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AUTHOR(S):

KOUNO, Toshihiko; HAYASHI, Muneaki; MIYASATO, Kenji

CITATION:

KOUNO, Toshihiko ...[et al]. Flashover Characteristics on the Gap of Rod to Plane Applied Bipolar Impulse Voltage. Memoirs of the Faculty of Engineering, Kyoto University 1986, 48(2): 195-208

ISSUE DATE:

1986-05-17

URL:

http://hdl.handle.net/2433/281322

Flashover Characteristics on the Gap of Rod to Plane Applied Bipolar Impulse Voltage

By

Toshihiko KOUNO*, Muneaki HAYASHI** and Kenji MIYASATO***

(Received December 26, 1985)

Abstract

This paper describes the fifty percent flashover voltage and the V-t curve for a rod-plane gap applied bipolar impulse voltage, and the behaviour of the space charge in the gap.

In the distribution line, the bipolar impulse voltage had been observed frequently when lightning hit near it. Then, the bipolar impulse wave used in the experiment was decided as the composite voltage wave made from the preceding wave of positive (or negative) polarity, 20/500 μsec. and the following wave of negative (or positive) polarity, 2/60 μsec. The connecting time of the abovementioned two pulses was decided as 20 ± 5 μsec.. The test gap was the rod-plane gap with a gap length of 6.0 cm, and the rod diameter of 1.0 cm as a non-uniform field, mainly.

As for the experimental results, when the applied preceding impulse voltage was positive polarity and a corona occurred, the fifty percent flashover voltage was up by 15%. And, when the preceding impulse voltage was negative polarity and with a corona, the fifty percent flashover voltage was down by 10%. The space charge phenomena as the cause given by the abovementioned results were observed by using an image converter camera.

1. Introduction

The various apparatus used on the distribution lines were made with the design to withstand lightning, still more to be protected by a lightning arrester. In the section to be protectted, frequently, even on the pole equipped by the lightning arrester, the pole transformer is broken by the lightning. It is considered as the cause that the current of lightning was very large, the distance of the distribution line to the earth point hit by lightning was very close, or, the transformer was directly hit by lightning. If there was another normal cause, the breakdown test must be looked over again on the apparatus as the arrester, the transformer and so on, included in the test by the applied bipolar impulse voltage.

* Department of Electrical Engineering II.
** Department of Electrical Engineering.
*** KANSAI Electric Co.

Today, the withstand lightning impulse test for all apparatus is done with applied monopolar impulse voltages of positive or negative polarity. But, we observed that the impulse waves induced in the distribution line by the lightning were not only monopolar impulse waves but also bipolar impulse waves[1]. Therefore, the withstand lightning impulse test must be checked by applied bipolar impulse voltages. We have an interest in this subject as to the problem of the physical meaning, as to the behaviour of the flashover in the period of the following impulse voltage with an opposite polarity to the preceding wave, in the space charges caused by the corona discharge on the preceding impulse voltage.

2. Experimental method and instruments

The flashover characteristic obtained by the applied bipolar impulse voltage was contrasted with the characteristic obtained by the applied normal monopolar impulse voltage. The experimental circuit of monopolar impulse voltage source is shown in Fig. 1. Also, as is shown in Fig. 2, the bipolar impulse voltage was obtained by the

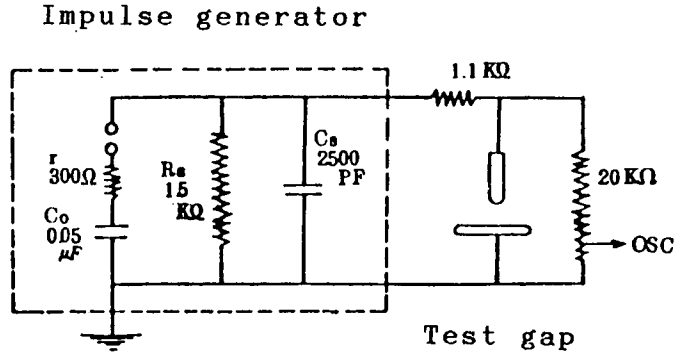


Fig. 1. The experimental circuit of monopolar impulse voltage source.

