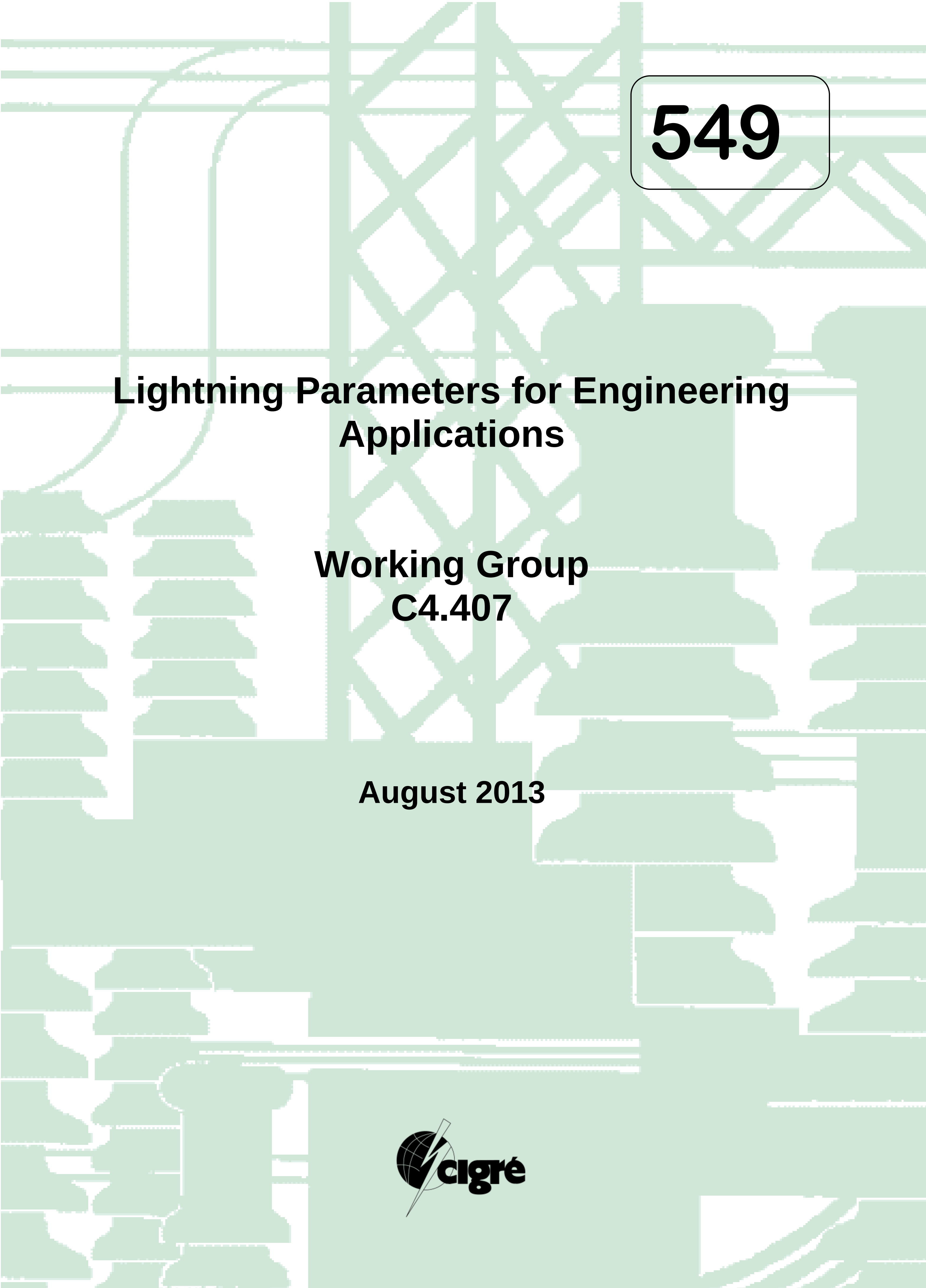

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Lightning Parameters for Engineering Applications

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LIGHTNING PARAMETERS FOR ENGINEERING APPLICATIONS

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About 80% or more of negative cloud-to-ground lightning flashes are composed of two or more strokes. This percentage is appreciably higher than 55% previously estimated by Anderson and Eriksson (1980), based on less accurate records. The average number of strokes per flash is typically 3 to 5, with the geometric mean interstroke interval being about 60 ms. Roughly one-third to one-half of lightning flashes create two or more terminations on ground separated by up to several kilometers. When only one location per flash is recorded, the correction factor for measured values of ground flash density to account for multiple channel terminations on ground is about 1.5-1.7, which is considerably higher than 1.1 previosly estimated by Anderson and Eriksson (1980). First-stroke current peaks are typically a factor of 2 to 3 larger than subsequent-stroke current peaks. However, about one third of cloud-to-ground flashes contain at least one subsequent stroke with electric field peak, and, by theory, current peak, greater than the first-stroke peak. Larger-than-first subsequent strokes may represent an additional threat to power lines and other systems.

