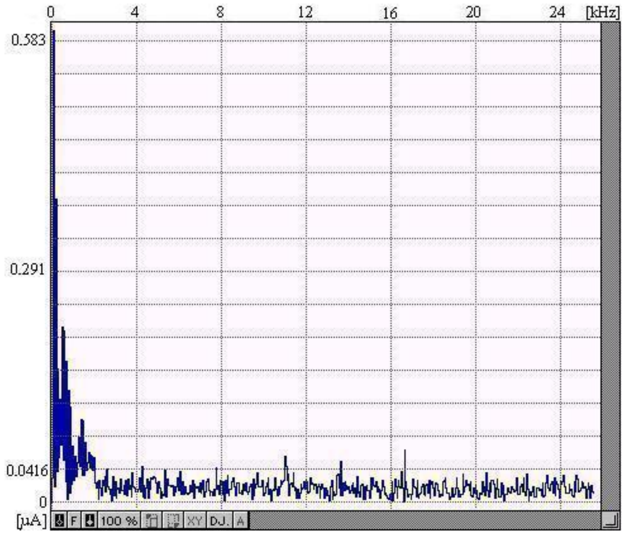
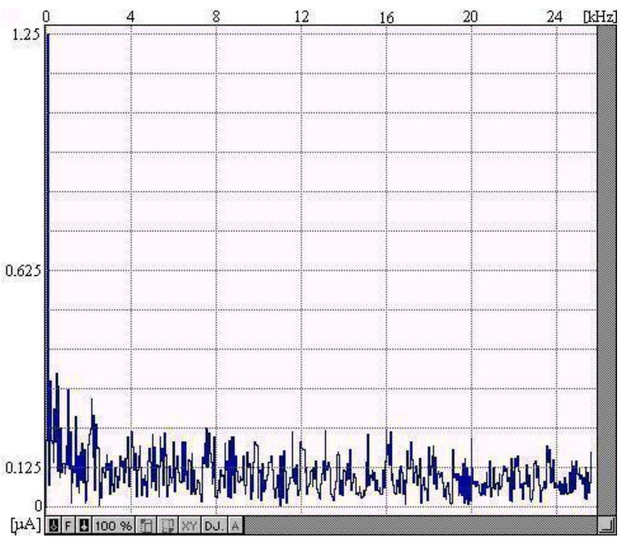


d.



g.

Fig.8. Positive current spectra for:
f. d=4cm, U=10kV; g. d=5cm, U=10kV



e.

Fig.8. Positive current spectra for: c. d=2cm, U=8kV; d. d=2cm, U=10kV; e. d=3cm, U=10kV

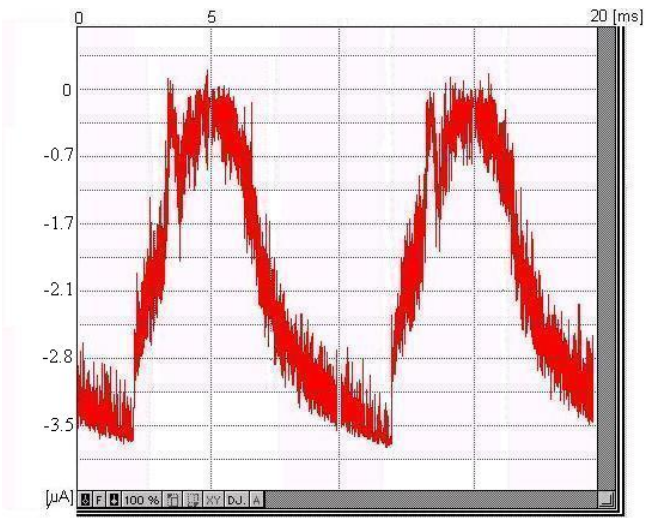
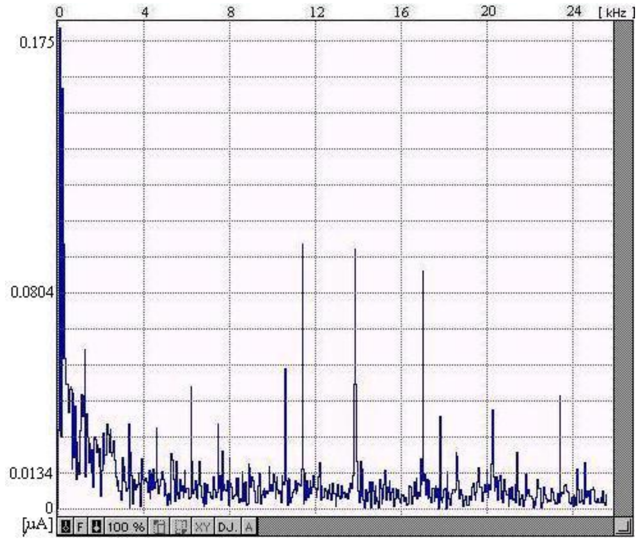
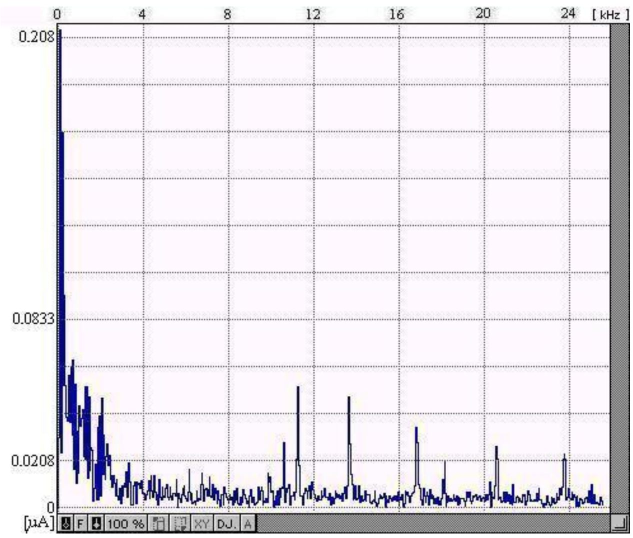