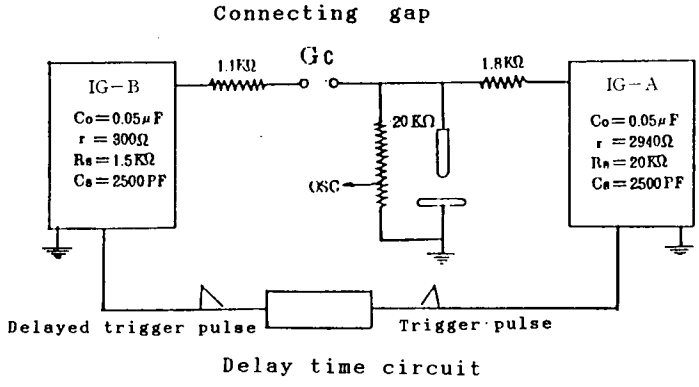


Fig. 2. The experimental circuit of bipolar impulse voltage source.

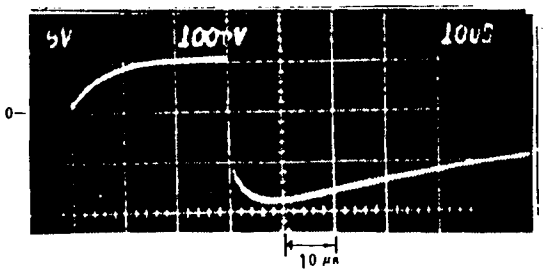


Fig. 3. A typical bipolar impulse voltage wave.

connection of two impulse voltage sources. The preceding impulse voltage was given by an impulse voltage source IG-A, as wave form of 20/500 μsec., and the following impulse voltage was given by an anither impulse voltage source IG-B, as the wave form of 2/60 μsec.. The two impulse voltage sources were operated and controlled by a delayed time generator. The typical wave form of the bipolar impulse voltage was given as shown in Fig. 3. That is simulated to the typical wave form induced in a distribution line by the lightning. The value of the applied voltage was selected in the range from the voltage of the corona onset to the maximum voltage for the unbreakdown. The delay time, as the connecting time of the two pulses consisting of opposities polarities, could be chosen with a wide range.

The following voltage wave form was decided as 2/60 μsec., for the reason of the comparison with the data obtained by the applied monopolar impulse voltage. The preceding impulse voltage source, shown as IG-A, was connected to the test gap through the resistor of 1.8 kΩ. The following impulse voltage source, shown as IG-B, was connected to the test gap through the connecting gap G_c and the resistor of 1.1 kΩ. The connecting gap cut the high voltage from the IG-A and made the task as not through it in the IG-B.

In this experimental series, the delay time was decided as 20±5 μsec.. The measurement of the applied voltage was done using a two beam oscilloscope and a resistor divider of 20 kΩ connected to the same poinr with the test gap.

The test gap was decided to be a rod-plane gap, for reason of obtaining a clearly distinguished result against the different polarity of the applied voltage. The diameter of the rod was 1.0 cm and the shape of the tip was of a hemi-sphere type. The gap length was 6.0 cm, for reason of to obtaining the 50% flashvoer voltage as the BIL-60 kV for the distribution line.

For the comparison, a rod-rod gap and a sphere-sphere gap were also used as the test gap.

Our experiments were done to obtain the 50% flashover voltages and the *V-t* curves. The values of the flashover voltage on the following impulse wave form were

measured in two casex of when the preceding corona appeared or did not appear. The flashover time was measured from the starting time of the following impules wave form[2].

3. *V-t* curve or the applied monopolar impulse voltage

The *V-t* curves for several test gaps were given by applied monopolar impulse voltage. Used test gaps were three kinds: the sphere-sphere gap, the rod-rod gap and the rod-plane gap. The applied voltages of both positive and negative polarity were used. These given data were compared with each other and discussed as below and in the next section.

