ATMOSPHERIC DISCHARGE EFFECT ON POWER NETWORKS

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Abstract: *The main effect of lightning is the induction of the surge voltage within power networks. The paper deals with the description and analysis of the atmospheric discharges and lightning models which affect the AC medium voltage overhead power lines. The surge voltage waveforms for different lightning currents are established, according to current regulations. The assessment of electric potential generated during lightning through phase wire of an overhead power line, in soil and near underground power cable, is done.*

Key words: *electric potential, lightning strike, surge voltage, ground potential rise.*

1. Introduction

Power networks are affected by electro-magnetic interferences, especially during transient states [1], [3], [7], [11]. Electro-magnetic disturbances [13], [17] generated by indirect/direct lightning strikes may cause, through galvanic/inductive/capacitive couplings, faults in the electrical network [5-6], [10], [14] and [16].

2. Lightning Strike Model and Parameters

2.1. Description of the Phenomena

Lightning is an atmospheric discharge of electricity, which typically occurs during thunderstorms and sometimes during volcanic eruptions or dust storms [17].

In the atmospheric electrical discharge, a leader of a bolt of lightning can travel at speeds of 60,000 m/s (220,000 km/h), and can reach temperatures approaching 30,000 °C (54,000 °F).

Lightning flashes to earth lead to a neutralisation of charge between the cloud charges and the electrostatic charges on the ground. There are two types of lightning flashes to earth:
- Downward flash (cloud-to-earth flash),
- Upward flash (earth-to-cloud flash).

In the case of downward flashes, leader discharges pointing towards the ground guide the lightning discharge from the cloud to the earth. Downward flashes can be recognized by the branching which is directed earthwards [18].

The most common type of lightning is negative lightning flashes to earth, where a leader filled with negative cloud charge pushes its way from the thunder cloud to earth (Figure 1). This leader propagates in a series of jerks with a speed of around 300 km/h in steps of a few 10 m. The interval between the jerks amounts to a few 10 µs. When the leader has drawn close to the earth, (a few 100 m to a few 10 m), it causes the strength of the electric field of objects on the surface of the earth

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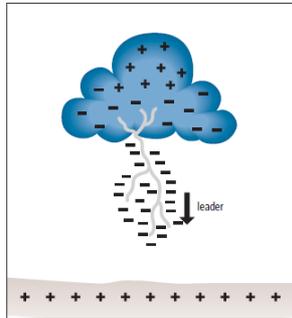in the vicinity of the leader (e.g. trees, buildings) to increase.

Fig. 1. *Discharge mechanism of a negative downward flash (cloud-to earth flash)*

Positive flashes to earth can arise out of the lower, positively charged area of a thundercloud (Figure 2).
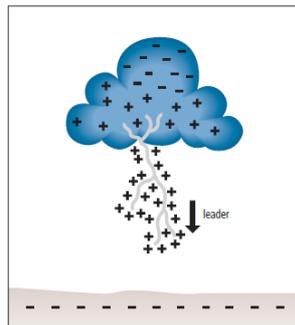

Fig. 2. *Discharge mechanism of a positive downward flash (cloud-to earth flash)*

On power lines, radio masts, telecommunication towers, steeples, upward flashes (earth-to-cloud. flashes) can occur. In the case of upward flashes, the high electric field strength required to trigger a leader is not achieved in the cloud, but rather by the distortion of the electric field on the exposed object, and the associated high strength of the electric field [18], [19].

From this location, the leader and its charge channel propagate towards the cloud. Upward flashes occur with both negative polarity (Figure 3) and also with positive polarity (Figure 4).

Depending on the type of lightning flash, each lightning discharge consists of one or more partial strikes of lightning.
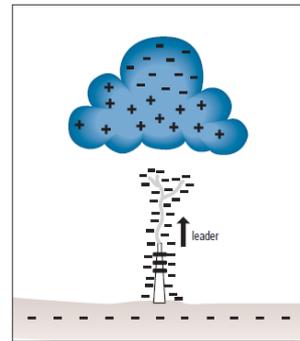

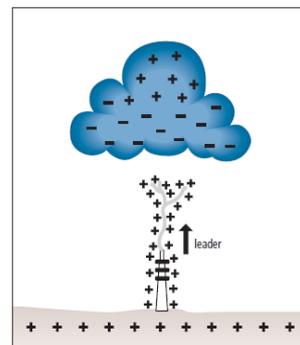Fig. 3. *Discharge mechanism of a negative upward flash (earth to cloud flash)*

Fig. 4. *Discharge mechanism of a positive upward flash (earth to cloud flash)*

One can distinguish between short strikes with less than 2 ms duration and long strikes with duration of more than 2 ms. Possible combinations of partial lightning strikes are shown in Figure 5 for downward flashes, and Figure 6 for upward flashes [19].