Fig.9. Negative corona: d=2cm, U=8kV



a.



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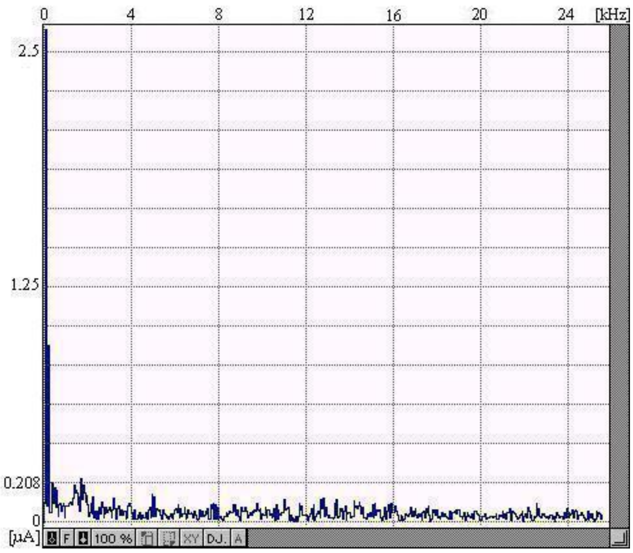
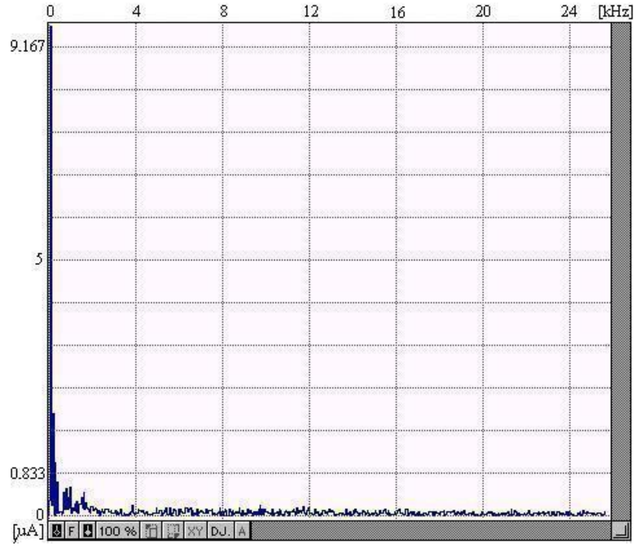


c.

