THE INFLUENCE OF SENSOR POSITION ON CONTAMINATION OF LIGHTNING CURRENT WAVES FOR MEASUREMENTS TAKEN AT SHORT TOWERS

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Abstract: An evaluation concerning the influence of the current sensor position along short instrumented towers on the contamination of measured lightning current waves is presented. The evaluation was performed by means of computational simulation, employing a hybrid electromagnetic model - HEM. Assuming certain simplifications, the dynamic behavior of lightning channel is considered, including core losses and corona sheath. The results showed that, for short towers and realistic values for wave front time, the current wave measured at tower top or at tower base should be practically the same. Their amplitude would be very similar for both first and subsequent strokes.

Keywords: Lightning current measurement, Lightning current contamination, Instrumented towers.

1. Introduction

The design of protection systems is very dependent on lightning current parameters. Most of the knowledge about such parameters comes from direct measurements taken at instrumented towers. In this respect, the most important database is that derived from Berger's measurements, taken at San Salvatore Station, Switzerland [1]. Additional data were provided by instrumented towers, installed in several other countries, such as South Africa, Germany, Russia and Canada.

The lightning current measurement has been taken at the tower base or top, depending on the specific measuring station. In San Salvatore, the current sensor was positioned at the top of tower, while, in South Africa, it was placed at the tower base. In technical literature, several works considers the influence of elevated stricken objects on the wave profile of the measured lightning current [2,3,4] and discuss the current wave profile along the tower. This influence is very clear for very tall structures.

Some researchers states that, in general, measurements taken at the top of instrumented towers are subject to very short contamination, while those taken at the tower base have the current wave strongly disturbed. This aspect is very clearly shown in the works of Rachid [3], which refers specifically to tall towers. In her study, Melander [2] concludes that, even for short towers (such as the South African one), significant errors can occur for measurement near the bottom. The amplitude of current wave measured in this position is estimated to exceed in more than 60% the value measured at the top. Maybe, due to such works, it is very usual to hear that, in general, the amplitude of current wave measured at base is significantly larger than that taken at top. Sometimes, this statement is referred to, in order to explain differences observed in lightning current amplitude for measurements taken at different places of the world.

Even in a simplified electromagnetic approach, it is possible to verify this conclusion to be real for strikes to tall towers. Nevertheless, for short towers, this assumption does not seem to be reasonable, when typical front time values of real lightning current waves are considered. This paper is specifically dedicated to the evaluation of current contamination effect for short towers.

The investigation is mainly motivated by the authors' involvement with lightning current measurements at Morro do Cachimbo Station (MCS). This station is located at Minas Gerais State, Brazil. It was installed in 1985 over a hill, 1430 m above sea level, in the vicinities of Belo Horizonte city (43°58' W, 20°00' S). Its instrumented tower is 60 m high and the measurement is presently taken at tower base. The 13-year local database show that the median peak current for downward negative lightning strokes is around 48 kA [5], a value around 50% larger than that found by Berger [1].

2. Basic Considerations

In order to correctly evaluate the question on focus, it is prudent to have an insight in the dynamics of return current establishment. The understanding of such fundamental aspect may allow a good representation of the physical system where current is measured and also a better computation of the process that determines the amplitude and waveform of measured current. Such dynamics is following commented with reference to Figure 1.

After the attachment is achieved, two current components are established along the channel, one traveling upwards and the other downwards. The descending current wave flows towards the tower. When it reaches tower top, it is partially reflected upwards and partially transmitted to the tower body. The transmitted wave follows towards the tower base and is reflected at soil level. The ascending reflected wave is once more reflected after reaching tower top. Following, a sequence of reflections occurs at tower base and top, while current wave travels along the tower. This transient process establishes the resulting current along the tower.