The *V-t* curves for the sphere-sphere gap with a diameter of 12.5 cm and a gap length of 2.5 cm were given as shown in Fig. 4. In Fig. 5, the resuls for the

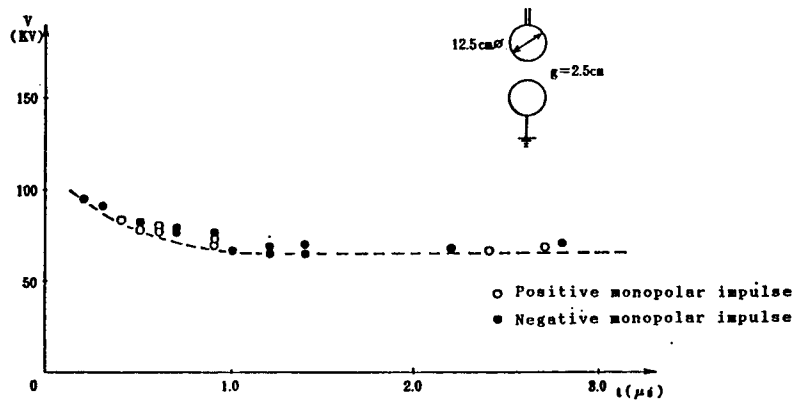


Fig. 4. The *V-t* curve for the sphere-sphere gap (g=2.5 cm).

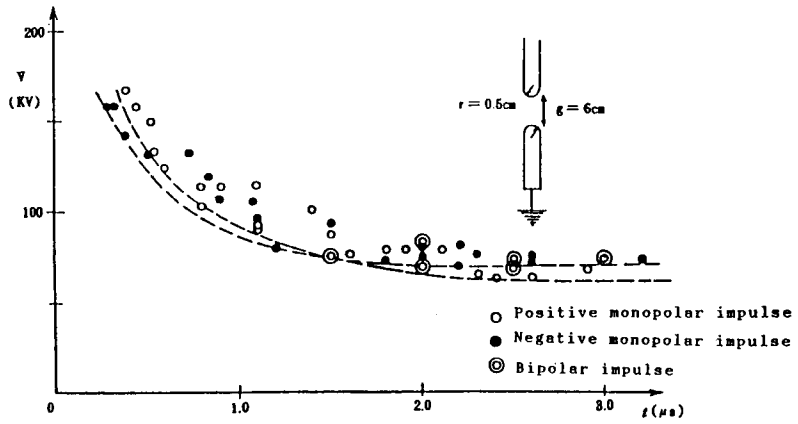


Fig. 5. The *V-t* curve for the rod-rod gap (g=6.0 cm).

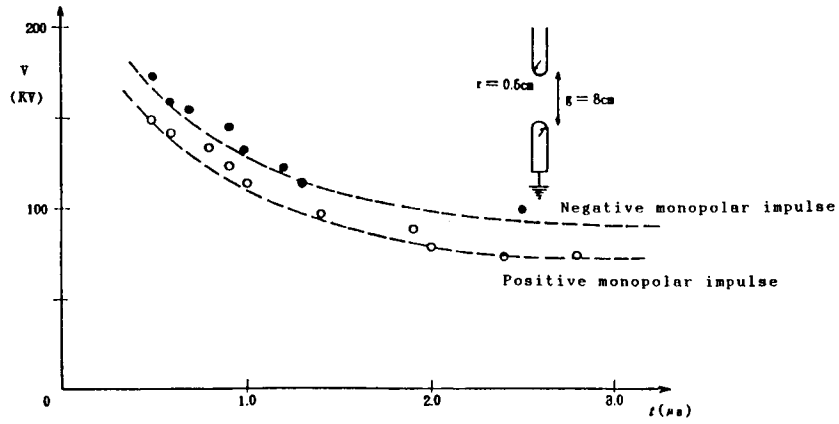


Fig. 6. The V-t curve for the rod-rod gap (g=8.0 cm).

rod-rod gap with a gap length of 6.0 cm, and in Fig. 6, for the gap length of 8.0 cm, were each shown.

The gap length of the sphere-sphere gap was selected as 2.5 cm for following reason. Namely, the 50% flashover voltage for the sphere-sphere gap was almost the same as the one for the rod-rod gap with the gap length of 6.0 cm. Two V-t curves for the sphere-sphere gap applied voltages of positive or negative polarity appear as the flashover characteristic for the gap in the uniform electric field as a curve to be flat, and to have a little difference of the two curves given for the polarity change of the applied voltage.

