Currents in Buried Grounding Strips Connected to Communication Tower Legs during Lightning Strikes

***Nelson Theethayi*[1], *Rajeev Thottappillil*[1], *Gerhard Diendorfer*[2], *Martin Mair*[3] and *Hannes Pichler*[3]**

[1]Division for Electricity, Uppsala University, Box 534, SE-75121, Uppsala, Sweden and e-mail: Nelson.Theethayi@angstrom.uu.se
[2]Austrian Electrotechnical Association (OVE), Dept. ALDIS (Austrian Lightning Detection & Information System) Kahlenberger Str. 2a, A-1190 Vienna, Austria
[3]Institute of Electrical Power Systems and Energy Economics, Vienna University of Technology, Gusshausstraße 25 / E373, A-1040 Vienna, Austria

Abstract

During a lightning strike to communication tower stroke currents are shared by the tower and by the shields of the cables along the tower. The currents in the tower proceed towards the grounding system (possibly a combination of counterpoises or ring conductors or ground rods or grounding grids) connected to tower legs' foundation. In this paper, lightning strike to communication tower on mount Gaisberg in Austria is considered and measured currents at the tower top and those shared by an instrumented grounding strip connected to one of the tower leg's is presented.

1. Introduction

Lightning strike to communication towers is a usual phenomenon. Communication towers and its associated electronics require lightning protection. Grounding of towers is an integral part of the overall lightning protection design. Communication towers are not isolated systems. Usually transmitting and receiving electronics are kept in a building adjacent to the towers and different types of cables run from the tower to the building. In the event of a lightning strike to the tower the stroke currents are shared among the tower cross arm members and the bonded shields of the cables' running along the tower.

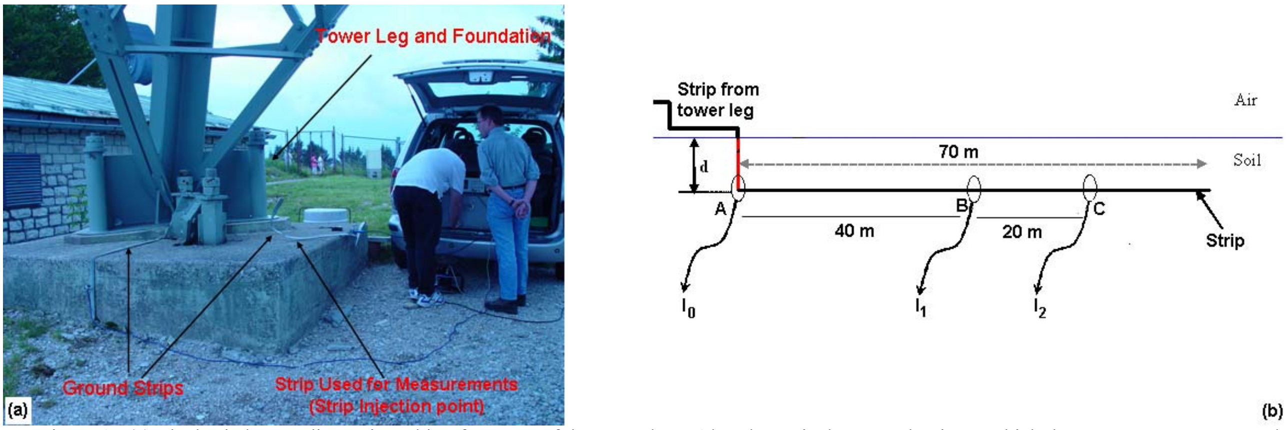

Figure 1: (a) The buried grounding strips taking from one of the tower legs. Also shown is the ground strip on which the currents were measured (b) The three measurement points along the grounding strip; I_0 is measured at the injection point (0 m at location A), I_1 and I_2 are measured at distances 40 m (location B) and 60 m (location C) from the injection point.