In practice, considering strikes to short towers, the attachment height is expected to vary from some tens of meters to a few hundred meters, for first strokes. For subsequent ones, it is much more reduced. In Figure 1, regarding the present evaluation, this height was arbitrated as 100m. This definition does not affect the results, at the wave front. The relevant issue is to assure the presence of a superior channel above attachment point, as it prevents a reflection of the second ascending current wave at the attachment point that would not correspond to physical reality.

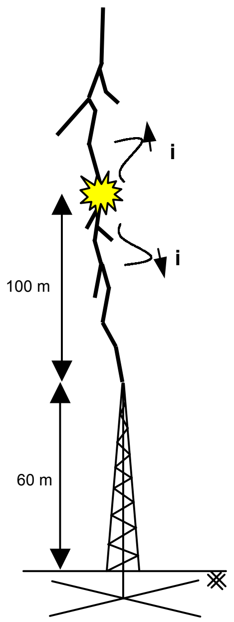

Figure 1: Representation of lightning channel and tower to consider return current establishment dynamics.

3. Developments

3.1 Introduction

The present evaluation was developed from the systematic application of an elaborated hybrid electromagnetic model – HEM. Details about such model are presented in other authors' publications [6,7]. As explained in these references, such model develops an electromagnetic representation of the physical system (channel-tower-grounding electrodes) based on information (input) about the geometrical configuration of the analyzed system and physical parameters of the involved media (air, conductors, channel and soil). It may also include the effects of corona sheath and core losses along the lightning channel. From such information the model develops the electromagnetic coupling relations among all the involved physical components and determines current and voltage distribution along the current path.

In this particular case, it is important to comment that the HEM model is able to take into account the real distribution of electromagnetic field in the vicinities of tower and channel. Most of models employed in similar evaluations assume a TEM mode for the field propagation along the tower and channel. Due to the vertical position of tower and channel and the presence of soil, the electric field lines are displaced from the typical transversal lines of this mode. As a result, for a realistic representation of tower, its transversal parameters would change along channel. In a distributed circuit approach it would correspond to diminish the capacitance per unit length as height is increased.

3.2 Representation of the Physical System

This model was applied to simulate lightning strikes to the tower of Morro do Cachimbo Station and real dimensions of such tower were adopted. The first simulated system consists in the lightning channel and tower (60m high) above the soil. Grounding electrodes, as shown in Figure 1, are buried in the soil and its resistivity value is varied. Simulations depart from the instant of attachment occurrence.

The process is supposed to begin from the injection of a current wave at the attachment point, positioned 100 m above tower top. The current waveform was assumed as a ramp, with different values for the front time, able to resemble the first and subsequent strokes. The waveshape is not a critical aspect, as the same wave generates the results at top and base of tower. The ramp was chosen in order to make the analysis of results clearer.

The present evaluation followed two steps:

(i) First, a simplified representation for the dynamics of current establishment was evaluated. The channel parameters were assumed not to vary during the process. Though for each simulation the parameters were considered not to vary, a sensitivity analysis was performed, considering different conditions for such parameters (channel losses and corona, grounding impedance).

(ii) In a second step, a more realistic behavior was considered for the dynamics of current establishment. The variation of channel parameters was partially accounted for, assuming a transition for the physical characteristics of lightning channel. The current wave (injected at the attachment point) was assumed as the result of superposing two waves. The first one, defined by its amplitude would correspond to that parcel of front wave that propagates along the channel at the beginning of the process and finds the channel with low ionization level (high core losses or equivalently large value for the parameter resistance per unit length) and surrounded by a wide corona sheath. The other parcel, obtained from the difference of the original injected current and the first parcel, is assumed to propagate in an already modified channel, due to the flow of first current. In this case, the channel ionization is considered increased (lower core losses) and corona sheath is considered to be reduced. This procedure tries to resemble the evolution of channel parameters during the process.

3.3 Results and Analyses

As a first result of simulations, Figure 2 shows the current waves observed at tower top and base for the condition of step (i).