The V-t curves for the rod-rod gap with the gap length of 6.0 cm appear

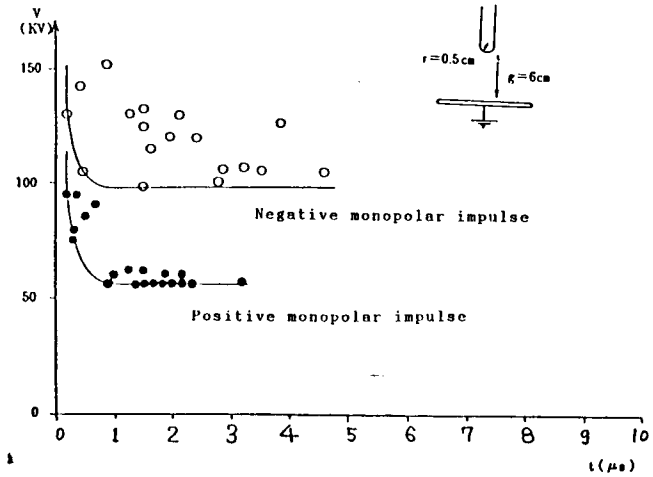


Fig. 7. The V-t curve for the rod-plane gap applied monopolar impulse voltage (g=6.0 cm).

rapidly to be raised at a time less than 1.0 μsec.. However, the two curves for the positive applied voltage (as shown by the solid line in the figure) and the negative voltage (as shown by the dotted line) are almost the same as each other. These phenomena happened in the condition that the field intensity for the gap was non-uniform. However, the two maximum field intensities of the positive side and the negative side had little difference.

Then, the V-t curves for the rod-rod gap with the gap length of 8.0 cm were given such that the curve for the positive applied voltage was just below one for the negative. That is the flashover characteristic for the gap in the non-uniform field intensity, completely.

Next, the V-t curves for the rod-plane gap are shown in Fig. 7. In the figure, two curves for the positive and the negative had large differences, and the curve for the positive voltage was clearly lower than the one for the negative.

4. V-t curve for the applied bipolar impulse voltage

There are two types of bipolar impulse voltage consisting of the positive preceding voltage or the negative preceding voltage. In both cases, the V-t curves and the fifty percent flashover voltages were given respectively for the rod-plane gap with the gap length of a 6.0 cm. The experiments were done for the two cases of with a corona or no corona during the applied preceding voltage.

4.1. On the applied bipolar impulse voltage with the preceding positive and the following negative polarity

By the preliminary experiments, the 50% flashover voltage for the test gap by the applied monoplar positive voltage was given as 57 ± 5 kV, and the corona onset voltage was 37 kV. Then, by the applied bipolar impulse voltage, the preceding poositive impulse voltage was selected as 34 kV in the case of no corona and 40 kV in the case of a corona.

In the case of no corona during the applied preceding positive voltage, the 50% flashover voltage for the following negative impulse voltage was given as 98 ± 15 kV. And, it was given as 113 ± 15 kV for the case of a corona during the applied preceding positive voltage. The V-t curve for no corona during the applied preceding voltage is shown by the sign " • " in Fig. 8. The flashover occurred during the applied following negative voltage, Then, we compared this curve shown in Fig. 8 with the curve for the negative monopolar voltage as shown by sign " ○ " in Fig. 7.

These two V-t curves were almost the same as each other. Namely, if the space charge in the gap was neither increased nor decreased, the flashover voltage for the gap had no change. But, the V-t curve for the case with a corona during the applied preceding voltage was given as shown by sign " ○ " in Fig. 8. Then, we

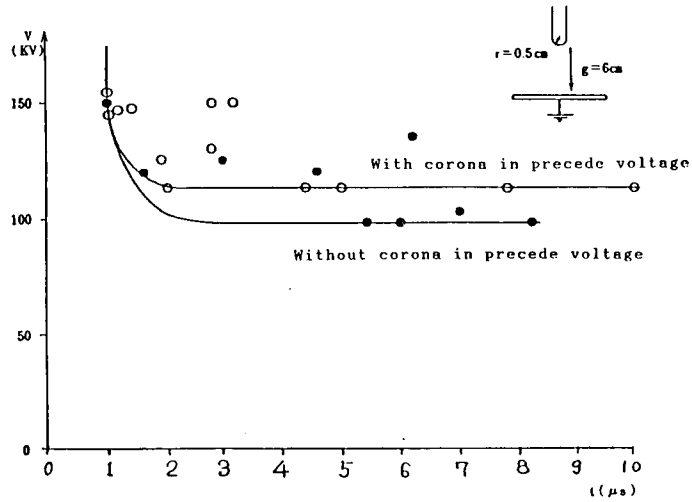


Fig. 8. The V-t curve for the rod-plane gap applied bipolar impulse voltage of positive preceding and negative following voltage wave (g=6.0 cm).