In order to better understand the lightning interaction with the communication towers several researchers are carrying out direct and indirect lightning current and field measurements with a variety of communication towers around the world, e.g. [1-5]. It is found that all the research on lightning interaction with communication tower is concentrated on understanding the current distribution in the tower and associated radiated electromagnetic fields for comparison with strikes to flat ground. For these reasons the currents in the tower were measured both at tower top and tower bottom and different models for tower current distributions have been proposed [6-8]. A summary of different instrumented towers for studying the interaction between lightning and tall structures can be found in [9]. However, it seems that no attempt is made to study the behavior of grounding system under such towers in the event of lightning strike to it. As a first step into measuring the currents in the grounding systems under the communication tower we chose to conduct controlled measurements at the communication tower on mount Gaisberg in Austria. This communication tower is 100 m tall and is on the top of a mountain about 900 m tall compared to the surrounding terrain [4]. The tower is located about 5 km east from the city of Salzburg, Austria and at a height 1287 m above sea level. This tower is most of time submerged in the cloud under thunderstorm conditions and receives lightning strikes about 50 times a year [4].

The tower top current is measured using a current sensor and analog data is transmitted using a fiber optic link to the digitizer system housed in the building next to the tower. The lightning current is measured just below the air termination on the tower top using a 0.25 mΩ current shunt. The shunt output signal is recorded by an 8 bit digitizer. The digitizing board has a memory of 16 MB/channel and is operated with a sampling rate of 20 MSamples/s to give record length of 800 ms [4]. Later, the tower current is offset corrected and filtered with 250 kHz. To reduce the data size for the analysis of this paper, it was resampled to 2 MS/s. There are buried grounding strips connected to each of the tower legs as shown in Fig. 1a. The grounding strips are expected to carry some part of the total lightning currents measured at the tower and dissipates them into the soil. This mechanism is not clear. The authors wish to acknowledge the lack of information on the details of any complex grounding system under and nearby the tower other than the grounding strips taking off from the tower legs and down conductors of lightning protection system of the nearby buildings. The currents were measured on one grounding strip as shown in Fig. 1a. The strip's take off point from the tower or the current injection point into the grounding strip is shown in Fig. 1a. The length of the grounding strip considered for measurements was 70 m long and was at a depth of about 0.5 m. The strip had a rectangular cross section with an approximate dimension 30 mm × 3 mm, (overall conductor area of 9×10^{-5} m^2). The currents were measured at three points along the strip at distances marked in Fig. 1b. The currents I_0 and I_1 were measured using Pearson current monitor (Model 301X). This current monitor has a bandwidth of 5 Hz – 2 MHz. Current I_2 was measured using a Rogowski coil (LEMflex RR3000-SD/24) with a bandwidth of 8 Hz to 100 kHz. Fibre optic systems with a bandwidth of 0,2 Hz to 5 MHz were used for data transmission from all three sensors to the data acquisition system (Yokogawa DSO 708E operated with a sample rate of 10MS/s, 10 bit vertical resolution) located in the building.

2. Measured currents at tower top and in the grounding strip

We concentrate on two flashes to the tower, referred to as FLASH-513 (Fig. 2a-c) and FLASH-524 (Fig. 2d-f). Both the flashes belong to the category of tower initiated upward negative lightning [9]. In Fig. 2 for each current pulse a time window of 1 ms was extracted from the actual current records and then aligned to a flash data set. Hence the x-axis in Fig. 2 is a relative time scaling and does not correspond to the real inter stroke time interval.

