Soviet-era science, translated into English

NEW MATERIALS ON THE DEVELOPMENT OF A NEGATIVE SPARK AND ITS COMPARISON WITH LIGHTNING

I. S. Stekol'nikov and A. V. Shkilev

1962

SovietRxiv

View the original and related papers at https://sovietrxiv.org/items/ru-196201.42330

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.

SovietRxiv

Abstract

Full Text

NEW MATERIALS ON THE DEVELOPMENT OF A NEGATIVE SPARK AND ITS COMPARISON WITH LIGHTNING

I. S. Stekol' nikov and A. V. Shkilev

(Presented by Academician L. A. Artsimovich on 3 IV 1962)

With the aid of an electron-optical converter (EOC) with light amplification [1], the authors investigated the development of a spark under impulse voltage in gaps: rod + plane (–r + p) and rod + rod on a plane (–r + r/p). The negative electrode was a rounded rod 20 mm in diameter; in the case –r + r/p, a rounded rod 10 mm in diameter and of height h from 2.5 to 50 cm was mounted on the plane. The length of the discharge gap in the case –r + p was varied from 100 to 300 cm, and for –r + r/p $S_0 = 270 \div 300$ cm. The voltage wave had the form 1.5×1000 μsec, with amplitude U close to the minimum discharge value ($k = U/U_{\text{min}} \simeq 1.0$). The EOC was used with lenses: 1) quartz ($D = 3.5$), 2) "Yupiter-3" ($D = 1.5$), and 3) "Yupiter-12" ($D = 2.8$). The EOC shutter was used according to the "open—closed" principle, owing to which the photographs yielded a static picture of the discharge processes that had developed by the beginning of the time sweep. Synchronism of the EOC and oscilloscope recording was ensured by connecting their time-base plates to a common source of sweep voltage. The current was recorded by means of a shunt connected to a measuring plane 3×3 m^2. The latter was installed at a height of 15 cm above a grounded plane 8×8 m^2. In order to make it possible to analyze in detail the temporal picture of spark development obtained with the EOC, the discharge processes were simultaneously photographed with a static camera with a quartz lens ($D = 4.5$); for this purpose the known method of voltage "cutoff" at S_0 by another gap $S_1 < S_0$ was used.

Results of the experiments. Examples of the records obtained in the gaps –r + p and –r + r/p are shown, respectively, in Figs. 1 and 2*. The switching on of the time sweep in Fig. 1B occurred at the instant t_0, after the front of the voltage wave. Therefore, at the beginning one sees the static picture of the discharge processes that had developed up to t_0 (channels ab_1, ac_1, etc.). Noteworthy is the stepwise character of the advance of the channels into the depth of the gap, with an average effective velocity equal to $1.1 \cdot 10^7$ cm/sec. The process has a complex structure: bright flashes are observed at the lower ends of the channels (possibly being stems of the impulse corona), downward from which luminous channels of the "branches" type of the impulse corona depart, while upward

[1] On the time sweeps, the angle $> 90^\circ$ between the sweep direction and the axis of the gap is due to the characteristics of this EOC.

SovietRxiv

Fig. 3

Figure 1: Fig. 3

there is an expanding diffuse glow. The brightness of the glow weakens in the direction toward the rod electrode. It ends at the head of an ordinary leader (line e_1—e), which develops with a velocity of $4.2 \cdot 10^6$ cm/sec. After t_1, branches from the bright flashes begin to touch the plane. The magnitude of the current does not change appreciably in this case (see Fig. 1B). At the same time, the bright flashes continue to advance toward the plane until t_2, when a brighter branch is formed and an increase occurs in the brightness of the previously ionized channel; the current then increases somewhat. The leader (kg) begins to grow from the plane only after it is touched by the stepped leader (t_3); its initial velocity is $2 \cdot 10^7$ cm/sec. From its head develop "bundles of filaments" [^2]; they end at the head of the negative leader. With the appearance of the positive leader, the current increases rapidly. With the appearance of the leader (kg), the velocities of both leaders become approximately equal and begin to increase rapidly. Closure of the EOC shutter occurred at the instant t_4, preceding the instant t_5 of voltage cutoff.

For the article by I. S. Stekolnikov and A. V. Shkilev, p. 782

Fig. 1. Optical picture of the discharge in the gap $-c+p$, with $S_0 = 2.7$ m and $k = U/U_{\min} \approx 1.0$: **A** –static photograph (quartz, $D = 4.5$); **B** –time sweep (image-converter tube with a "Jupiter-12" lens, $D = 4.5$); **V** –oscillogram of the current (1), time calibration (2), and voltage pulse (3) for closing the image-converter tube.

Fig. 2. Same as in Fig. 1, but in the gap $-c + c/p$, with $S_0 = 2.9$ m and $h = 10$ cm.

