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Fractal Analysis of Long Laboratory Sparks of high Speed Video Recordings

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***Abstract*— Variation of fractal dimension of long laboratory sparks were studied using high speed video recordings and still images. Four sparks were selected for the study, including both positive and negative polarities in lightning and switching impulses. Temporal and spatial variation of fractal dimension was studied. It was found that the fractal dimension is maximum at the breakdown. No particular pattern was observed for the variation of fractal dimension along the channel. Results show that the value of fractal dimension depends on the angle of view.**

Keywords-component; fractal dimension, long laboratory sparks.

I. Introduction

Fractals are complex, unpredictable and dynamic patterns which show the same details in different scales. Most of the time, fractal patterns are characterized by fractal dimension [1]. The fractal dimension of a curve can be explained as an object, too complex to define as 1 but less complex to define as 2; hence having a fractional dimension between 1 and 2. There are number of methods to estimate fractal dimension such as, box counting, fractal measure relations, correlation function, distribution function and power spectrum [2].

The most common method to find fractal dimension is box counting method which is performed by covering the figure using squares of side l. At each step, the magnitude of l is changed. If $N(l)$ denotes the number of squares necessary to completely cover the considered pattern, one can describe the relationship between the total number of covering squares $N(l)$, the magnitude of the square side (l) and the fractal dimension D as follows,

$$N(l) \sim l^{-D}$$

Then,

$$D = -\lim_{l \to 0} \frac{\log N(l)}{\log l}$$

This means that the fractal dimension D, equals the slope of the linear part of the log-log plot of $N(l)$ versus l [3]. It is reported 1.34±0.05 as the fractal dimension of the projected lightning images [4]. Application of several algorithms including box counting algorithm to estimate the fractal dimension of well known shapes such as Sierpinski gasket (D=1.58) and Sierpinski carpet (D=1.89) is given in [5].

II. Methodology

The experimental setup used in this work to generate long electrical discharges was a part of the measurement campaign conducted at The Institute of Power Engineering, High Voltage Laboratory, Warszawa, Poland. The schematic diagram of the experimental setup and details about the experiment are documented elsewhere [6].

The discharges were created in air at atmospheric pressure between two electrodes. One electrode was connected to the high voltage impulse generator (Haefely, Marx circuit 375 kJ; 23 steps; real maximum voltage: lightning impulse - 4,5 MV, switching impulse – 2,8 MV) and the other electrode was connected to a grounded rod. The high voltage electrode was a steel rod connected to the high voltage impulse generator through an insulator string. The grounded electrode was a copper sphere placed on a steel rod. In this experiment, both a standard lightning impulse voltage (the so-called 1.2/50 μs impulse) and a standard switching impulse voltage (the so-called 250/2500 μs impulse) of both positive and negative polarities were used to create discharges. Discharges were generated with different gap lengths. In this study we report findings for gap length 6 m. Voltage across the gap was recorded by Dr Strauss voltage 4-channel recorder with WinTRAS software (200 MS/s; 14 bit).

A digital high speed frame camera 'PhotronFastcam SA5' was used to record the discharges. High speed camera together with transient recorder was placed inside a shielded grounded mobile cabin which had a tiny window to focus on the discharge channel. Three different frame rates were used with three different resolutions. They are 581,250 fps (frames per second) with 64x64 pixel resolution, 465,000 fps with 64x88 pixel resolution and 420,000 fps with 64x96 pixel resolution.

(a) (b)

Figure 1: Edge detection process. (a) Original image (b) Image after processing through the Sobel edge detection operator.

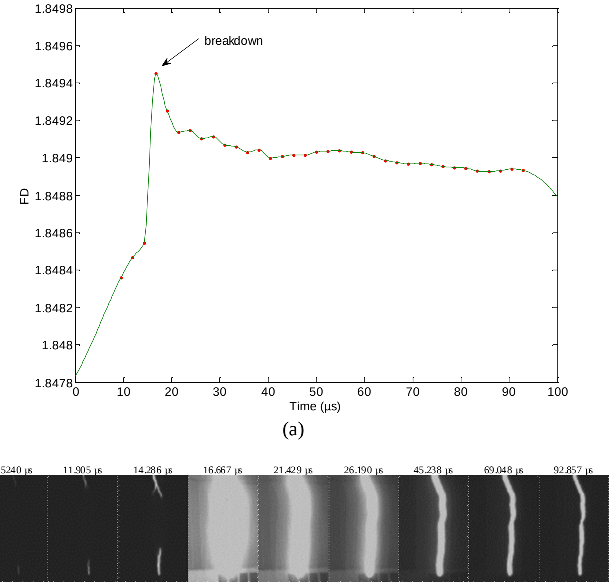
Moreover, two still cameras located at 22.4 m and 13.5 m away from the discharge channel, with an angle of 34.5° between the cameras were used to obtain the still images of the discharges.

