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Observation of a lightning flashover with a high-speed video camera

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***Abstract*— In this paper we analyze images of a lightning flashover induced by a downward negative lightning flash that struck a transmission line located in São Paulo, Brazil. The lightning flash and the flashover were recorded by a high-speed camera running at 10,000 images per second. The approach of the negative downward leader did not launch an induced positive upward leader prior to the return stroke. One of the AC transmission lines that run over a railway line was struck. The flashover exhibits an oscillatory behavior. The flickering of the image occurs at exactly 120 Hz. The return stroke that struck the line had an estimated peak current of a moderate intensity. It was however, followed by a continuing current lasting 17 ms and an intense M-component that may have contributed to the occurrence of the flashover.**

Keywords- Flashover, cloud-to-ground flash, transmission lines

I. INTRODUCTION

Lightning flashovers are the most frequent cause of transmission line outages, resulting in a direct cost to utilities of more than $1 billion per year in damaged or destroyed equipment. Substantial indirect costs involved due to the reduction in power quality caused by frequent lightning outages should also be taken into account [1]. The understanding of the characteristics of a flashover can help the design of systems that protect overhead transmission lines.

As far as the authors know there are no high-speed video observations of a lighting flash and flashover reported in the literature. This work reports some characteristics of a negative cloud-to-ground lightning that occurred in the city of S. Paulo, Brazil, as shown in Fig. 1, and produced a flashover in an insulator of a transmission line pole.

The pole belongs to Line-7 (Rubi) of CPTM (Companhia Paulista de Trens Metropolitano) which has the longest line of the entire subway-railway networks in the state of São Paulo, with 60.5 km of extension and comprises the stretch defined between the stations of Luz - Francisco Morato - Jundiaí. Part of this line was originally built by the extinct São Paulo Railway, and was inaugurated in 1867. The electrification of this line (Santos Jundiaí Railroad) began to operate experimentally in 1950. Currently, two substations are present on this line, the Tietê and Jaraguá substations. The high voltage side is supplied at 88 kV (subtransmission) and is stepped down to 34.5 kV (distribution). As showed in Figure 2, two 3-phase 34.5kV / 60Hz circuits (two rectifier substations) are distributed, as well as two 13.2kV / 60Hz single-phase circuits (signal circuit supply). In each substation, a conversion of 34.5 kVAC to 3 kVDC (traction power from the trains) and 13.2 kV to 220 V is used to feed the auxiliary services. The rectification at each substation (34.5 kVAC to 3 kVDC) is done through 12-pulse rectifier groups [2].

Figure 1. Negative cloud-to-ground flash that produced a flashover.

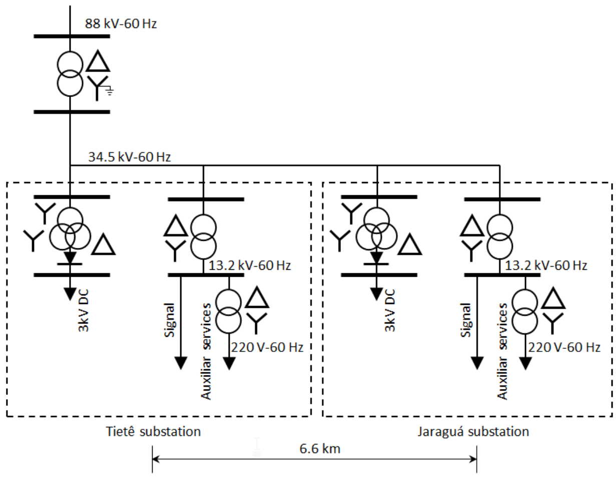

Figure 2. Schematics of the substations of Line 7.

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Each pole has three different voltages as shown in Fig. 3: 34.5 kV/60 Hz (three-phase rectifier substation for power supply), 13.2 kV/60 Hz (single-phase line responsible for signaling circuit and for the power supply) and 3 kV DC (power supply for trains). More details on the dimensions of the lines and poles can be found in [2].

II. METHODS

A high-speed digital video camera (Vision Research Phantom v711) with exposure times of 99.04 and time resolution of 100 microseconds (10,000 images per second), was used to record the images of the lightning attachment to the transmission line (Fig. 1). For more details about use of high-speed camera for lightning observations, see the works by Saba *et al*. [5]. Each frame of the video is time stamped by means of a GPS antenna.