From direct current measurements, the median return-stroke peak current is about 30 kA for negative first strokes in Switzerland, Italy, South Africa, and Japan, and typically 10-15 kA for subsequent strokes in Switzerland and for triggered and upward (object-initiated) lightning. Corresponding values from measurements in Brazil are 45 kA and 18 kA. Additional measurements are needed. The “global” distributions of lightning peak currents for negative first strokes currently recommended by CIGRE and IEEE (see Fig. 3.2) are each based on a mix of direct current measurements and less accurate indirect measurements, some of which are of questionable quality. However, since the “global” distributions have been widely used in lightning protection studies and are not much different from that based on direct measurements only (median = 30 kA, σlgI = 0.265 for Berger et al.’s distribution), continued use of these “global” distributions for representing negative first strokes is recommended. For negative subsequent strokes, distribution 4 (median = 12 kA, σlgI = 0.265) in Fig. 3.1 should be used. For positive lightning strokes, distribution 2 (median = 35 kA, σlgI = 0.544) in Fig. 3.1 is recommended, although the data are very limited and may be influenced by the presence of strike object located on the mountain top. Direct lightning current measurements on instrumented towers should be continued. Currently, direct current measurements are performed on instrumented towers in Austria, Brazil, Canada, Germany, and Switzerland, although the overwhelming majority of flashes observed on those towers (except for Brazil) are of upward type.

Recommended lightning current waveshape parameters are still based on Berger et al.'s (1975) data (see Table 3.6), although the current rate-of-rise parameters estimated by Anderson and Eriksson (1980) from Berger et al.'s oscillograms are likely to be significantly underestimated, due to limitations of the instrumentation used by Berger et al. Triggered-lightning data for current rates of rise (see Table 3.7) can be applied to subsequent strokes in natural lightning. Relatively strong correlation is observed between the lightning peak current and impulse charge transfer and between the current rate-of-rise characteristics and current peak and relatively weak or no correlation between the peak and risetime.

The field-to-current conversion procedure employed by the U.S. National Lightning Detection Network (NLDN) and other similar lightning locating systems has been calibrated only for negative subsequent strokes, with the median absolute error being 10 to 20%. Peak current estimation errors for negative first strokes and for positive lightning are presently unknown. Besides systems of NLDN type (such as the European systems participating in EUCLID or nationwide (JLDN) and regional systems in Japan), there are other lightning locating systems that are also reporting lightning peak currents inferred from measured fields, including LINET (mostly in Europe), USPLN (in the U.S., but similar systems operate in other countries), WTLN (in the U.S. and other countries), WWLLN (global), and GLD360 (global). Peak current estimation errors for the latter systems are presently unknown.

The percentage of positive flashes or strokes containing continuing currents (CC) is much higher than that of negative flashes or strokes. Positive strokes tend to be followed by longer and more intense CC than negative strokes. Positive strokes can produce both a high peak current and a long CC, a feature that has not been found in any negative stroke. CC in natural cloud-to-ground flashes exhibit a variety of waveshapes that may be grouped into six categories. The average number of M components per CC differs significantly from one polarity to the other: while an average of 5.5 M components per CC were observed for negative flashes, an average of 9.0 M components per CC were observed for positive flashes. Strokes initiating long CC in negative flashes often have a smaller peak current and are preceded by high peak current return strokes and by relatively short interstroke intervals. Relatively-low-magnitude long continuing currents transfer considerably larger charges than high-amplitude return-stroke pulses.

The average propagation speed of a negative return stroke (first or subsequent) below the lower cloud boundary is typically between one-third and one-half of the speed of light. It appears that the return-stroke speed for first strokes is lower than that for subsequent strokes, although the difference is not very large (9.6 x 107 vs. 1.2 x 108 m/s). For positive return strokes, the speed is of the order of 108 m/s, although data are very limited. The negative return-stroke speed within the bottom 100 m or so (corresponding to current and field peaks) is expected to be between one-third and two-thirds of the speed of light. The negative return stroke speed usually decreases with height for both first and subsequent strokes. There exists some experimental evidence that the negative return stroke speed may vary non-monotonically along the lightning channel, initially increasing and then decreasing with increasing height. There are contradicting data regarding the variation of positive return stroke speed with height. The often assumed relationship between the return-stroke speed and peak current is generally not supported by experimental data.