2.2. Induced Voltages by Lightning Currents

The lightning currents consisting of both impulse currents and continuing currents are load-independent currents, i.e. the objects struck exert no effect on the lightning currents.

From the lightning current profiles shown in Figure 5 and Figure 6, four important parameters for lightning protection can be established:

- the peak value of lightning current I;
- the charge of the lightning current Q_{flash}, comprising the charge of the short strike Q_{short} and the charge of the long strike Q_{long};
- the specific energy W/R of the lightning current;
- the steepness di/dt of the lightning current.

The slope $\Delta i/\Delta t$ of the lightning current wave is connected with the amplitude of the induced voltage, in all conductors through which lightning current flows [4]. Figure 7 shows the wave voltage U induced during the time interval Δt [15]. The current waveform of 8/20 µs, is considered according [8], [12] for tests and this lightning current may lead to conventional voltage waveform like 1.2/50 µs.

Lightning currents are load-independent currents. If a load-independent active electric current flows through conductive components, the amplitude of the current, and the impedance of the conductive component the current flows through, help to regulate the potential drop across the component flown through by the current. In the simplest case, this relationship can be described using Ohm´s Law.
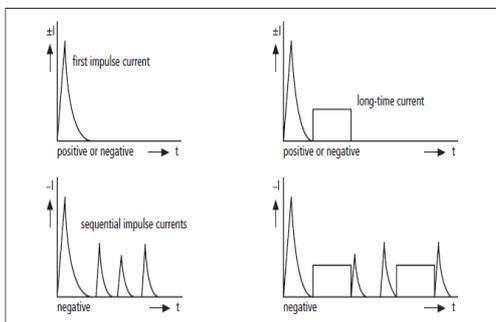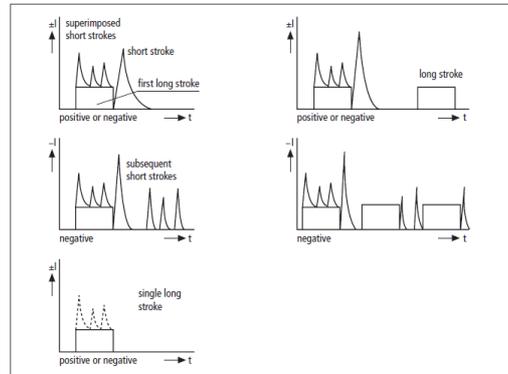

Fig. 6. *Possible components of upward flashes*

If a lightning current flows through conductive components of power networks, the distribution of the electric potential is influenced by the values of the electric current and impedances of each component.

Thus, if the current flows through a single point on a homogeneous conducting surface, the electric potential V rises, with a specific distribution with r distance, meaning the distance from the point of strike. The same effect occurs when lightning hits the homogeneous ground (Figure 8).

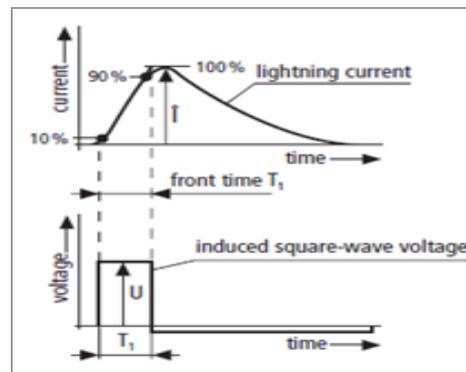The higher the conductivity of the ground is, the flatter is the shape of the potential gradient area.