also compared this curve with the curve for the negative monopolar voltage shown by sign " ○ " in Fig. 7, or with the curve for the preceding positive bipolar impulse voltage as shown by sign " • " in Fig. 8. This curve for the corona occurred when the preceding positive voltage was higher by 10% than the curve for no corona, or for the monopolar negative voltage. The phenomena occurred as the effect of a space charge of the corona grown at the applied preceding voltage with an opposite polarity.

4.2. On the applied bipolar impulse voltage with the preceding negative and the following positive polarity

By the preliminary experiments, the 50% flashover voltage for the test gap applied monopolar negative was given 98±10 kV, and the corona onset voltage was 59 kV. Then, by the applied bipolar impulse voltage, the preceding negative impulse voltage was selected as 46 kV in the case of no corona, and 74 kv in the case of a corona.

In the case of no corona, during the applied preceding negative voltage, the 50% flashover voltage for the following positive impulse voltage was given as 56±10 kV. And, it was given as 51±10 kV, for the case with a corona during the applied preceding positive voltage. The V-t curve for no corona during the applied preceding voltage is shown by sign " • " in Fig. 9. The flashover occurred during the applied following positive voltage. Then, we compared this curve shown in Fig. 9 with the curve for the negative monopolar voltage as shown by sign " ○ " in Fig. 7. These two V-t curves were almost the same as each other. Namely, if the space charge in the gap has no change, the flashover voltage for the gap has no change.

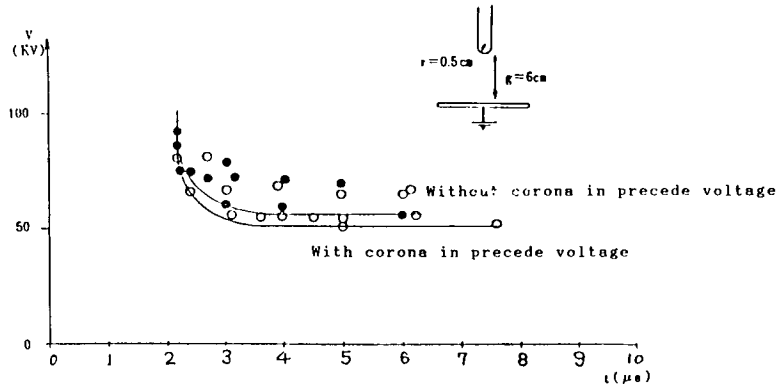


Fig. 9. The V-t curve for the rod-plane gap applied bipolar impulse voltage of negative preceding and positive following voltage wave (g=6.0 cm).

The phenomenon was same as the one of the applied preceding positive voltage and with out a corona. It is remarkable that a rising part of the curve happens at a longer time as 2 μsec.. The V-t curve for the case with a corona during the applied preceding voltage was given as shown by sign " ○ " in Fig. 9. Then, we compared this curve with the curve for the positive monopolar voltage shown by sign " • " in Fig. 7, or with the curve for the preceding negative without a corona as shown by sign " • " in Fig. 9. This curve for the applied voltage with a corona occurred while the preceding negative voltage was higher by 10% than the curve for the case of no corona, or for the monopolar positive voltage. The phenomena occurred as the effect of a space charge of the corona grown when applying the preceding voltage of the opposite polarity.

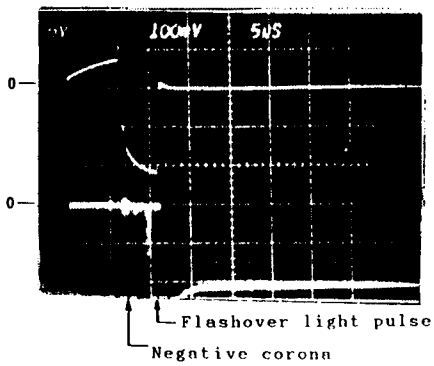
On the other hand, in a previous study[3], it was described already that the V-t curve for the applied bipolar impulse voltage was almost the same as the V-t curve for the applied monopolar impulse voltage. But, in the study, the gaps of the sphere-sphere and the rod-rod had been used. In our experimental results for such a gap with uniform or symmetrical field, they were the same as each other, as shown in Fig. 5.