From Fig. 1B one may conclude that, when voltage is applied to the gap with a rod electrode, after the impulse corona (the rod zone $-mn$), thin channels advance stepwise toward the plane in several directions (ab_1b, ac_1c, adf). We shall call this process the **step leader** of the spark*, the bright flashes at its ends the **steps**, and the channels proceeding downward from them the **branches of the impulse corona**.

Fig. 3. Scheme of spark development in the gap $-c+p$. 1 –impulse corona; 2 –step leader; 2a –branch of the impulse corona; 2b –step; 3, 4 –negative and positive leaders; 5 –filamentary glow; 6 –main channel. In the rectangle, the scheme of process development during the next elongation of the step leader is shown (aeb –the preceding static-image sweep, e_2b_1c –the sweep).

Spark development in the gap $-c+c/p$ is illustrated in Fig. 2. At first the spark develops analogously to the case $-c+p$, i.e., a step leader (bc) advances toward the plane. When it approaches to within a certain distance of the rod mounted on the plane, branches (kd) of the type of the branches of a positive impulse

SovietRxiv

Fig. 4. Diagram of spark development in the gap –c + c/p. 7—branches of the positive impulse corona; the remaining designations correspond to Fig. 3

Figure 2: Fig. 4. Diagram of spark development in the gap –c + c/p. 7—branches of the positive impulse corona; the remaining designations correspond to Fig. 3

corona begin to develop from the latter at the instant t_1, with an average velocity of $\simeq 7 \cdot 10^7$ cm/sec. The current does not change appreciably in this case. As these branches approach the step leader, their velocity increases. In the region traversed by the heads of the branches, afterglows are relatively small and are not always recorded. In the region traversed by the step leader, the brightness of the branches increases considerably. Only after the branches of the positive impulse corona (t_2) have merged with the step leader is a bright glow observed along the whole gap, and a leader ($k_1 g$) begins to develop from the grounded rod; the current rises sharply.

In a number of cases, the formation in the channel of the step leader of detached channels of the leader type was observed; their heads develop in both directions with a velocity close to the velocity of the leader at the electrode.

In Figs. 3 and 4, schemes are given for spark development in the gap $-c+p$ and $-c+c/p$. The negative impulse corona forms a zone of excess charge; at $U_{\min}$ the radius of the zone does not exceed $1/3S_0$. At the boundary of the zone of negative space charge, conditions are created for its subsequent introduction in one or several directions toward the plane in the form of step leaders. The effective velocity of advance of the step leaders lies within $(0.8 \div 2) \cdot 10^7$ cm/sec. During each elongation of the step leader, three processes take place (see the inset in Fig. 3): 1) a branch of the impulse corona grows toward the plane with a velocity of $(1 \div 3) \cdot 10^8$ cm/sec in the form of one or several thin channels 25–50 cm long; 2) the head of a step also advances toward the plane, with a velocity of the order of $5 \cdot 10^7$ cm/sec (full step lengths 5-15 cm); and 3) upward along the previously formed channel of the step leader there propagates, with a velocity of $\simeq 10^8$ cm/sec, an expan-

* The idea of a jerky or stepwise advance of the leader has long been encountered among a number of authors who investigated the spark by other methods ([3],[4]).

an upward-extending glow, whose brightness is greater in the lower parts. During the development of a step this process may be repeated several times, always from the moving head of the step. Between the leader steps there are pauses of the order of 1 μsec. Each subsequent step usually

Fig. 4. Diagram of spark development in the gap –c + c/p. 7—branches of the positive impulse corona; the remaining designations correspond to Fig. 3.

begins from the end of the preceding one. Simultaneously with the advance of the stepped leader toward the plane, an ordinary leader develops in its channel

SovietRxiv

from the rod, with a velocity of $(1 \div 5) \cdot 10^6$ cm/sec. The stepped leaders ionize the air and carry a negative charge deep into the gap, which changes the initial distribution of gradients along the gap in the direction of increasing them near grounded objects up to critical values. In the case $-c + c/p$, this leads to the development, from a grounded rod of height h, of a counter process in the form of branches of a positive impulse corona; the average velocity of their heads is $\simeq 5 \cdot 10^7$ cm/sec; the process arises at a certain critical height S_{cr} of the stepped leader. As the branches approach the stepped leader, the velocity of the branch heads increases. At the moment of their merging with the stepped leader, the glow flashes along the entire gap and a positive leader begins to develop from the rod. S_{cr} depends substantially on h of the rod and on its displacement relative to the axis of the gap. As h decreases, S_{cr} also decreases. In the limiting case of a smooth surface ($h = 0$), the stepped leader reaches the plane and, from the point of contact, a counter positive ordinary leader develops along the path of its channel with an initial velocity $\simeq 10^7$ cm/sec. With the appearance of the positive leader, both for $-c + p$ and for the gap $-c + c/p$, the velocities of both leaders become approximately equal and rapidly increase. Jumps may occur in the development of the leaders, and their closure is accomplished by the final jump ([5]). The latter leads to the main channel and to the completion of the breakdown.