Fig. 5. *Possible components of downward flashes*

Fig. 7. *Induced square-wave voltage in loops via the current steepness Δi/Δt of the lightning current*
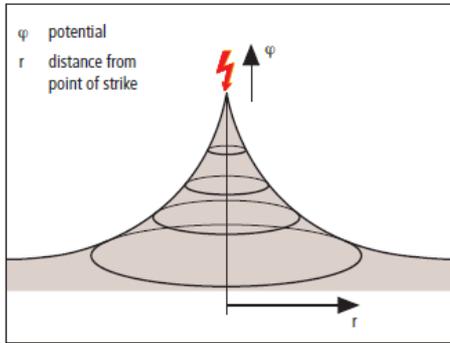
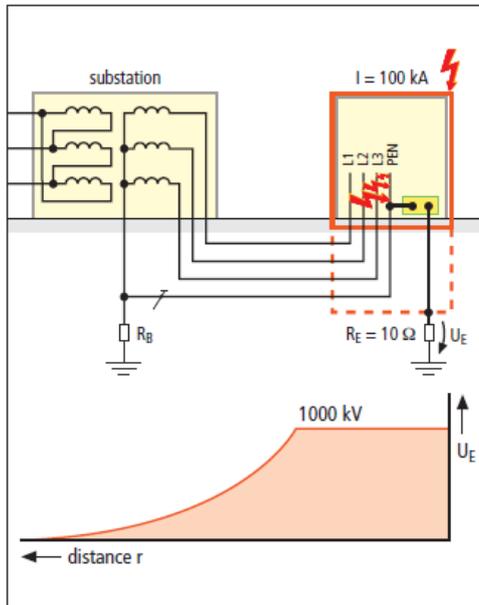Fig. 8. *Potential distribution of a lightning strike into homogenous soil*

Fig. 9. *Threat to electrical installations by potential rise at the earth-termination system*

The rise in potential of the earth-termination as a result of the lightning current creates a hazard for electrical installations (Figure 9).

2.3. Mathematical Model of the Lightning Current

The mathematical model of the lightning current $i_{\text{surge}}(t)$ is described by the Heidler function:

$$ i_{surge(t)} = k_i \cdot \left[\frac{I_p}{k_{surge}} \cdot \frac{\left(\frac{t}{\tau_1} \right)^{\eta_{surge}}}{1 + \left(\frac{t}{\tau_1} \right)^{\eta_{surge}}} \cdot e^{\frac{-t}{\tau_2}} \right], \quad (1) $$

where: k_i is current correction coefficient; τ_1, τ_2 are rise and fall time of the pulse; η_{surge}, k_{surge} are wave shape correction coefficients; I_p is the peak value of the surge current.

The function (1) describes a lightning pulse [9], suitable to express the phenomenon with a rapid change during the increase of its value, followed by a slow variation during the decrease of its waveform.

The coefficient k_{surge} is strongly dependent on the parameters of the wave lightning pulse:

$$ k_{surge} = \exp\left[-\frac{\tau_1}{\tau_2} \cdot \left(\frac{\eta_{surge} \cdot \tau_2}{\tau_1} \right)^{\left(\frac{1}{\eta_{surge}} \right)} \right]. (2) $$

The parameters for different lightning current wave shapes, according to 61000-4-5:2013, are presented in Table 1 [9], [16].

Parameters of lightning channel   Table 1

Test type	k_i	η_{surge}	τ_1 [µs]	τ_2 [µs]
Surge current 8/20 µs	1	2.741	47.52	4.296
Surge current 5/320 µs	1	1.556	1.355	429.1

As specified in [2], the front time of the lightning current shape is about 8 µs, and the duration is around 20 µs.

2.4. Mathematical Model of the Surge Voltage

Considering the lightning current as an ideal current source, and using the parameters of lightning channel, the surge voltage model is obtained based on Ohm's Law [9]:

$$u_{surge}(t) = k_v \cdot \left[\frac{U_p}{k_{surge}} \cdot \frac{\left(\frac{t}{\tau_1}\right)^{\eta_{surge}}}{1 + \left(\frac{t}{\tau_1}\right)^{\eta_{surge}}} \cdot e^{\frac{-t}{\tau2}} \right] .(3)$$

The values of the voltage wave shape parameters (Table 2) are specified in [16].

Table 2

Parameters of voltage surge wave shape

Test type	k_v	η_{surge}	τ_1 [μs]	τ_2 [μs]
Surge voltage 1.2/50 μs	1	1.852	0.356	65.845
Surge voltage 10/700 μs	1	1.556	1.355	429.1

3. Discussions

High electric fields generated by lightning near ground reference can cause electric potential rise in low voltage networks/residential buildings. Of great importance is the rise of the ground electrodes resistance, which can affect the earth connection of low/medium voltage networks, especially in the case of the IT connections. Also, the soil resistivity has a great influence on the electric potential variation, as for the soils with resistivity higher than 500 Ωm, are more exposed to high electric potentials variations.

Acknowledgements

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