Proceedings of the 2006 IASME/WSEAS International Conference on Energy & Environmental Systems, Chalkida, Greece, May 8-10, 2006 (pp349-356)

# The phenomenon of Ground Effect in contradiction to the Polarity Effect in rod –plate air gaps.

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*Abstract*: The values of the breakdown voltage of an air gap depend on the maximum value of the field strength in the gap, as well as the corona leakage current through the gap. In the present paper we investigate the Ground Effect of small rod–plate air gaps, a phenomenon, which is observed due to the grounding of one of the electrodes. Values of the field strength in the gap are recorded and analyzed for the two different arrangements, with the rod or the plate grounded. The distribution of the field along the axis of the gap is strongly affected by the geometry of the gap, and especially by the electrode chosen to be grounded. The Ground Effect affects the corona onset and the breakdown voltage of the rod-plate air gaps analogically. The Ground Effect is intense in small rod-plate air gaps, slightly affected by the Polarity Effect, while the influence of the corona leakage current appears in longer air gaps, where the Ground Effect is decreased, then is vanished and after it is reversed, as the gap length increases..

*Key Words:* Ground Effect**,** Polarity Effect, Corona, Simulation, FEM, Air Gaps, Field Strength.

## 1 Introduction

One of the most determinant factors of the dielectric behavior (strength) of the insulating arrangements and especially of the air gaps is the field strength distribution inside the volume of the arrangement, and especially the maximum value of the field strength in the gap, which appears on the rod. Other factors are the polarity and the form of the applied voltage as well as the corona effects, which take place when the field strength exceeds some specific value, [1], [2], [3], [4], [5].

In every insulated arrangement and especially in air gap arrangements, where there is no symmetrical charging, because one of the electrodes is grounded and the other is electrically charged, differences of the electric field's distribution and of the maximum value of the field strength are observed in comparison to the arrangement where both electrodes are electrically charged with opposite charges. The differences occur due to the asymmetry that is caused by the grounding of one of the electrodes. The two basic factors that affect the differences in the field distribution are the geometry of the arrangement as well as the size and shape of the boundary surface in the simulation analysis, [6], [7], [8], [9], [10], [11].

The above differences in the field distribution influence the corona onset and the breakdown voltage of the arrangement accordingly, [8], [9], [10], [11].

In symmetrical arrangements such as rod-rod air gaps the influence caused due to the grounding of one of the electrodes is rather small, resulting this way to small differences of the breakdown voltage between the two cases where the stressed voltage is of positive or negative polarity, [12], [13]. This occurs because of the Polarity Effect which would not exist if the symmetrical arrangement was symmetrically charged, that is positive charge for one of the electrodes and negative for the other.

In non-symmetrical arrangements, such as rod-plate air gaps, the grounding's influence in the distribution of the field is significant, depending on the rod's and plate's size. This is easily revealed with the analysis of the field with the Finite Element Method. Respectively important can also be considered the influence of one of the electrode's grounding to the corona onset and the breakdown voltage of the gap, [6], [7], [8], [9], [10], [11].

This recently studied phenomenon is called the Ground Effect and is clearly different from the

Polarity Effect although slightly influenced by it, [8], [9], [10], [11].

This paper investigates the Modelling and Analysis of the electric field distribution in rod-plate air gaps under different geometries and arrangements of the gaps, using the Finite Element Method. The Ground Effect is investigated as it concerns the field's distribution as well as the corona onset and the breakdown voltage. The influence of the corona leakage current is also presented.

Special software has been used in the present paper for the simulation analysis. It is based on the Finite Element Method in order to solve two-dimensional problems with axisymetric models.

The program is based on Gauss's and Poisson's equations.

$$E = -\nabla V \qquad (1)$$

$$\nabla D = -\rho \qquad (2)$$

or $$\nabla^2 V = -\frac{\rho}{\varepsilon} \qquad (3)$$

where E is the field strength, ρ is the space charge density in $C/m^3$, ε is the dielectric constant of the medium, V is the voltage, and $D=\varepsilon E$ is the dielectric displacement.

The electric charge density, and the total electric charge on a particular surface S, or in the volume included in surface S, are calculated by equations.

$$q = \Delta D_n, \quad \text{and} \quad Q = \int_s D_n \cdot d_s \qquad (4)$$

The boundary conditions and especially the mesh density used for the analysis are of great importance for accurate results.