2.1 Current records for FLASH-513

The tower top pulse currents for FLASH-513 are shown in Fig. 2a and the corresponding ground strip currents are shown in Fig. 2b. It is seen that there are three prominent current pulses as shown in Fig. 2a, marked as Pulse-1, Pulse-2 and Pulse-3. The current peaks are 2.7 kA, 5.3 kA and 2.5 kA respectively. These current pulses have a 30%-90% rise times as: 52 μs (Pulse-1), 11.5 μs (Pulse-2) and 8 μs (Pulse-3), respectively. All current pulses in Flash-513 were superimposed on the initial continuing current (ICC) and therefore some of them had considerably longer rise times than return strokes [5]. From Fig. 2b top window, it is seen that the currents entering the grounding strip corresponding to 5.3 kA tower top current is about 150 A (I_0), indicting that only about 3% of the total pulse current is shared by the instrumented ground strip connected to the tower legs. The currents at locations B and C (I_1 and I_2) corresponding to distances 40 m and 60 m, as shown in Fig. 1b, are 100 A and 50 A, respectively. The strip currents have a 30%-90% rise times variation between about 8 μs (point A) to 10.5 μs (point C) corresponding to Fig. 1b. A comparison of the tower top current and the strip current I_0 for Pulse-2 is shown in Fig. 2c. It is seen from Fig. 2c that the current entering the strip in general have faster rise times compared to tower top currents, about 0.5-0.7 times the tower top current rise times, when the pulse did not represent a typical return stroke current. However, for return stroke pulses the current at the tower top and the current entering the strip have similar/identical rise times (shown later). It is seen from the measurements that the current dissipation into the soil is not really linear or uniform. At location B, beyond one-half length of the strip, the current has reduced to two-third of its value, while at location C, beyond the three-fourth length of the strip, the current has reduced to one-third of its value. Along the length of the grounding strip the current dissipation rate between A and B is 1.25 A/m and between B and C it is 2.5 A/m. The rate of current dissipation was less during the first 40 m when compared to the next 20 m. Assuming the current at the far end of the ground strip to be zero, the current dissipation beyond the 60 m length would be 5 A/m.

2.2 Current records for flash-524

The tower top current pulses for FLASH-524 are shown in Fig. 2d and the corresponding ground strip currents are shown in Fig. 2e. The FLASH-524 has five current pulses with current peaks 2 kA (Pulse-1), 1.9 kA (Pulse-2), 7.8 kA (Pulse-3), 0.7 kA (Pulse-4) and 9.4 kA (Pulse-5), respectively. These current pulses have a 30% to 90% rise times as:

2 μs, 7 μs, 1.5 μs, 14 μs and 1.2 μs. Pulse-3 Pulse 4 and Pulse-5 are return strokes as these pulses were following the cessation of the background continuing current and therefore most comparable to subsequent return strokes in natural downward lightning [8]. A comparison of current records of FLASH-513 and FLASH-524 shows that return strokes are very prominent and clear in FLASH-524. The current pulses in FLASH-524 excepting Pulse-4 have faster rise times compared to all the pulses in FLASH-513. It is seen from Fig. 2e that corresponding to each stroke there are currents in the ground strip. The strip currents corresponding to the return stroke Pulse-3 are 350 A and 90 A corresponding to locations A and C of Fig. 1b, respectively. These strip currents have a 30%-90% rise times as: 1.5 μs and 1.8 μs, respectively corresponding to points A and C in Fig. 1b.

