GROUND'2010

&

4th LPE

International Conference on Grounding and Earthing
&
4th International Conference on
Lightning Physics and Effects

Salvador - Brazil November, 2010

CUMULATIVE CHARGE TRANSFER BY UPWARD LIGHTNING TO THE GAISBERG TOWER

Gerhard Diendorfer[1], Hannes Pichler[1], Martin Mair[2]
1) Austrian Electrotechnical Association (OVE), Vienna, Austria
2) Central Institute for Meteorology and Geodynamics (ZAMG)

Abstract – Tall structures such as towers or wind turbines are able to initiate upward lightning. This type of discharges typically starts with an initial stage (IS) that may or may not be followed by one or more downward leader/upward return stroke sequences. At the instrumented Gaisberg Tower (GBT) we have measured significant amounts of charge up to 546 As per flash. This values clearly exceeds the 300 As specified in the IEC 62305-1 standard for Lighning Protection Level I (LPL I). Up to 3 735 As were transferred to ground by 22 flashes during a single storm within 25 minutes. During a 10 years period we determined at the GBT an annual average charge transfer of 4 100 As.

Highest charge transfer is observed in the months March and November, respectively, at the beginning and end of the winter season in Austria indicating certain similarities with so-called winter lightning typically observed in Japan.

At the GBT the maximum accumulated charge transfer in one year was 8 888 As corresponding to a total melted volume of 35 cm^3, 48 cm^3 and 100 cm^3 for Steel, Copper and Aluminum, respectively at the lightning channel attachment point.

1 – INTRODUCTION

The international standard for lightning protection IEC 62305-1 [1] defines a maximum flash charge of 300 As for lightning protection level I (LPL I).

In a recently published draft standard IEC 61400-24 for the lightning protection of wind turbines [2] upward lightning is considered by the following statement: "*For wind turbines placed in certain geographical areas where they are exposed to high numbers of upward lightning particularly during winter, it may be relevant to increase the required durability of air termination systems (e.g. receptors) with regard to flash charge to more than lightning protection level I, Q_{flash} = 300 C, as this parameter decides the wear (melting) of materials and therefore influences the need for maintenance of air termination systems.*"

In this paper we present results of statistical analysis on the accumulated charge transfer per day, per month and per year, respectively, based on the data collected at the Gaisberg Tower (GBT) in Austria from 2000 – 2009. For a comprehensive description of the experimental setup and statistical data on some lightning parameters see Diendorfer *et al.* [3].

2 – DATA

From 2000 to 2009 at total of 652 lightning events were recorded at the GBT which is about 65 flashes per year on average. 10 of these 652 flashes (1,5 %) transferred charge values exceeding 300 As to ground. Some parameters of these 10 events are listed in Table1.

# ID	Date	Time	Charge (As)	Comment
112	2000-01-21	16:25:28	356	Positive Flash
405	2005-02-12	22:36:25.7177557	385	
407	2005-02-12	22:42:16.3270326	> 305	Exceeds 800 ms recording time
446	2005-12-16	16:59:29.1319064	426	Positive Flash
511	2007-01-12	01:51:51.8107070	405	
520	2007-02-09	01:24:09.0881787	320	Bipolar Flash
614	2008-03-01	10:21:10.2436625	546	Continuing current, no return strokes.
631	2008-03-01	10:41:14.0119150	> 365	Exceeds 800 ms recording time
633	2008-03-01	10:43:17.3151246	310	
693	2008-11-21	13:52:01.2851257	314	

Table 1 - Flashes measured at GBT with charge transfer values exceeding 300 As

It is worth noting, that all the flashes in Table 1 occurred during the cold season (winter). Three flashes (# 614, # 631, and # 633 occurred within about 20 minutes on 2008-03-01. Only these three flashes transferred a total charge of 1 221 C to ground. During this particular storm on 2008-02-01 22 flashes were recorded at the GBT within 25 minutes. Accumulated charge transfer of these 22 flashes was 3 735 As.

The recorded lightning current waveform for flash #614 is shown in Figure 1. This flash consists of an initial continuing current (ICC) only with an amplitude of up to 2.5 kA and no return strokes followed the ICC.

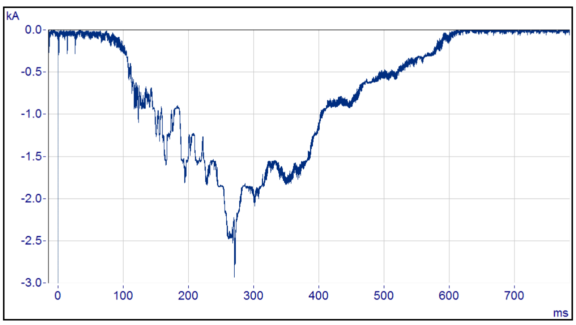

Figure 1 – Current record of flash # 614 with a transferred charge of 546 As

3 – RESULTS

In Figure 2 we show the accumulated charge transfer per year. At the GBT we have measured annual charge transfers ranging from 1 410 As in 2004 up to 8 888 As in 2008. Over the ten years period from 2000 – 2009 the average charge transfer was 4 100 As. Berger *et al.* [4] determined for the flash charge of downward lightning flashes a 50%-value of 7.5 As. Hence the accumulated 8 888 As determined for the year 2008 are equivalent to about 1 185 average downward flashes in a single year.