The equivalent impedance of the lightning channel is needed for specifying the source in studies of either direct-strike or induced lightning effects. The estimates of this impedance from limited experimental data suggest values ranging from several hundred ohm to a few kiloohm. In many practical situations the impedance “seen” by lightning at the strike point is some tens of ohm or less, which allows one to assume infinitely large equivalent impedance of the lightning channel. In other words, lightning in these situations can be viewed as an ideal current source. In case of direct lightning strike to an overhead conductor of a power line with 400 ohm surge impedance (effective impedance 200 ohm, since 400 ohm is “seen” in either direction), the ideal current source approximation may still be suitable. Representation of lightning by a current source with internal impedance of 400 ohm, similar to that of an overhead wire, is probably not justified.

Although positive lightning discharges account for 10% or less of global cloud-to-ground lightning activity, there are several situations, including, for example, winter storms, that appear to be conducive to the more frequent occurrence of positive lightning. The highest directly measured lightning currents (near 300 kA) and the largest charge transfers (hundreds of coulombs or more) are thought to be associated with positive lightning. Positive flashes are usually composed of a single stroke, although up to four strokes per flash were observed. Subsequent strokes in positive flashes can occur both in a new and in the previously-formed channel. In spite of recent progress, our knowledge of the physics of positive lightning remains considerably poorer than that of negative lightning. Because of the absence of other direct current measurements for positive lightning return strokes, it is still recommended to use the peak current distribution based on the 26 events recorded by K. Berger (see Fig. 3.1 and Table 7.3), even though some of those 26 events are likely to be not of return-stroke type. However, caution is to be excersized, particularly for the waveshape parameters listed in Table 7.3, for which sample sizes are smaller than for peak currents. Clearly, additional measurements for positive lightning return strokes are needed to establish reliable distributions of peak current and other parameters for this type of lightning. Bipolar lightning discharges are usually initiated by upward leaders from tall objects. However, natural downward flashes also can be bipolar.

Tall objects (higher than 100 m or so) located on flat terrain and objects of moderate height (some tens of meters) located on mountain tops experience primarily upward lightning discharges that are initiated by upward-propagating leaders. Upward (object-initiated) lightning discharges always involve an initial stage that may or may not be followed by downward-leader/upward-return-stroke sequences. The initial-stage current often exhibits superimposed pulses whose peaks range from tens of amperes to several kiloamperes (occasionally a few tens of kiloamperes). Object initiated lightning events may occur relatively independent from downward lightning during non-convective season, and it has been observed that frequently several flashes were initiated from a tall object within a period of some hours. Diendorfer et al., (2006) reported 20 flashes to the Gaisberg Tower during one night in February 2005 (winter season) transferring a total charge of more than 1,800 coulomb to ground. At tall objects, the probability of occurrence of bipolar lightning is about the same as for positive lightning. Possible reasons for the observed differences from downward lightning and the high complexity of upward lightning are the multiple upward branches of leaders initiated from the tower tip and the relatively short upward leader channels approaching charged regions above the object.

From the information available in the literature at the present time, there is no evidence of a dependence of negative cloud-to-ground lightning parameters on geographical location, except maybe for first and subsequent stroke peak currents, for which relatively insignificant (less than 50%), from the engineering point of view, variations may exist. It is important to note, however, that it cannot be ruled out that the observed differences in current measurements are due to reasons other than "geographical location", with limited sample size for some observations being of particular concern. Similarly, no reliable information on seasonal dependence is available. In summary, at the present time, the available information is not sufficient to confirm or refute a hypothesis on dependence of negative CG lightning parameters on geographical location or season. On the other hand, some local conditions may exist (for example, winter storms in Japan) that give rise to more frequent occurrence of unusual types of lightning, primarily of upward type, whose parameters may differ significantly from those of “ordinary” lightning. Further studies are necessary to clarify those conditions and their possible dependence on geographical location.

Lightning parameters needed for specific engineering applications are summarized. The emphasis is placed on the parameters that have an influence in the electric power engineering calculations, although lightning parameters needed for designing lightning protection of ordinary ground-based structures are also discussed.