## 2 The investigated arrangements.

The arrangements, which have been drawn, analyzed, and experimentally studied, are typical rod-plate air gap arrangements of different geometries. The rod electrode is a cylinder long enough, with a small diameter (2-14 mm) and a hemisphere tip. The plate electrode is a disk plate of 50 - 200 mm in diameter. One electrode of each arrangement is stressed by high DC voltage of negative or positive polarity or AC voltage while the other is grounded. All the analyzed models are axisymetric, with a spherical shield big enough in diameter, (figs 1, 2 and 3). Also the node's spacing is small enough.

The average value of the field strength, along the axis of an air gap is defined by equation:

$$E_{av} = \frac{V}{G} \qquad (5)$$

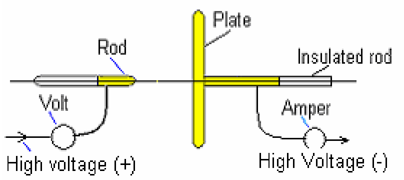
The field factor (or efficiency factor) **n** is a net number, which defines the inhomogeneity of the field in the gap and is expressed by equation:

$$n = \frac{E_{max}}{E_{av}} \qquad (6)$$

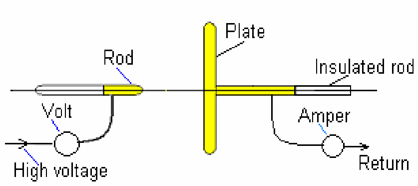
For a rod-plate air gap the field factor is given by equation [1], [2].

$$n = \frac{2G}{r \cdot \ln \frac{4G}{r}} \qquad \text{If } G \gg r \qquad (7)$$

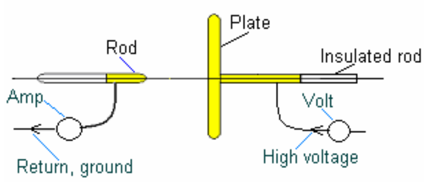
, where V is the applied voltage, G is the gap length, Emax is the maximum value of the field strength (on the rod), and r is the radius of the rod's tip. The plate's diameter is big enough.




(a) Rod - plate air gap, with symmetrical charging of the electrodes.




(b) Rod - plate air gap, with grounded plate.




(c). Rod - plate air gap, with grounded rod.

Fig. 1. The experimental arrangements

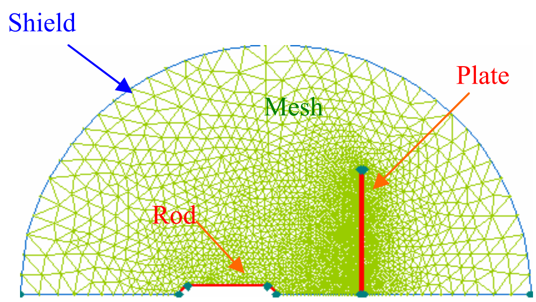



Fig 2. The simulated model

The Polarity Effect affects the Corona Onset field strength and hence the Ground Effect slightly according to equations, [1], [2]:

$E_+ = A_+\delta + B_+ * (\delta/r)^{0.5}$

$E_- = A_-\delta + B_- * (\delta/r)^{0.5}$

where $\delta = 2.94*P/273+\theta$, $A_+$=31 to 39.8 KV/cm, $A_-$=29.4 to 40.3 KV/cm, $B_+$=11.8 to 8.4 KV/cm, and $B_-$ = 9.9 to 7.3 KV/cm., r is the radius of the rod, P is the pressure and θ is the centigrade temperature of the air.

## 3 The influence of the Ground Effect to the field distribution.

Rod-plate arrangements, with different grounded electrode, different dimensions of the plate and the rod, and different length of the gap have been modeled and analyzed. From the comparison between the three different cases of arrangement with the rod or the plate grounded, either with symmetrical charging of the electrodes, it is resulted that the Ground Effect causes big differences in the field distribution between the three different arrangements.

The field distribution, the maximum value of the field strength in a rod – plate air gap and the field factor of the gap are demonstrated in figs 4, 5, 6, and 7. It is obvious that the Ground Effect is intense in rod-plate air gaps.

In both arrangements, the maximum value of the field strength in the gap (field strength on the rod) decreases with the gap length. It is higher in the arrangement with the plate grounded and tends to get a steady value for each value of the rod's diameter when the gap is longer than 80% of the plate's diameter.