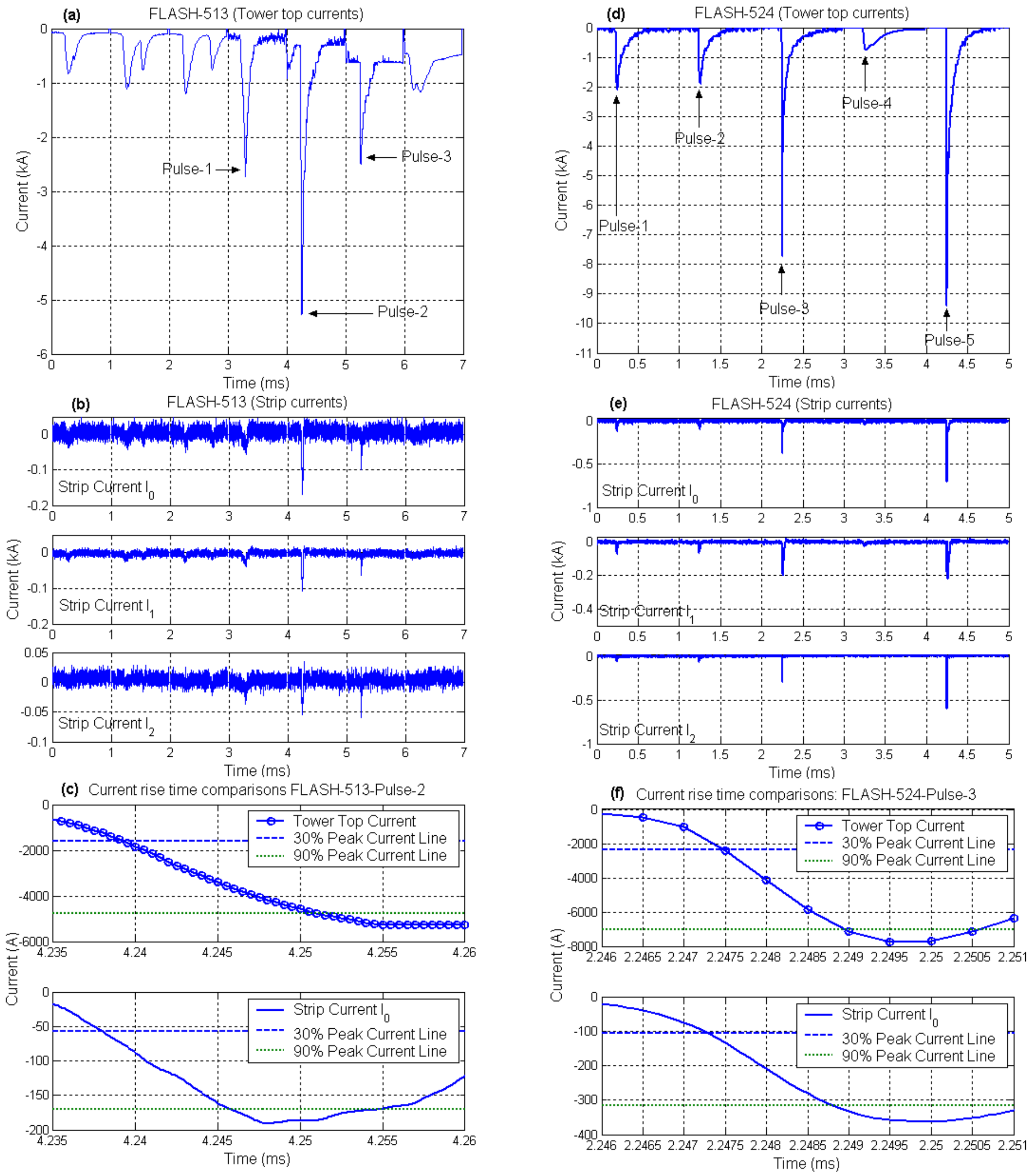

Figure 2: (a) Current pulses measured at the tower top corresponding to FLASH-513, (b) Currents in the ground strip at the locations shown in Fig. 1b corresponding to FLASH-513 and (c) Comparisons of rise times for tower top current and the current entering the strip for Pulse-2 of FLASH-513. The data is a sequence of 1 ms extracts and hence x-axis do not give the correct time interval between pulses. (d) Currents measured at the tower top corresponding to FLASH-524 and (e) Currents in the ground strip at the locations shown in Fig. 1b corresponding to FLASH-524 and (f) Comparisons of rise times for tower top current and the current entering the strip for Pulse-3 of FLASH-524. The data is a sequence of 1 ms extracts and hence x-axis do not give the correct time interval between pulses.