Fig.10. Negative current spectra for: a. d=2cm, U=4kV; b. d=2cm, U=6kV; c. d=2cm, U=8kV



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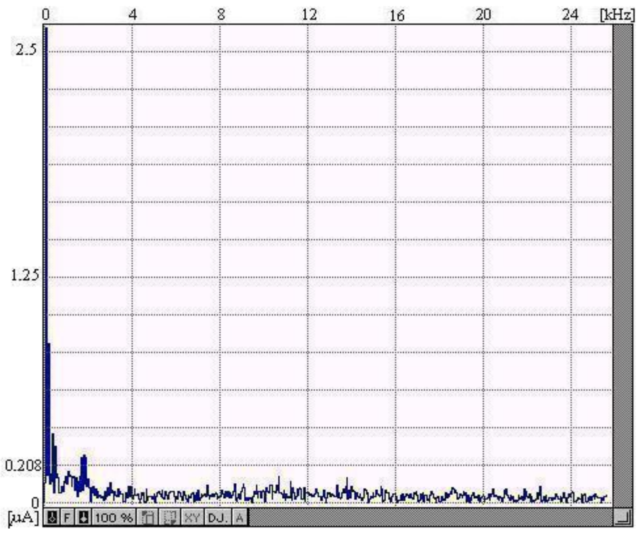

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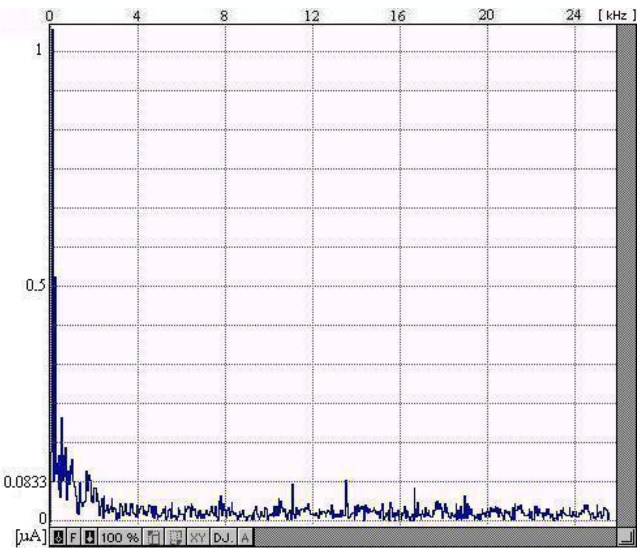
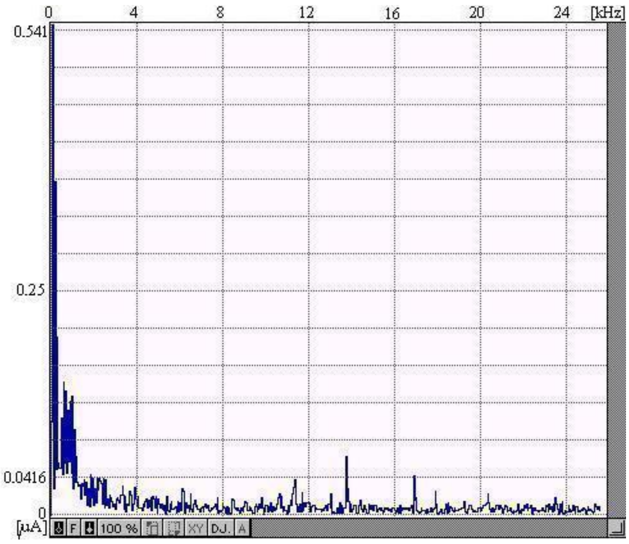


f.

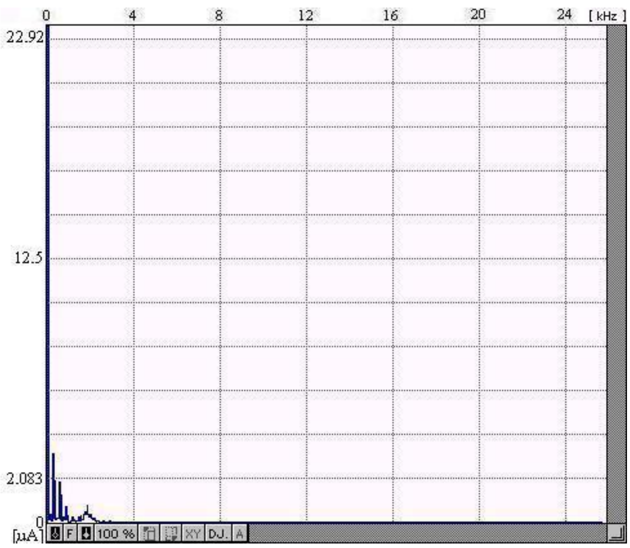
Fig.10. Negative current spectra for: d. d=2cm, U=10kV; e. d=3cm, U=10kV; f. d=4cm, U=10kV



g.