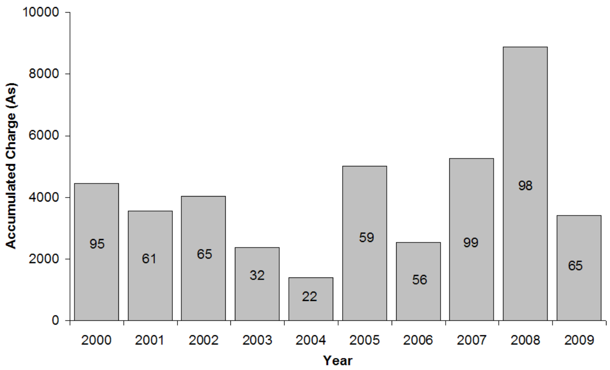

Figure 2 – Accumulated charge transfer per year measured at the GBT (2000 – 2009). Numbers in the bars indicate the number of flashes contributing to the total annual charge

In Figure 3 we show the average monthly charge transfer observed at the GBT. The highest values of 907 As and 562 As are observed in March and November, respectively, at the beginning and the end of the winter season in Austria. During March and November at the GBT site (altitude of 1280 meter above sea level) temperatures are still around freezing level and most of the lightning events can be considered as so called winter lightning. This type of lightning is observed more frequently in Japan [e.g. 5,6,7] and is typically associated with large charge transfers.

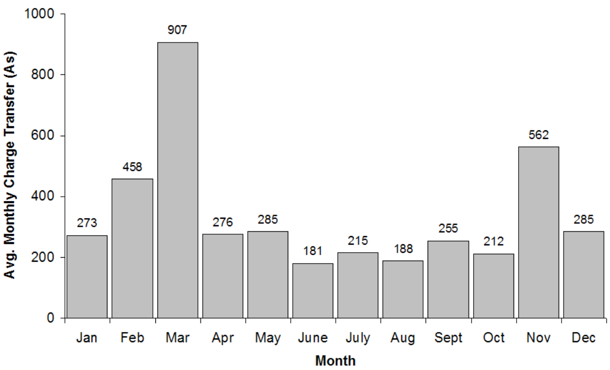

Figure 3 – Average Charge transfer per month measured at the GBT (2000 – 2009)

Frequently several flashes are recorded at the GBT within a few hours when conditions seem favorable to trigger upward lightning. The 22 flashes within 25 minutes on 2008-03-01 have been mentioned before. In Figure 4 we have plotted a histogram of on-site thunderstorm days, where a given amount of charge (x-axis) was transferred. Each bar in the diagram corresponds to 50 As and we can see that 1 000 As was exceeded in 6 storms, with a maximum of 3 735 As. Typically we do not observe any significant lightning activity in the area around the GBT when there is a number of tower initiated flashes and hence those tower events do not occur during typical thunderstorms.

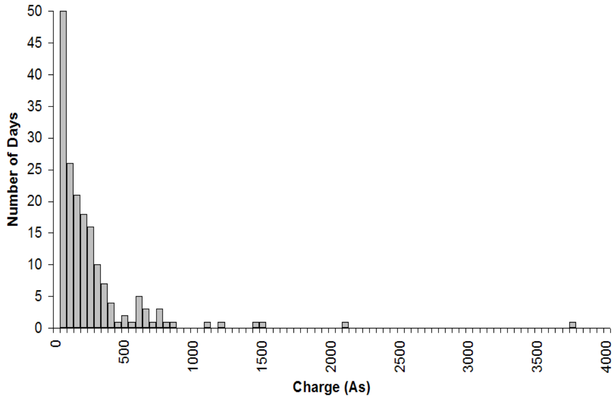

Figure 4 – Distribution of charge transfer per on-site thunderstorm day observed at the GBT (2000 – 2009)

We have to note that in case of upward flashes from a wind turbine flashes will likely be triggered by different blades, although we can not expect a fully balanced share of the charge by the available blades.