Using PFV (Photron Fastcam Viewer) user software which comes with the high speed camera, high speed videos was converted to gray scale intensity mapped image sequences. The image sequences were then enhanced using image processing techniques. Images were processed through the Sobel edge detection operator so that edges of the discharges were clearly identified. Fig. 1 shows a comparison of the original and the edge detected image. It was assumed that complexity of the edges shown by luminous channel is same to the complexity of the edges in normal channel. The edge detected images were finally processed through a fractal estimation algorithm, which was based on the box counting method. More details related to the box counting method applied to laboratory sparks can be obtained from [7]. Fractal dimension along the channel was studied by applying the same image processing techniques to still images. Since the channel complexity was found by considering the pixels at the edges of the channel, effect due to possible saturation of pixels after attachment can be neglected.

III. Results and Discusion

A. *Variation of Fractal Dimension with Time*

Variation of fractal dimension with time together with the corresponding original high speed photographs for 6 m positive lightning impulse rod to rod discharge is shown in Fig. 2. This discharge was recorded at a rate of 465,000 frames per second with 64x96 pixel resolution. The graph clearly shows that fractal dimension is maximum at the time of breakdown. The value of fractal dimension shows a sharp increase initially and a drop after the breakdown which continue to reduce gradually up to the end.



(b)

Figure 2: (a) Variation of fractal dimension with time for lightning impulse.(b) Corresponding high speed photographs.

Similar to positive lightning impulses, fractal variation with time for negative lightning impulses as well as for both polarities of switching impulses also show a maximum value for fractal dimension at the breakdown.

As shown in Fig. 2(a) both polarities in lightning and switching impulses show that fractal dimension increase sharply from a lower value before the breakdown which settle at a high value after the breakdown. For an example, Fig. 3 shows the variation of fractal dimension with time for 6 m negative switching impulse rod to rod discharge.

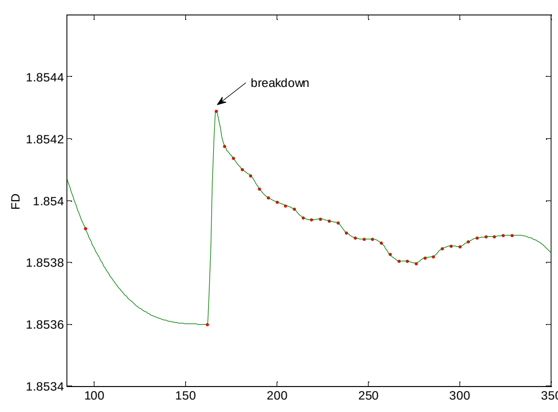


Figure 3: Variation of fractal dimension with time for switching impulse.