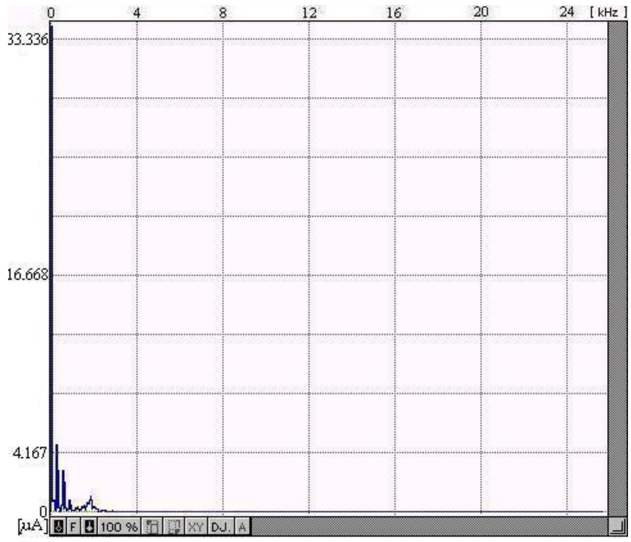
Fig.10. Negative current spectra for: g. d=5cm, U=10kV

In the case of positive corona at the 1cm distance and 7 kV voltage the electrical discharge turns on, and in the case of negative corona at 1 cm distance and 10 kV voltage the electrical discharge does not turn on.



a.

Fig.11. Alternative current spectra for: a. d=2cm, U=4kV



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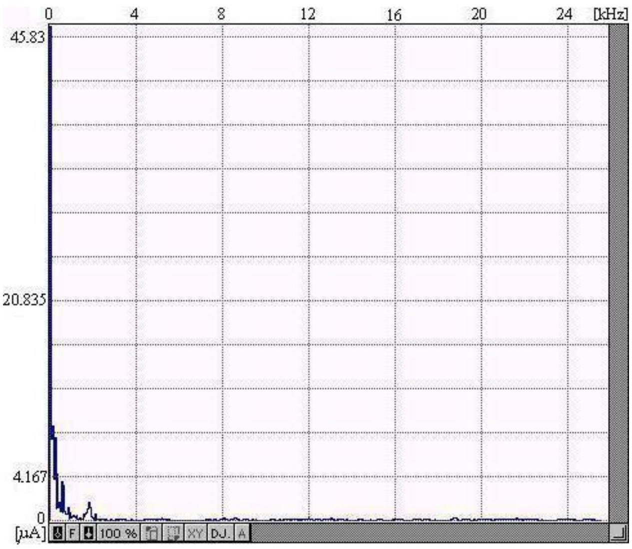

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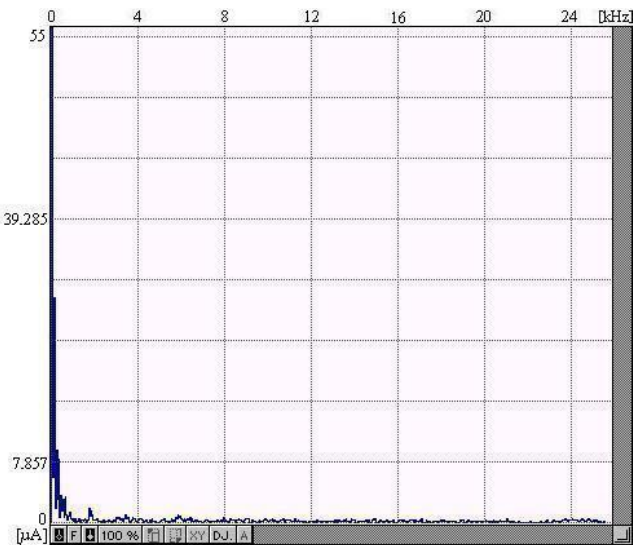
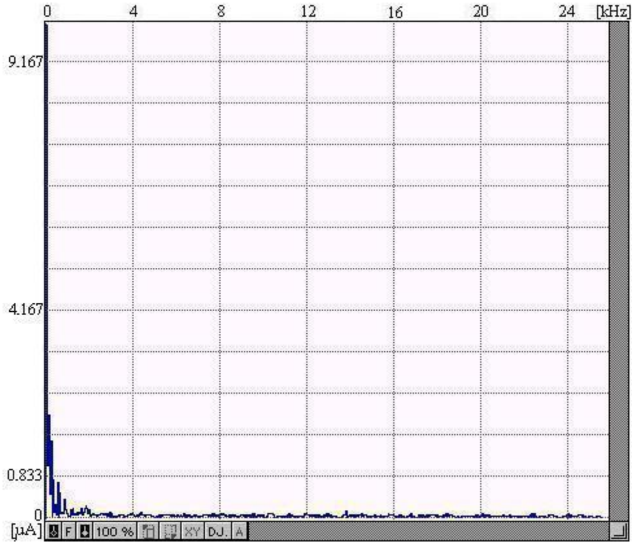


d.