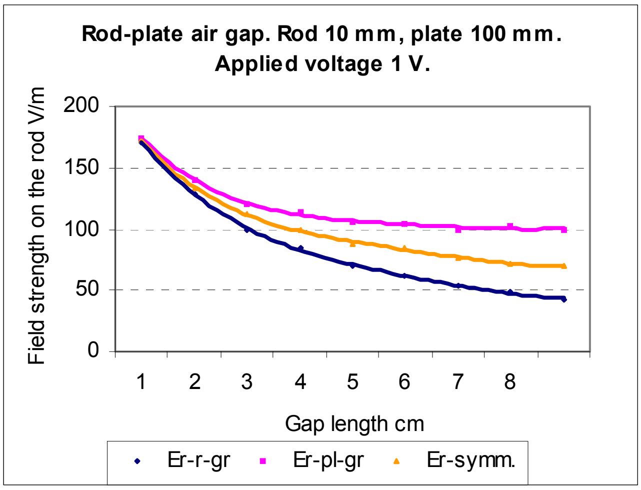



Fig 3. Rod - plate air gap. The maximum values of the field strength on the rod, Er, for the three different arrangements are shown in comparison.

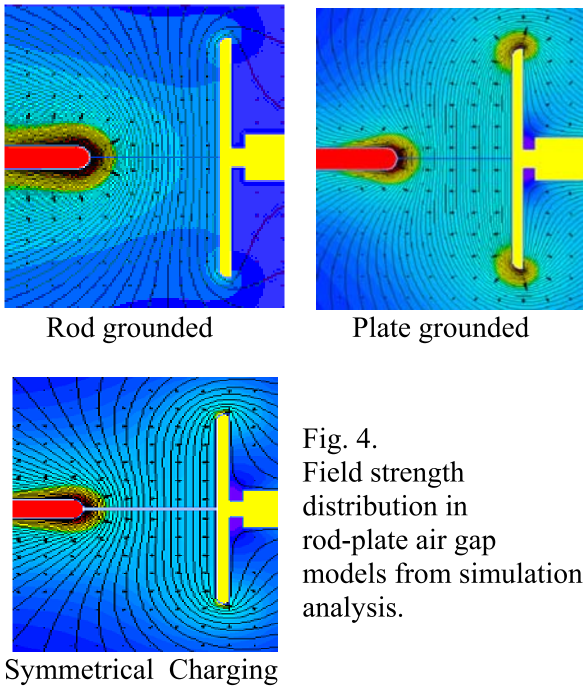
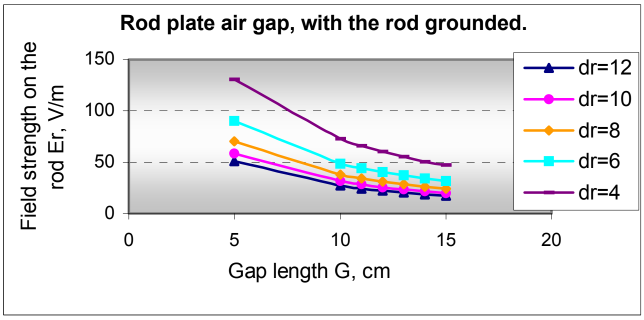
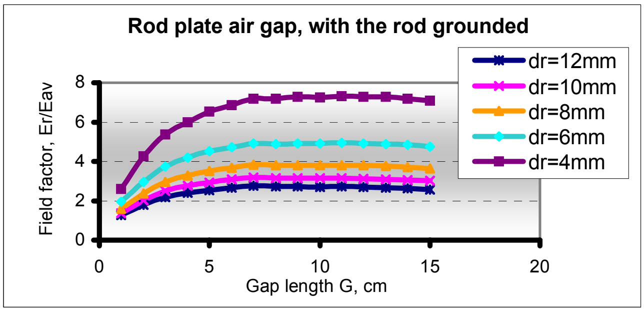



Fig. 4. Field strength distribution in rod-plate air gap models from simulation analysis.