4 – MELTED VOLUME AT THE ATTACHMENT POINT

In Figure 5 we show a plot of the estimated volume of melted material that may occur at the attachment point as a function of transferred charge. For this calculation we are using the simplified anode-or-cathode voltage drop model, described in Annex D of IEC 62305-1 [1]. This model is particularly effective for thin metal skins and is neglecting the heat diffusion within the metal. Therefore calculated volumes are estimates and more sophisticated models are probably needed for more accurate calculations. Especially in case of wind turbines there are probably additional effects due to the rotation of the turbine resulting in a high speed of the attachment point at the blade tip.

Based on this model the volume of melted metal is estimated by the following equation (1):

$$V = \frac{u_{a,c} \cdot Q}{\gamma} \cdot \frac{1}{C_W(\theta_s - \theta_u) + c_s} \qquad (1)$$

where

V	is the volume of metal melted (m^3);
$u_{a,c}$	is the anode-or-cathode voltage drop (assumed as constant) (V);
Q	is the charge of the lightning current (As);
γ	is the material density (kg/m^3);
C_W	is the thermal capacity (J/kg.K);
θ_s	is the melting temperature (°C);
θ_u	is the ambient temperature (°C);
c_s	is the latent heat of melting (J/kg).

In Table 2 the constants for aluminium, steel and cooper are listed. Those materials are often used for lightning protection systems.

Quantity	Aluminium	Steel	Copper
γ in kg/m^3	2700	7700	8920
θ_s in °C	658	1530	1080
c_s in J/kg	397.10^3	272.10^3	209.10^3
C_w in J/kg.K	908	469	385

Table 2 – Material constants needed to estimate the melted volume at the attachment point

Figure 5 shows for the three different materials the estimated melted volumes as a function of charge when using Eq.(1). For the accumulated charge transfer of 8 888 As that we observed at the GBT in 2008 we estimate total melted volumes of 35 cm^3, 48 cm^3 and 100 cm^3 for Steel, Copper and Aluminium, respectively.

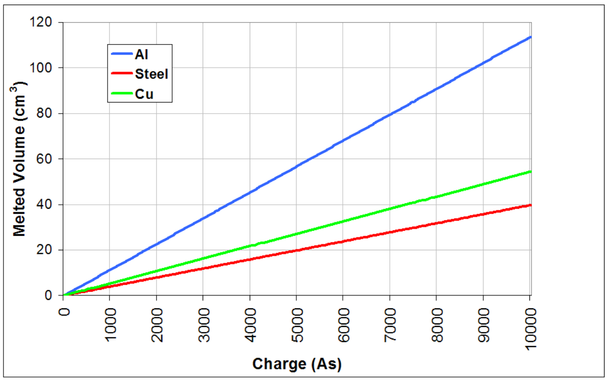

Figure 5 – Estimated melted volume as a function of charge using Eq.(1) for material Al, Steel, and Cu assuming $u_{a,c}$ = 30V, θ_u = 20°

5 – SUMMARY AND DISCUSSION

Elevated objects such as towers or wind turbines are possibly exposed to high numbers of upward lightning particularly during winter. This so-called winter lightning is often associated with charge transfer exceeding the 300 As, specified in the lightning protection standards IEC 62305-1 [1] for LPL I. In case of wind turbines the accumulated charge transfer decides the wear (melting) of materials and therefore influences the need for maintenance of air termination systems.

At the GBT we have measured charge transfers of up to several thousand As per year (maximum 8 888 As in 2008). For installations of wind turbines at exposed sites with such high charge transfers more frequent maintenance circles for the air termination system could be required.

REFERENCES

[1] IEC 62305-1,2,3,4: Protection against lightning, Part 1,2,3,4. IEC standard, 2006

[2] IEC 61400-24 Ed.1 (FDIS): Wind turbines – Part 24: Lightning protection, IEC draft standard, 2010

[3] Diendorfer, G., H. Pichler and M. Mair (2009), Some Parameters of Negative Upward-Initiated Lightning to the Gaisberg Tower (2000–2007), IEEE Trans. Electromagnetic Compatibility, 51, 3, pp.443-452.

[4] Berger, K., R. B. Anderson, and H. Kroninger (1975), Parameters of lightning flashes. Electra 80: 223-37.

[5] Rakov, V. A. and M. A. Uman (2003), Lightning: Physics and Effects, Cambridge University Press.

[6] Asakawa, A., K. Miyake, S. Yokoyama, T. Shindo, T. Yokota, and T. Sakai (1997), Two types of lightning discharges to a high stack on the coast of the Sea of Japan in winter, IEEE Trans. Power Delivery, 12: 1222-31.

[7] Goto, Y. and K. Narita, "Electrical characteristics of winter lightning," J. Atmos. Terr. Phys., vol. 57, pp. 449–459, 1995.

Main author
Name: Gerhard Diendorfer
Address: Kahlenberger Str. 2A, 1190 Vienna, Austria
Phone: +43 (1) 3705806-215
E-mail: g.diendorfer@ove.at