Fig.11. Alternative current spectra for: b. d=2cm, U=6kV; c. d=2cm, U=8kV; d. d=2cm, U=10kV



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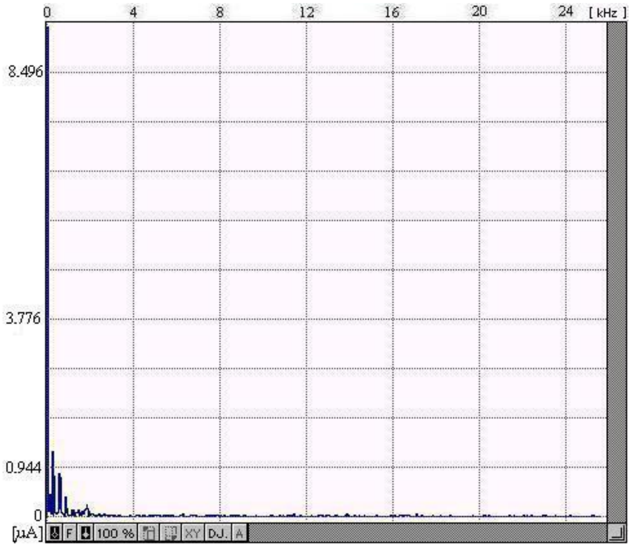

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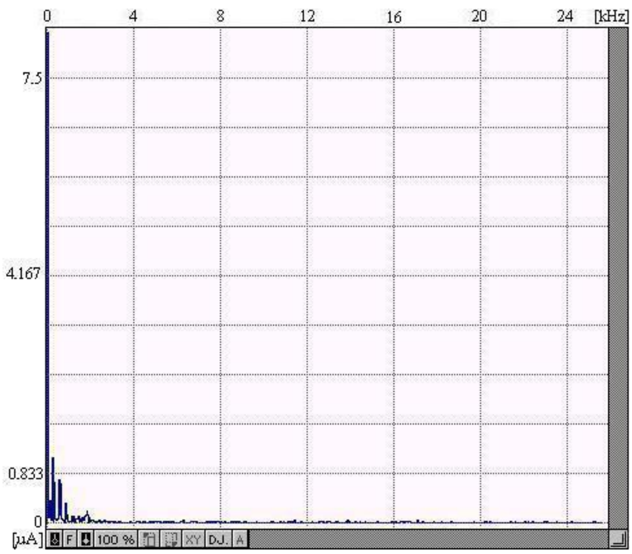

g.

Fig.11. Alternative current spectra for: e. d=3cm, U=10kV; f. d=4cm, U=10kV; g. d=5cm, U=10kV

The negative current spectras (fig.10.a-g), have bigger harmonics values than alternative current harmonics (fig.11.a-g), but have lower harmonics values than positive current harmonics (fig.8.a-g).

For the same distance between electrodes and the same voltage the fundamental (50 Hz) alternative current is bigger than fundamental negative current, that is bigger than the fundamental positive current (fig.8,10,11). The alternative current spectras indicates the biggest value for fundamental current than other situations (positive and negative corona), but the current harmonics have the lower values (fig.11).

The positive corona current (fig.7), the negative corona current (fig.9) indicates other shape of current, for the same conditions (distance and voltage) because the ionization process is different.

The biggest noise occurs at positive corona than alternative corona and the last negative corona for the same operation conditions.

4 Conclusions

The EDS was used to measure corona currents in one ray electrode discharge system (needles to plane type) with needles electrode positive, negative and when supplies with alternative current.

The PC and DAC can provide data recording, processing of the corona current and graphic user interface. For the experiments, the high voltage ground is the same with EDS’s ground.

The needles to plane geometry can be used to obtaining a high localized stress and dense space charge. The air gap ionization depends on the gap distances, polarity type and the voltage values. The positive current spectras indicate that have the most harmonic current and have a lot of noise than the alternative or negative corona. The difference in emission current spectra for negative and positive current indicate different ion emission between electrodes.

A reason to use negative corona in practice is the electron emission is better, more stable and control, than other type of corona (alternative or positive).

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