Unfortunately, strip current measurement at point B has malfunctioned for fast currents with large amplitudes, distorting the waveshapes. Distortion in the waveform at point B has happened corresponding to Pulse-3 and Pulse-5. A comparison of the tower top current and the strip current I_0 for Pulse-3 is shown in Fig. 2f. Unlike the Pulse-2 of FLASH-513, the Pulse-3 of FLASH-524 is a typical return stroke and the rise time of the current at the tower top is similar to the current entering the strip (I_0). Similar to the observation in Fig. 2f, for Pulse-5 as well, the 30%-90% current rise time at location A on the strip is the same as the 30% to 90% current rise times of the corresponding tower top currents.

3. Conclusion

This paper is a beginning into the understanding on how the currents are shared by the buried grounding strips connected to tower legs when communication tower is struck by lightning. The measurements were carried out at a communication tower complex on mount Gaisberg in Austria. The measured currents at the tower top and at various points along one of the buried grounding strips are presented. It is seen that the particular ground strip connected to the tower legs takes about 3% - 5% of the stroke current. It is found that when the current pulses are not return strokes the rise times of currents entering the strip are faster than the corresponding tower top currents (e.g. see Fig. 2c). On the contrary the currents entering the strip have similar rise time as that of the corresponding return stroke current pulse at the tower top (e.g. see Fig. 2f). It is worth investigating the possible reasons for this phenomenon.

6. Acknowledgments

The authors thank the financial support received from the Swedish Research Council (VR Grant: 621-2005-5939) and the Swedish National Rail Administration (Banverket). Lightning current measurements at the Gaisberg Tower are made possible by financial support from Verbund (Contract 4500157745), the Austrian Science Fund (Project P17336-N07), Telekom Austria and Austrian Broadcasting Services (ORS). The authors also thank the support of the European COST Action P-18 'Physics of Lightning Flash and its Effects'.

7. References

1. W. Janischewskyj, A.M. Hussein, V. Shostak, I. Rusan, J.X. Li, and J.S. Chang, "Statistics of lightning strikes to the Toronto CN Tower (1978-1995)," IEEE Trans. Power Delivery, vol. 12, no. 3, ,1997, pp. 1210-1221.
2. F. Heidler, W. Zischank and J. Wiesinger, "Statistics of lightning current parameters and related nearby magnetic fields measured at the Peissenberg Tower," Proc. 25th Int. Conf. on Lightning Protection, Rhodes, Greece, 2000.
3. B. N. Gorin and A. V. Shkilev, "Measurements of lightning currents at the Ostankino tower," Elektrichestvo, 8, 64-65, 1984.
4. G. Diendorfer, W. Schulz and M. Mair, "Evaluation of a LLS based on lightning strikes to an instrumented tower", Proc. of International Lightning Detection Conference (ILDC), Tuscon, Arizona, 2000.
5. M. Miki, V. Rakov, T. Shindo, G. Diendorfer, M. Mair, F. Heidler, W. Zischank, M.A. Uman, R. Thottappillil and D. Wang, "Initial Stage in Lightning Initiated from Tall Objects and in Rocket-Triggered Lightning", J. Geophysical Research, 110, D02109, 2005.
6. F. Rachidi, V. A. Rakov, C. A. Nucci, J. L. Bermudez, "The effect of vertically-extended strike object on the distribution of current along the lightning channel", J. Geophys. Res. 107 (2002) 4699.
7. Y. Baba and V. A. Rakov, "Lightning electromagnetic environment in the presence of a tall grounded strike object," Journal of Geophysical Research, 2005.
8. S. Guerrieri, C. A. Nucci, F. Rachidi and M. Rubinstein, "On the influence of elevated strike objects on directly measured and indirectly estimated lightning currents", IEEE Trans. on Power Delivery, Vol. 13, No. 4, 1998, pp. 1543 – 1555.
9. V. A. Rakov, and M. A. Uman, *Lightning: Physics and effects*, Cambridge University Press, 2003.