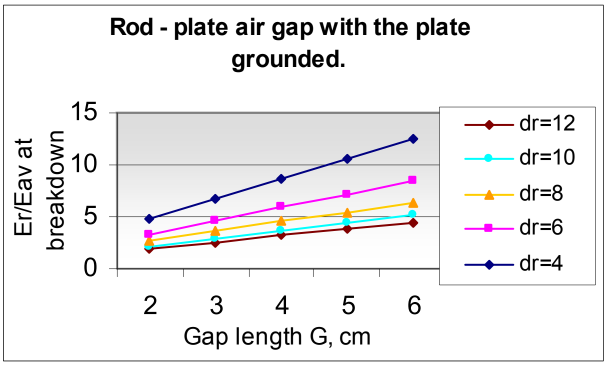

(a) Values of field strength on the rod.



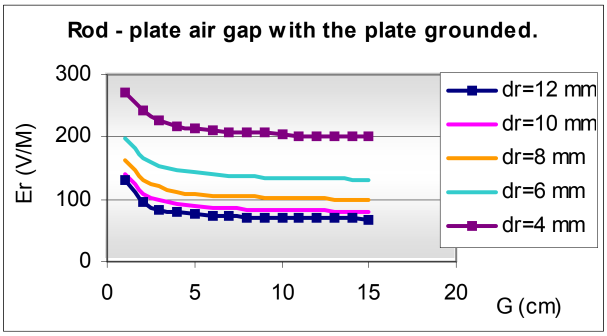

(b) Field factor along the axis of the gap

Figs 5. Rod-plate air gap, with the rod grounded. The rod's diameter is dr, and the plate's diameter is 100 mm.

It is also resulted that the field factor (n=Er/Eav) increases with the gap length. It takes lower values in the arrangement with the rod grounded and tends to get a steady value for each value of the rod's diameter when the gap length is longer than 80% of the plate's diameter, (fig 6b). In the arrangement with the plate grounded it increases continuously and is in complete agreement with equation 7, (fig 6a).

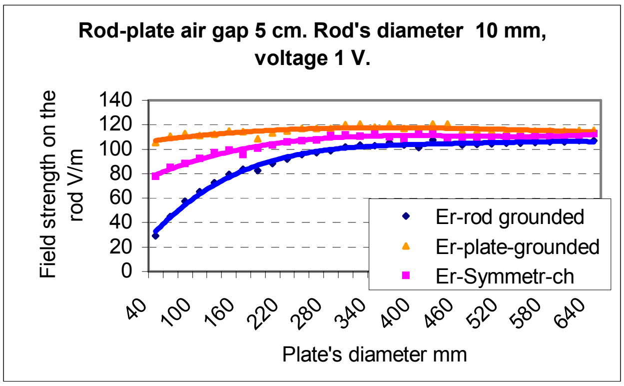



(a) The field factor along the axis

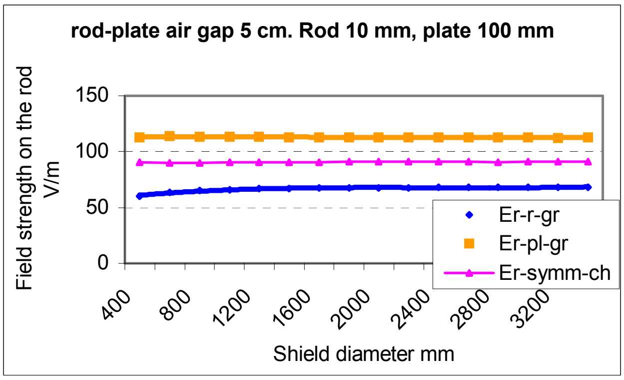



(b) The field strength on the rod.

Figs 6. Rod-plate air gap, with the plate grounded. The rod's diameter is dr and the plate's diameter is 100 mm.




(a) In function with the plate's diameter.




(b) In function with the shield's diameter.

Figs 7. The field strength on the rod in a rod plate air gap for the two different arrangements with the rod or the plate grounded. Voltage is 1 V.

From figs 8 it is resulted that the differences in the value of the field strength on the rod (maximum value in the gap), between the two different arrangements with the plate or the rod grounded, or with symmetrical charging of the electrode, decrease as the plate's diameter increase, while it is not affected by the shield's diameter. When the plate's diameter becomes very large the Ground Effect decreases, because of the mirror effect. In this case the rod-plate arrangement functions like a rod-rod arrangement of double length, stressed by double voltage.

## 4 The influence of the Polarity and the Ground Effect to the corona onset voltage in rod – plate air gaps.

The Polarity and the Ground Effect influence the corona onset voltage of small rod-plate air gaps as it is resulted from figs 9, 10, 11 and 12.