5. Discharge phenomena for the applied bipolar impulse voltage

If the corona occurred at the preceding polarity voltage, the flashover phenomena at the following opposite polarity voltage were different from the one for the applied monopolar impulse voltage. The space charge caused by the corona in the preceding voltage remained in the gap at the time of the applied following impulse voltage with the opposite polarity. In such a case, the discharge phenomena were observed as below, taking notice of the behaviour of the space charge.

5. 1. Observation by use of a photo-multiplier tube

The radiation phenomena were observed by use of a photomultiplier tube with a light guide cable and a two beam oscilloscope. The observed results of the light pulse and the applied voltage wave are shown in Fig. 10 and Fig. 11. In Fig. 10, under the condition of no corona during the applied preceding positive voltage, the light pulse appeared at the same time as the reverse of the applied voltage. The flashover was concluded after the time. Another case as shown in Fig. 11, under the condition of a corona during the applied preceding positive voltage, then, the light pulse was not observed at the same time as the reverse voltage. In this case, the negative corona appeared at the peak of the negative voltage after the time of the reversed voltage, but didn't complement the flashover. Comparing both cases, the different condition was that the applied preceding impulse voltage of the former was less by 6 kV than the preceding voltage of the latter, but, the applied following impulse voltage was the same for all. On the condition of a corona in preceding

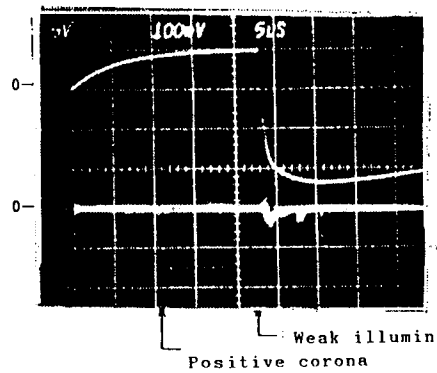


upper beam: Voltage wave 49.25 kV/div.

lower beam: Light pulse 100 mV/div.

5 μsec./div.

Fig. 10. The observed corona given by applied bipolar impulse voltage, in case of no corona in the preceding voltage.



upper beam: Voltage wave 49.25 kV/div.

lower beam: Light pulse 100 mV/div.

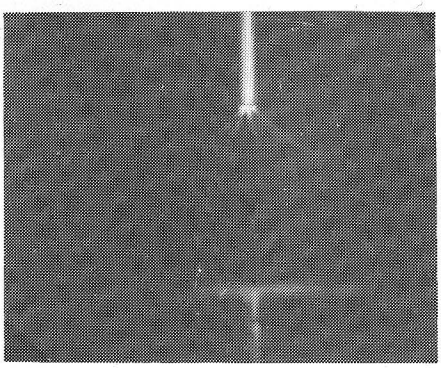
5 μsec./div.

Fig. 11. The observed corona given by applied bipolar impulse voltage, in case of a corona in the preceding voltage.

voltage, the space charge remained in the gap, and it was effective for deciding the flashover voltage for the applied reversed voltage. Then, the appearance of the negative corona in the following voltage delayed the propagation of the flashover, and there was no flashover under the condition of the higher voltage except the flashover voltage in the case of the monopolar impulse voltage. As a reasult, the V-t curve for the bipolar impulse voltage was up by 10% more than that for the monopolar impulse voltage.