The corona sheath is represented by a 2 m equivalent radius. This corresponds to a velocity around 0.6c for the current propagation.

Different values are considered for the resistance of channel core, in order to represent different levels of core losses (R=0.56 and 1 Ω/m and the same of a copper core).

Also two values of soil resistivity are assumed (100 and 2500 Ω.m), in order to consider extreme conditions for grounding impedance. The configuration of grounding electrodes is not varied.

Two values of front time are simulated (0.5/50 and 2/50 μs) in order to represent fast current waves associated to subsequent and first negative strokes.

The results for the assumed conditions are following commented.

As expected, for the lower grounding impedance condition, the amplitude of both currents are a little larger. Also, the effect of assuming more pronounced losses is a reduction of the current wave amplitude. For the faster wave, the amplitude of current is a little larger. In all cases, the differences are very discrete.

In spite of such differences, when the waves observed at the top and at the base are compared for the same condition, the amplitude is practically the same. The only difference is a discrete increase of the wave front slope for the wave considered at tower base. This is also an expected result due to the simultaneity of incident and reflected wave at the tower base.

Figure 3 refers to the same results, but concentrates on the analysis of the effect of tower grounding impedance. In this case the same velocity is assumed (same corona sheath) and losses are computed by a 0.56 Ω/m resistance per unit length of channel.

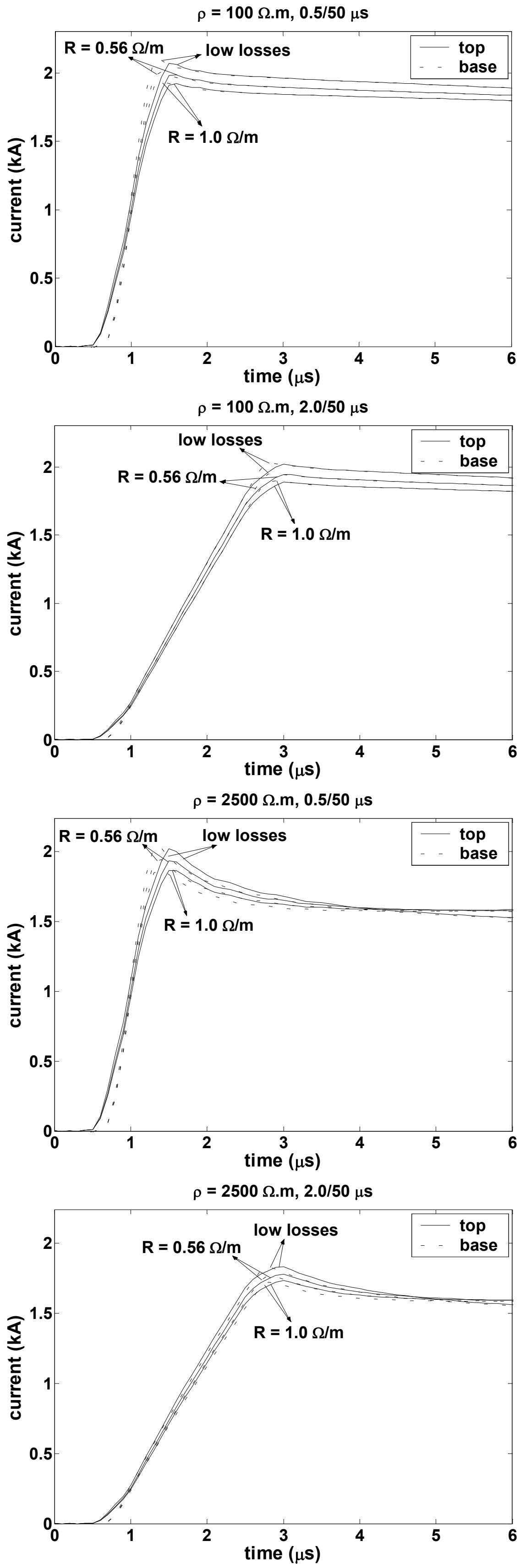

Figure 2: Current wave at tower top and base.