### 4.1 The influence of the Polarity Effect.

It is well known that the polarity of the rod's voltage in relation to the plate, which is grounded, influences the corona onset field strength and thus the corona onset voltage [1], [2], [14], [15], [16], [17], [18].

#### *4. 1.1. The arrangement with the plate grounded.*

In the arrangement with the plate grounded the Polarity Effect influences the corona onset voltage slightly in favour of the positive polarity of the applied voltage, as it is expected and shown in fig. 8.

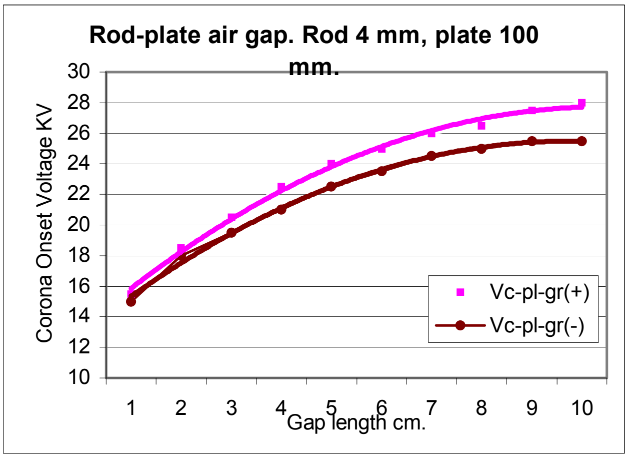



Fig. 8. The Polarity Effect in the rod-plate arrangement with the plate grounded.

#### *4.1.2. The arrangement with the rod grounded.*

In the arrangement with the rod grounded the Polarity Effect does not seem to influence the corona onset voltage in favour of the negative polarity of the applied voltage as it is expected, (fig. 9).

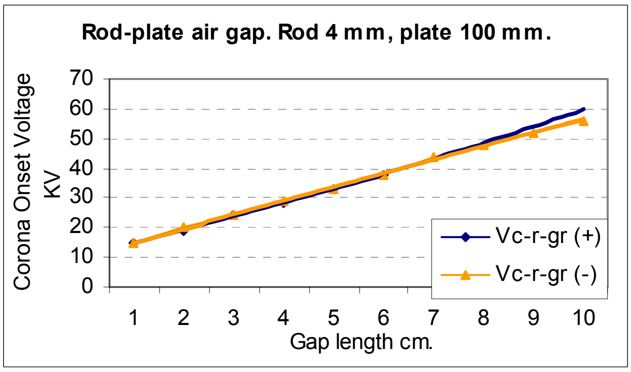



Fig.9. The Polarity Effect in the rod-plate arrangement with the rod grounded.

## 4.2 The influence of the Ground Effect.

The grounding of one of the electrodes influences the corona onset voltage significantly depending on the gap length, as well as the rod's and the plate's diameter.

### *4.2.1. The applied voltage is positive DC.*

When the applied voltage is DC positive the corona onset voltage of the arrangement with the rod grounded is significantly higher than the arrangement with the plate grounded, as it is shown in figs 10. The Polarity Effect reduces the Ground Effect slightly. The relation between the field strength on the rod (maximum value of field strength in the gap) and the corona onset voltage is:

$$V_{c\text{-}r\text{-}gr} / V_{c\text{-}pl\text{-}gr} = A^*(E_{c\text{-}pl\text{-}gr} / E_{c\text{-}r\text{-}gr}), \text{ where } A<1$$