All flashes were detected by lightning location systems (LLS). Data from the LLS were used to obtain the polarity, the exact time of the return stroke and an estimate of the peak current (Table 1). A study on the accuracy of peak current estimation given by the LLS has not been performed yet. However, for one recent event of a cloud-to-ground flash that struck a instrumented building in the area, the error was within 20%. During this event, four strokes were detected by the LLS and they were directly measured by a current sensor installed in the vertical lightning rod to where the attachment occurred.

III. DATA PRESENTATION

The negative cloud-to-ground flash that produced the lightning flashover occurred on 24 February 2014 at 17:30 (UT). The flash had 4 strokes and one stroke (the first) struck a transmission line (Figs. 2 and 3). Only the ground contact of the first stroke appears in the camera field of view. The other 3 subsequent strokes had ground contacts different from the first one and were out of the camera field of view.

Images of the negative downward leader, the first return stroke, the M-component and the flashover are shown if Fig. 5.

TABLE 1 – CHARACTERISTICS OF THE LIGHTNING FLASH AND FLASHOVER

Event	*Time (hh:mm:ss,ms)*	*Estimated Peak Current (kA)*
1st Return Stroke	17:30:16,846	-18
M-component	17:30:16,849	-7
End of CC	17:30:16,863	xxx
2nd Return Stroke	17:30:16,907	-38
3rd Return Stroke	17:30:16,932	-18
4th Return Stroke	17:30:16,998	-45
End of flashover	17:30:17,412	xxx

The first stroke was followed by an intense M-component (peak current detected as -7 kA) and a continuing current that lasted 17 milliseconds.

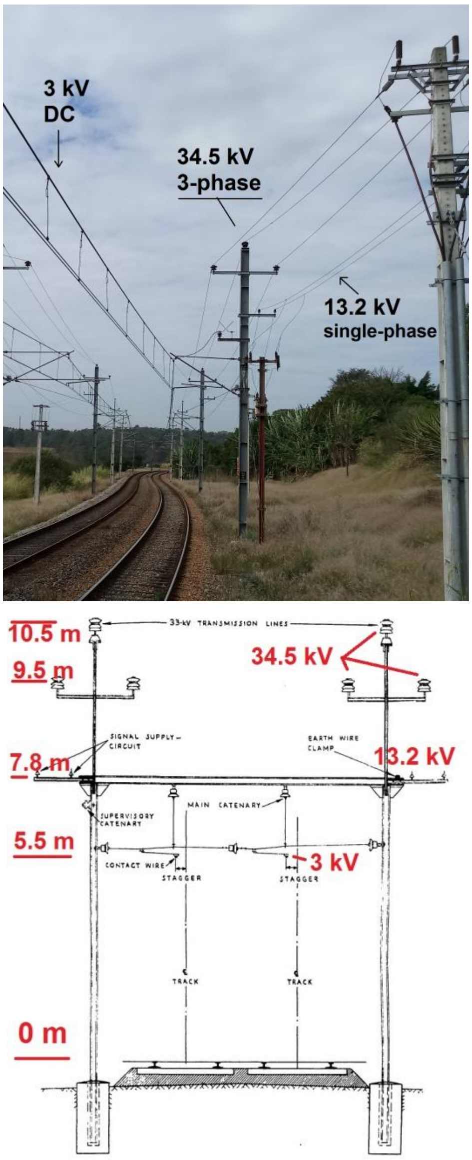


Figure 3.Transmission line struck by the lightning flash. Upper image: picture of the transmission lines. Bottom image: sketch of the poles.

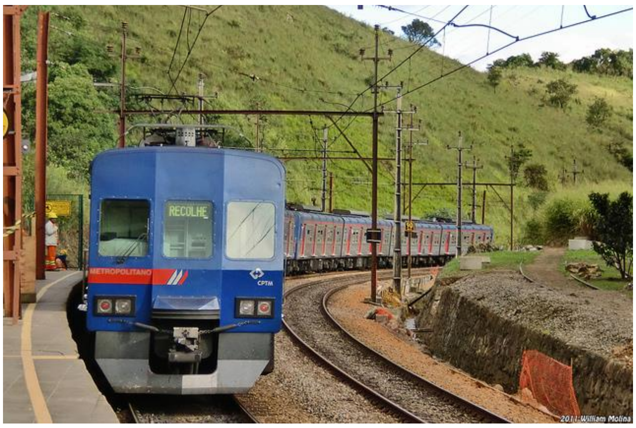
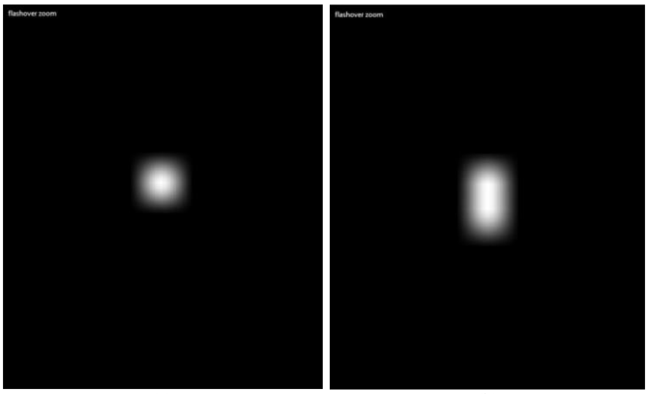