Discussion of the results

1. Analysis of the materials makes it possible to explain qualitatively the higher values of the discharge voltages (U_p) in the gap $-c + p$ as compared with U_p for the gap $-c + c/p$. Indeed, the introduction into the gap of an impulse corona and a stepped leader of negative charge reduces the potential gradients near the high-voltage electrode and makes it difficult for a leader to develop from it. For continued development of the spark it is necessary either to raise the voltage across the gap or to reduce the negative space charge. This latter function is performed by the positi-

leader. In the gap $-c + p$, the positive leader arises only after the stepped leader touches the plane; for this it must traverse the entire length S_0. In the case $-c + c/p$, the positive leader arises already after the stepped leader has traversed only part of the gap ($S_0 - S_{\text{cr}}$). This accounts for the lower discharge voltage.

2. The development of the negative spark is often compared with the mechanism of lightning formation, which in the overwhelming majority of cases also has negative polarity. If, following this path, one compares the scheme presented in Fig. 3 with the well-known scheme ([6]), based on streak photographs of lightning made with Boys cameras, or with its later speculative variants ([7,8]), it becomes clear that they are far from identical. Thus, if in the case of a spark, after the stepped leader touches the plane, as noted, there is no immediate formation of the main channel and breakdown, then for lightning striking a plane it is assumed that the main channel devel-

SovietRxiv

ops immediately after the stepped leader arrives at the Earth' s surface, the channel of which is considered highly conducting. Further, the development of the process of elongation of the stepped leader of a spark does not correspond to the described mechanism of a step of a lightning leader. Our photographs, obtained with apparatus having high optical sensitivity, did not reveal a "pilot leader" in the spirit of that postulated by Schonland ([9,10]). Turning to the history of this question, we note that in 1938 Allibone ([11]) made static photographs on which brushes and diffuse glows were visible from the ends of cut-off leaders and their branches. In addition, Lichtenberg figures were obtained from the electrodes when the voltage was cut off in discharge gaps. In 1948 Allibone ([12]), returning to these materials, concluded that the named glows were a "pilot leader" assumed to exist in lightning. Schonland supported this conjecture ([10]).

Recently Hagenguth, in the discussion of ([7]), expressed the opinion that the glow photographed by him in a gap $c - c$ at $S_0 = 500$ cm should be taken as a "pilot leader." In the light of our materials, the glows mentioned are stepped leaders and "bundles of filaments" from the head of the developing positive leader ([2]). Finally, Liao and Anderson ([13]) state that, during breakdown of a $c - p$ gap ($S_0 \simeq 7$ cm) placed in oil, an "equivalent pilot streamer" is visible, developing downward from the end of the "initial streamer" toward the grounded plane in a manner very similar to that postulated for lightning. However, the quality of the photographs and the speed of their time sweep do not provide grounds for such a conclusion.

The scheme of spark development in the gap $-c + c/p$ (Fig. 4) also differs substantially from the proposed schemes of lightning striking a metal mast (lightning rod). This case is of great importance for calculations of overvoltages arising when transmission-line towers are struck.

On the basis of the materials obtained, it may be assumed that the schemes of lightning development based on photographs made with Boys cameras require refinement.

Energy Institute
named after G. M. Krzhizhanovskii

Received
2 IV 1962

REFERENCES

1. E. N. Brago, *Épograph with Amplification*, Advanced Scientific-Technical Experience, VINITI, Academy of Sciences of the USSR, No. P-62-15/1, 1962.

2. I. S. Stekol' nikov, DAN, **141**, No. 5 (1961).

3. B. Walter, Ann. d. Phys. u. Chem., **66** (1898).

4. M. Toepler, Mitteilungen der Hermsdorf-Schomburg Isolatoren G. M. B. H., No. 25 (1926).

5. I. S. Stekol' nikov, A. V. Shkilev, DAN, **136**, No. 4 (1960).

6. B. F. J. Schonland, D. J. Malan, H. Collens, Proc. Roy. Soc., A **152** (1935).

7. C. T. Wagner, A. R. Hileman, Power Appar. and Systems, October (1961).

8. S. B. Griscom, Trans. Am. Inst. Electr. Eng., P. III, **76** (1957).

9. B. F. J. Schonland, Proc. Roy. Soc., A **164**, 916 (1938).

10. B. F. J. Schonland, Proc. Roy. Soc., A **220**, 25 (1953).

11. T. E. Allibone, J. Inst. Electr. Eng., **82**, 513 (1938).

12. T. E. Allibone, Nature, **161**, 970 (1948).

13. T. W. Liao, J. G. Anderson, Trans. Am. Inst. Electr. Eng., p. 1, **73** (1953).

Note: Figure translations are in progress. See original paper for figures.

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.