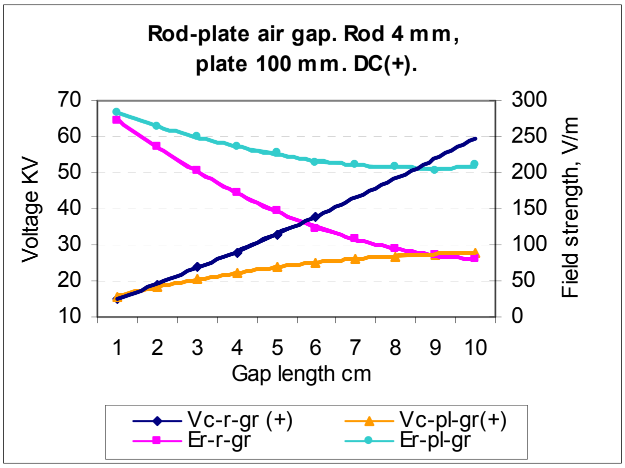
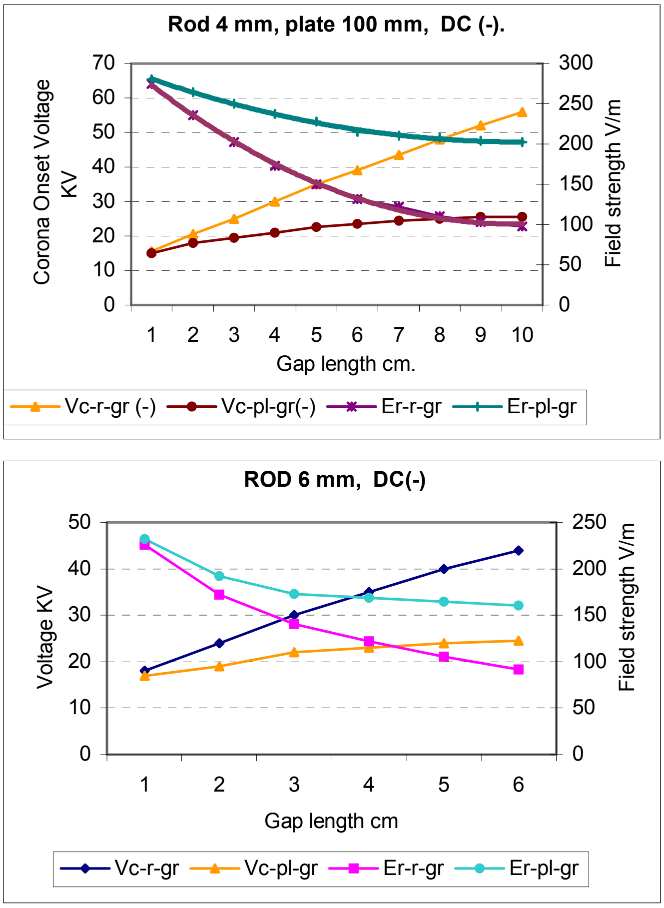



Fig 10. The Ground Effect for positive DC voltage.

### *4.2.2. The applied voltage is negative DC.*

When the applied voltage is DC negative the arrangement with the rod grounded appears much higher values of the corona onset voltage than in the arrangement with the plate grounded, as it is shown in figs 11. The Polarity Effect intensifies the Ground Effect. When the rod is grounded the rod is positive in relation to the plate and thus the influence of the Polarity Effect is added to that of the Ground Effect. The relation between the field strength on the rod (maximum value of field strength in the gap) and the corona onset voltage is:

$$V_{c\text{-}r\text{-}gr} / V_{c\text{-}pl\text{-}gr} = A^*(E_{c\text{-}pl\text{-}gr} / E_{c\text{-}r\text{-}gr}), \text{ where } A\approx 1$$




Figs 11 The Ground Effect for negative DC voltage.

### *4.2.3. The applied voltage is AC.*

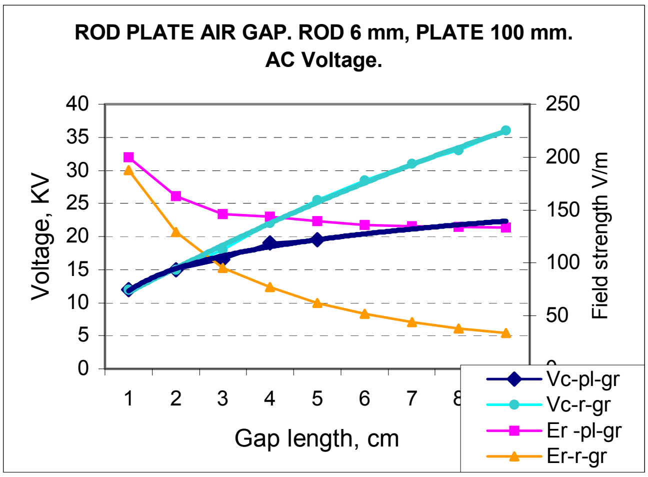



Fig 12. The Ground Effect for AC voltage

When the applied voltage is AC the arrangement with the rod grounded appears much higher corona onset voltage than the arrangement with the plate grounded, as it is shown in fig 12. The Polarity Effect reduces the Ground Effect. The corona effects appear in negative half cycle, when the plate is grounded and in positive half cycle when the rod is grounded. The relation between the field strength on the rod (maximum value of field strength in the gap) and the corona onset voltage is:

$V_{c\text{-}r\text{-}gr} / V_{c\text{-}pl\text{-}gr} = A*(E_{c\text{-}pl\text{-}gr} / E_{c\text{-}r\text{-}gr})$, where A<1

**4.3. The combined influence of the Ground and the Polarity Effect to the corona onset voltage of rod-plate air gaps.**

The corona onset voltage is higher for the arrangement with the rod grounded in small rod-plate air gaps. This is in full agreement with the results of the analysis, by which it is concluded that the maximum value of the field strength in the arrangement with the rod grounded is comparatively lower (figs 3, 5, 6, 7, and 8). The Polarity Effect influences the Ground Effect slightly, as it is shown in fig 13.

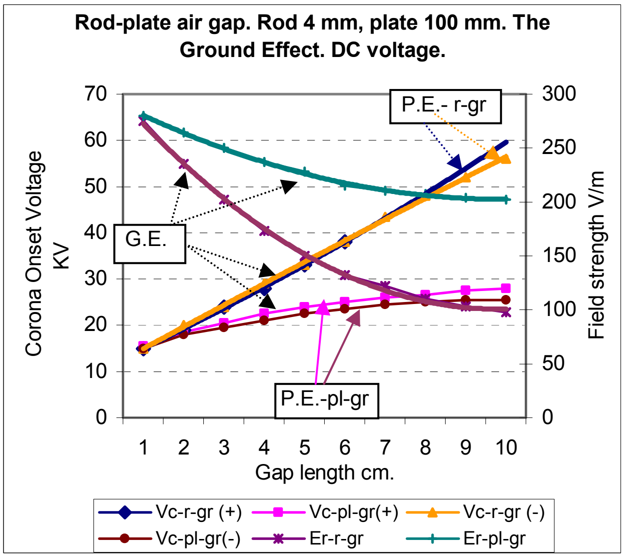



Fig 13. The Ground Effect and the Polarity Effect in rod plate arrangements.

# 5 The influence of the Ground Effect to the breakdown voltage in rod – plate air gaps.

The Polarity Effect influences the breakdown voltage in relatively long air gaps in favor of DC voltage of negative polarity, because of intensive corona effects, [1], [2].

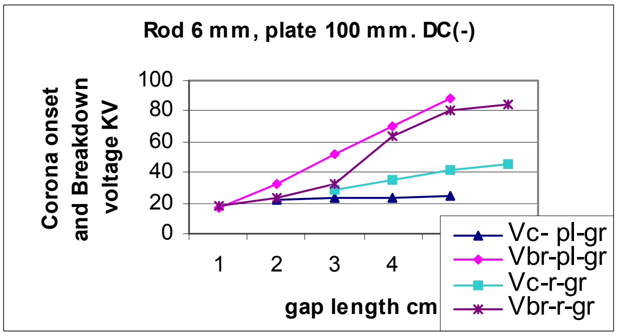
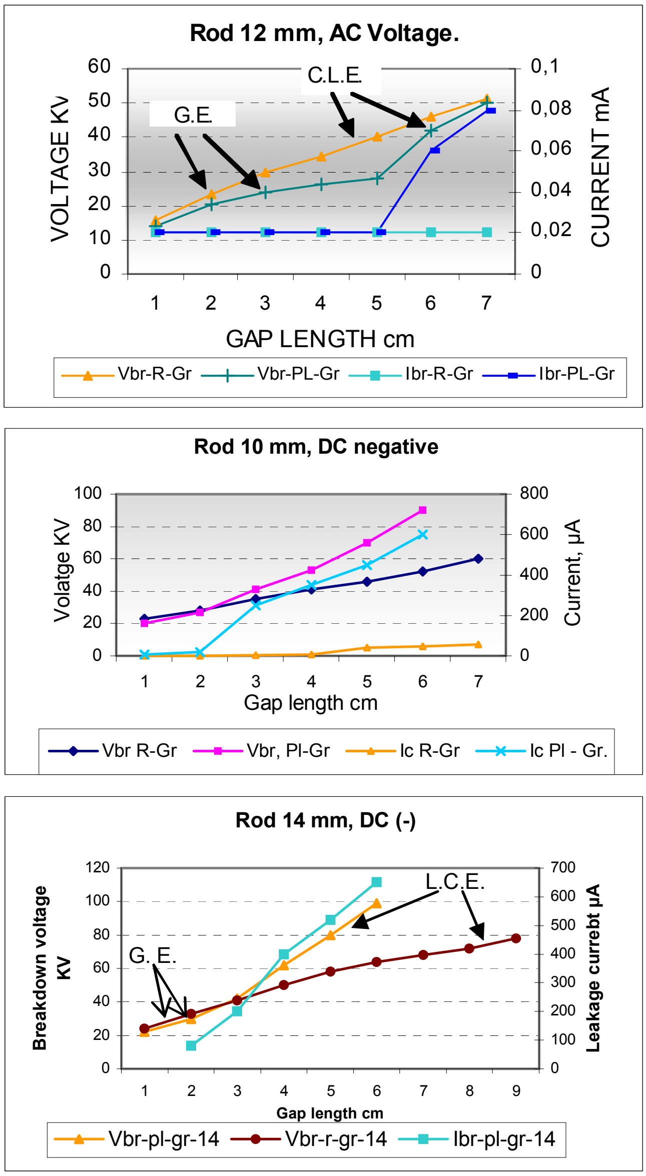