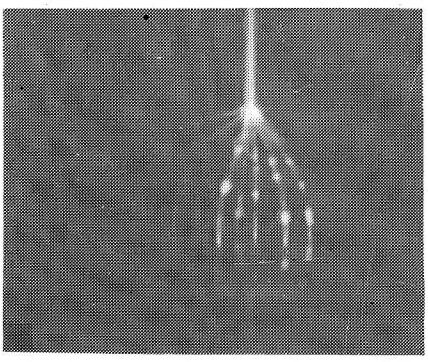
5.2. Observation used a still camera with image intensifier tube

The image of the corona and radiation phenomena were observed by useing a still camere with an image intensifier tube and shown in Figs. 12 to 14. In Fig. 12, it is shown that there was only a positive corona during the preceding positive voltage. Next, it is shown in Fig. 13 that only the negative corona occurred at the same time as the reverse of the applied voltage. Both had no differences about the corona phenomena for the positive or negative polarity of the applied monopolar impulse voltage. Then, in Fig. 14, the phenomena for the applied bipolar impulse



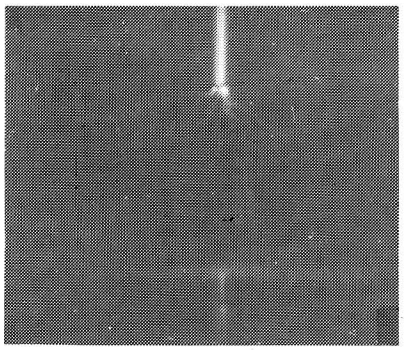
Applied voltage: 50 kV

Fig. 12. The observed positive corona given by applied monopolar impulse voltage.



Applied voltage: −90 kV

Fig. 13. The observed negative corona given by applied monopolar impulse voltage.



Applied voltage:
Preceding 50 kV and
following −110 kV

Fig. 14. The observed corona given by applied bipolar impulse voltage.

voltage were observed only when the positive corona occurred during the applied preceding voltage. There was noting about the negative corona, in spite of a higher following voltage being up by 20 kV more then the applied voltage under the condition shown in Fig. 13.

5. 3. The weak illumination observed by using an image converter camera

It was cleared that the phenomena in the gap during the reverse of the applied voltage were different by the conditions of a corona or no corona on the applied preceding impulse voltage. The observation was very difficult, of course, on the phenomena, the light pulse was very weak to measure and the noise was large. Then, it was a better observation that the image was observed by using the image converter camera. Then, the observation of the phenomena was done by the streak camera method.

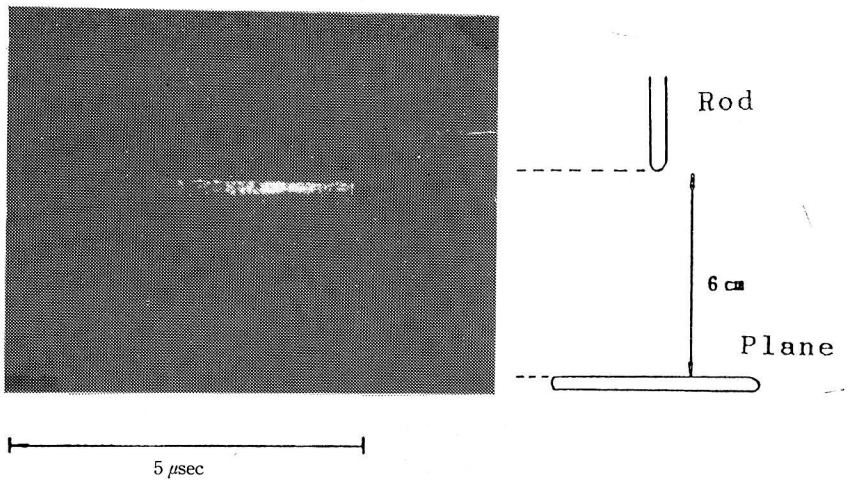


Fig. 15. The weak illumination given at the time of reversing voltage observed by streak method using an image converter camera.

It was known that the illuminating phenomena was very weak. Then, the observation by using the image converter camera was done with an image intensifier tube and a film of very high sensitivity (ASA 20000). The radiation phenomena was observed narrowly as shown by Fig. 15. In the figure, the illustration of the gap arrangement, on the right hand, and the time scale, on the bottom side were shown respectively. It is known by the figure that the length of the weakly illuminated part was only 5 mm from the tip of rod electrode, and went on during 4 μsec.. The time sequence is shown in Fig. 16 as the schema. From these figures, it is known that the weak illumination occurred just at the time of reversing the applied voltage.