Figure 4.Train that runs below the transmission line and is powered by a 3 kV DC line.

Figure 5. a) downward negative leader, b) almost striking the line, c) return stroke, d) continuing current, e) M-component, f) image of the flashover.

Right after the end of the return stroke, it is possible to see a bright spot on the place where the ground contact took place. This bright spot then flickers at an exact frequency of 120Hz for 556 ms (Figure 6).

The dimension of the bright spot when is at maximum luminosity is about 3 to 4 meters.



(a) (b)

Figure 6. Zoom image of flashover. a) minimum luminosity, b) maximum luminosity.

IV. Discussions

This preliminary study shows a negative downward leader that strikes a transmission line. The resolution of the video is able to see the approach of the downward leader and the pulsation of the flashover that results from a direct strike of a first return stroke of a 4-stroke cloud-to-ground flash.

From the observations we can conclude that:

a) the approach of the negative downward leader did not launch an induced positive upward leader prior to the return stroke. If any positive upward leader was produced it was too small or too faint to be observed (we have already observed upward leaders from objects located at a greater distance from the camera).

b) one of the AC transmission lines was struck. Although the 34.5 kV line is located at the top of the pole (10 m high), as the approach of the leader was not perpendicular to the ground but inclined (Fig. 6), the 13.2 kV line could have been struck. The 13.2 kV line is located at the right side of the pole and approximately 1.5m below the 34.5 kV line (see Figure 3).

c) the DC 3 kV line was not struck. This is confirmed by the oscillatory behavior of the flashover. The flickering at exactly 120 Hz corresponds to an arc that is intensified at the maximum and minimum AC potential.

d) The return stroke that struck the line had an estimated peak current of a moderate intensity (-18 kA). However, the presence of a continuing current lasting 17 ms and an intense M-component (estimated peak current of -7 kA), may have contributed to the occurrence of the flashover.

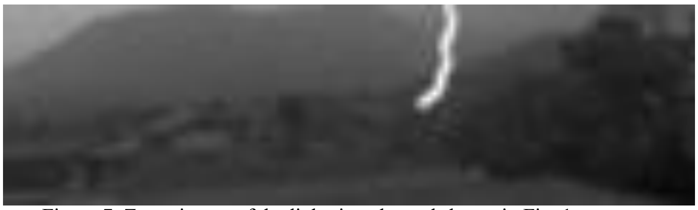


Figure 7. Zoom image of the lightning channel shown in Fig. 1.

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References

[1] *Guide for the Application of Transmission Line Surge Arrestors* – EPRI Report, Dec. 2009.

[2] *Manutenção da Rede Aérea, Companhia Paulista de Trens Metropolitanos-CPTM*, 112 p., May 2008 (in Portuguese).

[3] Ferrovia magazine, special edition, edition 172, 2017 (in Portuguese).

[4] R.J.B. Chatterton, D.H. Rooney, “The first stage of the electrification of the Estrada de Ferro Santos a Jundiai (late São Paulo Railway),” Proceedings of the IEE - Part I: General, Vol 100, Issue: 126, Nov. 1953.

[5] M. M. F. Saba, A. R. Paiva, C. Schumann, M. A. S. Ferro, K. P. Naccarato, J. C. O. Silva, F. V. C. Siqueira, and D. M. Custódio, “Lightning attachment process to common buildings”, *Geophys. Res. Lett.*, 44, doi:10.1002/2017GL072796, 2017.

[6] M. M. F. Saba, C. Schumann, A. A. Warner, J. H. Helsdon. “High-speed video and electric field observation of a negative upward leader connecting a downward positive leader in a positive cloud-to-ground flash”. *Electric Power System Research*, vol 118, pp 89-92, 2015.