Fig. 14. Corona onset and breakdown voltage of rod – plate arrangements with the rod or the plate grounded for negative DC applied voltage. Rod's diameter 6 mm.




Figs 15. The breakdown voltage in connection to the corona leakage current in rod-plate air gaps for the two different arrangements with the rod or the plate grounded, and for DC and AC voltage.

The Ground Effect influences the breakdown voltage in small air gaps. The breakdown voltage is higher for the arrangement with the rod grounded. This is in full agreement with the results of the analysis, by which it is concluded that the maximum value of the field strength in the arrangement with the rod grounded is comparatively lower (figs 3, 5, 6, and 7).
We can say that the Ground Effect is overturned and the breakdown voltage increases significantly and becomes higher in the arrangement with the plate grounded, because of the influence of the corona leakage current (Polarity Effect) (figs 14, 15).
The results are most significant and clearer when the breakdown voltage appears before the corona effects, and this happens when the gap length is very small. If the gap length is large enough the influence of the corona leakage current suppresses the Ground Effect, and the breakdown voltage is considerably higher in the arrangement with the plate grounded.
The effect is stronger when the rod's diameter is very small, because in this case the corona leakage current is a lot higher.

## 6 Conclusions

1. The influence of the Ground Effect to the field distribution is intense in all rod-plate arrangements, and it grows stronger when the rod's and the plate's diameter is decreased and when the gap length is increased. This means that the inhomogeneity of the electric field influences the Ground Effect. That leads the maximum value of the field strength that usually appears on the rod and hence the value of the field factor to be high, and turn much higher when the arrangement is used with the plate grounded than with the rod grounded. The Ground Effect is negligible when the Plate's diameter is very large.
2. The Ground Effect influences the corona onset and the breakdown voltage of small rod-plate air gaps strongly. In the arrangement with the rod grounded, the corona onset voltage and the breakdown voltage are higher.
3. The Polarity Effect also influences the corona onset voltage, but in a different way, and reduces or reinforces the Ground Effect respectively.
4. A relation between the maximum value of the field strength on the rod and the corona onset as well as the breakdown voltage appears.
5. When the air gap is long enough and the corona leakage current is relatively high the Polarity Effect suppresses the Ground Effect and the breakdown voltage is higher for the arrangement with the plate grounded.
6. Future work will contain the full analysis of the Ground Effect for rod-plate air gaps of different geometries as far as the diameter of the rod and the plate is concerned, stressed by DC voltages of negative or positive polarity and AC voltages. The mathematical functions between the field strength and the breakdown voltage (dielectric strength) of the air gaps, as well as between the breakdown voltage of the gap and the corona leakage current through the gap will also be investigated.

Acknowledgments.
The project is co-funded by the European Social Fund & National Resources –EPEAEK II, under the action 2.2.3z., "Archimidis II".
Special thanks to Stamatia Maglara, Konstantina Giannakopoulou, and Evaggelia Gani, who offered considerable help in experimental and simulation work and useful suggestions during the preparation of this paper.

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