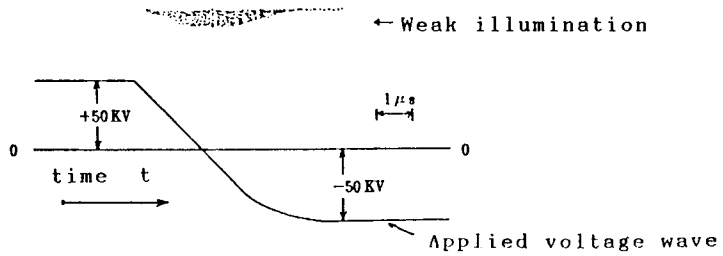


Fig. 16. The schema for the observed weak illumination and the applied voltage wave.

5. 4. The space charge observed by the probe method

The space charge in the gap was observed by the probe method[4], as shown in Fig. 17. In the figure, the observed result was given as the differential from the pulse given by the small sphere put on near the main gap, and the pulse given by the voltage divider. The typical results are shown by Fig. 18 and Fig. 19. In there figures, the upper beam shown the applied voltage, and the lower beam shows the space charge.

In Fig. 18, the pulse of the space charge appeared on the preceding positive voltage and the pulse died out after the voltage was reversed. Therefore, it is considered that the space charge was swept at the time during the reverse of the applied

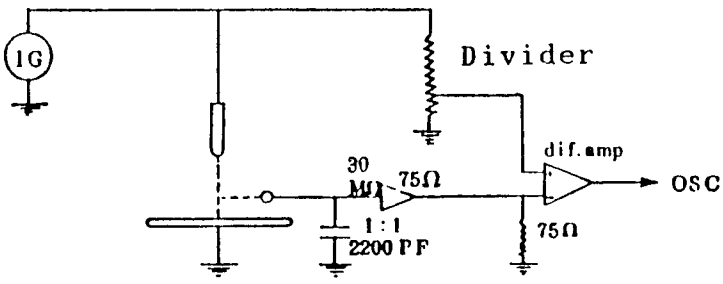
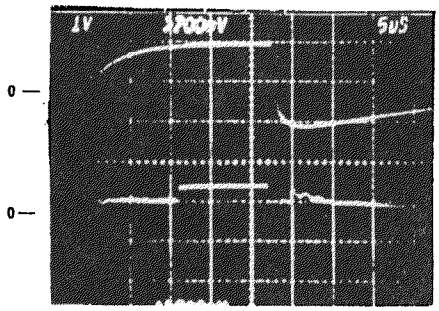


Fig. 17. The measurement circuit for the space charge.

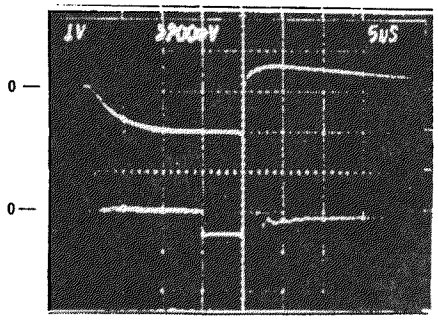


upper beam: Voltage wave 42.25 kV/div.

lower beam: Space charge wave (Arbitrary)

5 μsec./div.

Fig. 18. The space charge measured by using sphere probe (The applied bipolar impulse voltage was positive preceding).



upper beam: Voltage wave 42.25 kV/div.

lower beam: Space charge wave (Arbitrary)

5 μsec./div.

Fig. 19. The space charge measured by using sphere probe (The applied bipolar impulse voltage was negative preceding).

voltage. The space charge phenomena when the bipolar impulse voltage with the preceding negative voltage and the following positive voltage were applied to the gap are shown in Fig. 19.

6. Conclusion

When the rod-plane gap with the non-uniform field was applied to the bipolar impulse voltage, the flashover on the stage of the following voltage with an opposite polarity depended on the space charge made form the occasion of the corona on the stage of the preceding voltage. As for the experimental results, when the preceding impulse voltage had a positive polarity and with corona, the fifty percent flashover voltage as the level voltage at the tail of the V-t curve was up by 15%. When the preceding impulse voltage had a negative polarity and with a corona, the fifty percent flashover voltage was down by 10%. The space charge phenomena as the cause given by the abovementioned results were observed by using an image converter camera.

Acknowledgement

The authors wish to thank Mr. Takanori MATSUMOTO for his kind assistance.

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