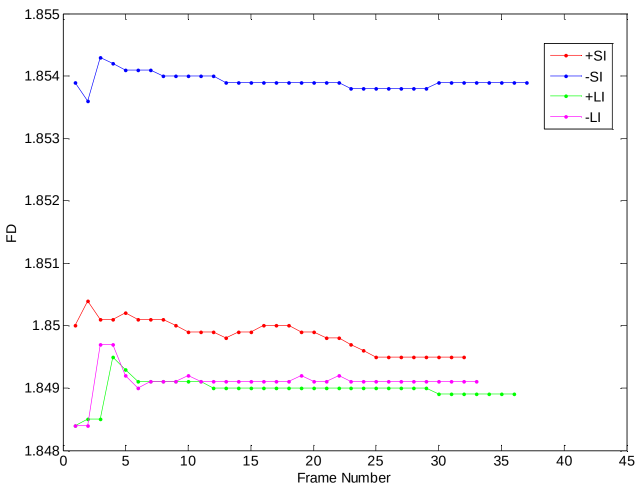


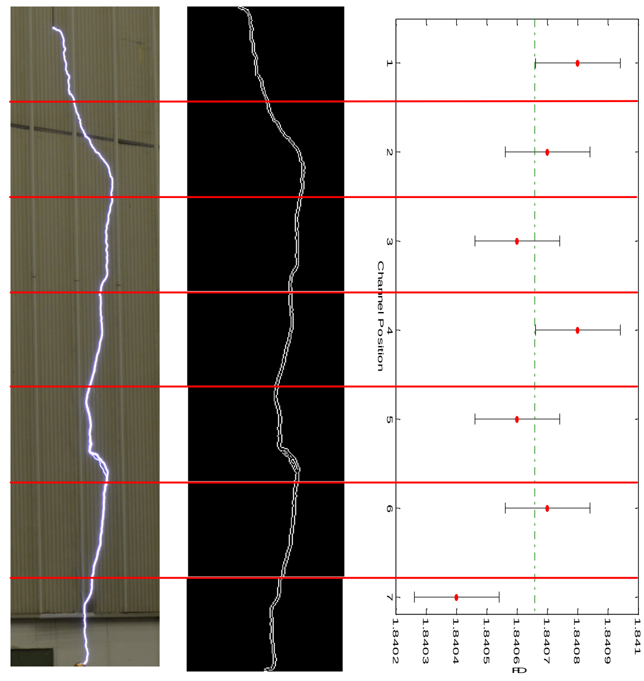
Figure 4: Variation of fractal dimension with time for switching and lightning impulses in both polarities. (+SI - Positive switching impulse, -SI - Negative switching impulse, +LI - Positive lightning impulse, -LI - Negative lightning impulse)

Fig. 4 shows the variation of fractal dimension with time for switching and lightning impulses in both polarities. Overall shapes of the all four distributions are very similar to each other. Fractal dimension of switching impulses are at a higher level than the lightning impulses. The negative polarities show a higher value for fractal dimension than positive polarities.

B. *Variation of Fractal Dimension along the Channel*

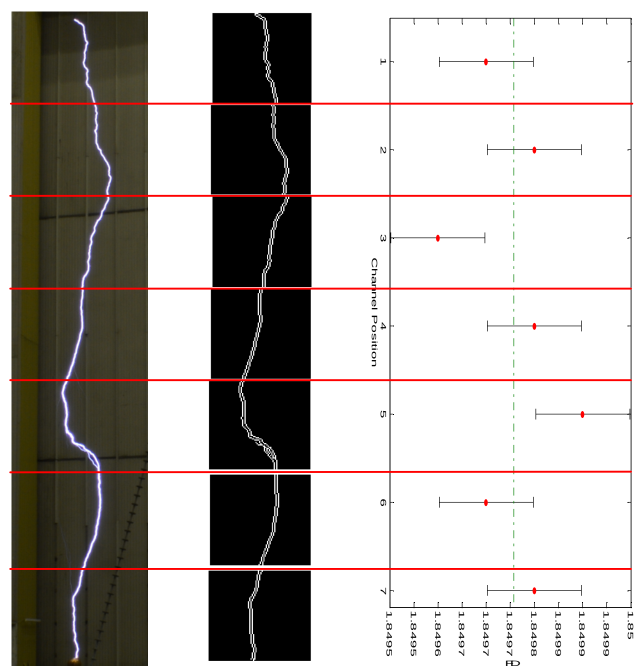
Still images taken from two cameras were used to study the variation of fractal dimension along the channel length. Fig. 5 and Fig. 6 show the variation along the channel length calculated for two still images for 6 m positive switching impulses respectively.

As shown in Fig. 5 and Fig. 6, variation of fractal dimension along the channel does not show a particular pattern. According to Fig. 5, fractal dimension has increased in 4th segment and 6th segment. But it does not agree with Fig. 6, which is the image taken by camera 2 for the same discharge. Fig. 6 shows that fractal dimension has increased in segment 2, 4, 5 and 7. According to Fig. 5, channel is more fractal at the 4th and 6th segments. The images of all other discharges also show the same observation. This implies that fractal dimension not only depend on the way discharge or breakdown occur, but also on the viewing angle. Thus, to calculate more accurate value for fractal dimension, further research should be carried out by reconstructing 3-dimensional view by using two 2-dimensional images.



(a) (b) (c)

Figure 5: Variation of fractal dimension along the channel length for still image taken by camera 1 for 6 m positive switching impulses. (a) original image (b) Edge detected image (c) Fractal dimension. Dash line shows the mean value.



(a) (b) (c)

Figure 6: Variation of fractal dimension along the channel length for still image taken by camera 2 for 6 m positive switching impulses. (a) original image (b) Edge detected image (c) Fractal dimension. Dash line shows the mean value.

IV. CONCLUSION

This study reports variation of fractal dimension with time and along the channel length for long laboratory sparks. Results show that channel is highly tortuous or complex at the time of the breakdown. After the breakdown, channel gradually reduces its complexity. Switching impulses are more tortuous than lightning impulses. Initial findings show that positive polarity gives higher value for fractal dimension compared to negative polarity. Variation of fractal dimension along the channel does not show a clear pattern. Same channel positions show different values for fractal dimension for two still images taken by two different viewing angles. Based on these preliminary observations it is concluded that the channel is more fractal at the break down and the value of fractal dimension depends on the angle of view.

Although it would be interesting to compare the fractal dimension obtained for long sparks with triggered lightning, it is out of the scope from the analysis presented here.

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