The tower grounding impedance is varied about 25 times by increasing the soil resistivity and little effect is observed for both waves. Though the current amplitude tends to increase as grounding impedance is reduced and larger amplitudes are found for the faster wave, practically no differences are observed for the current at top or base, unless the moderate increase of front wave slope for the wave measured at tower base.

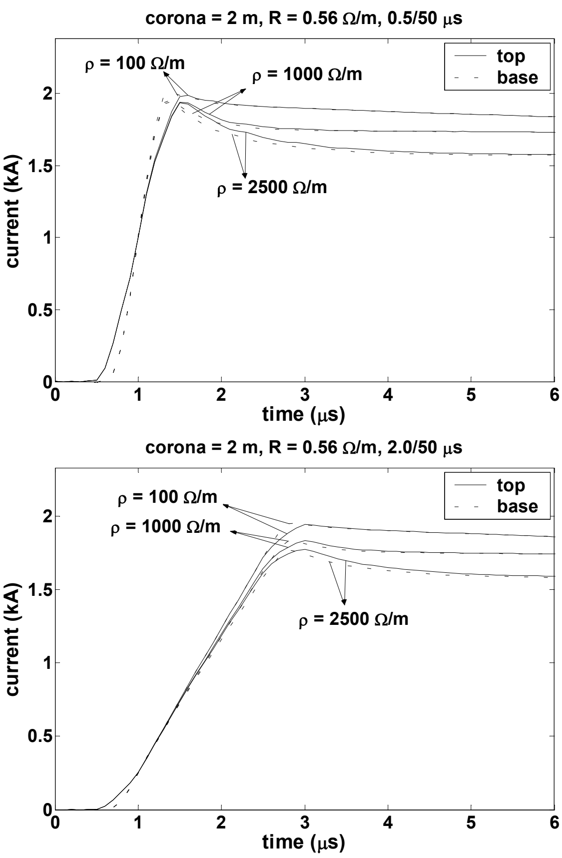

Figure 3:Current wave at tower top and base: the effect of grounding impedance.

Following, the simulations contemplated the evolution of channel conditions, as described in step (ii). For this evaluation, the current was supposed the superposition of the two waves represented in Figure 4. Both waves departs from the attachment point and reaches the tower top at the same instant however they are supposed to travel along channels with different parameters. For the first current wave, assumed channel parameters are: 2 m equivalent radius for the corona sheath and R= 0.56 Ω/m. This corresponds to the condition of channel in beginining of wave propagation (v=~0.6c and large losses at channel core). For the second wave, the corona sheath is reduced to a 0.5m equivalent radius (v=~0.72c) and the losses are significantly reduced (R=0.035 Ω/m). This approach tries to resemble the dynamic nature of channel parameters during the process of current establishment. It makes the reflections at tower top closer to reality in relation to the assumptions considered for the first step.

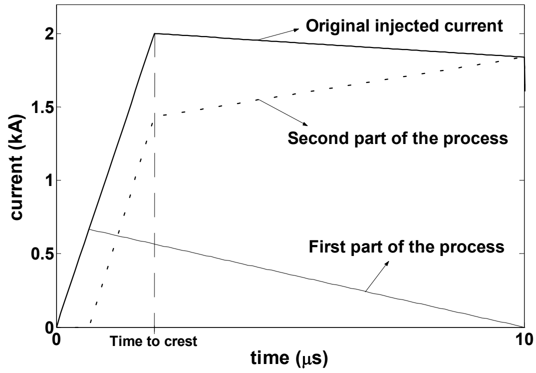

Figure 4: Composition of the injected current wave.

The results of simulation are presented in Figure 5, for a fast and a slow waves. The results are quite similar to those obtained for the conditions assumed for first step and demonstrates that the dynamic behavior of channel parameter are not able to influence the results.

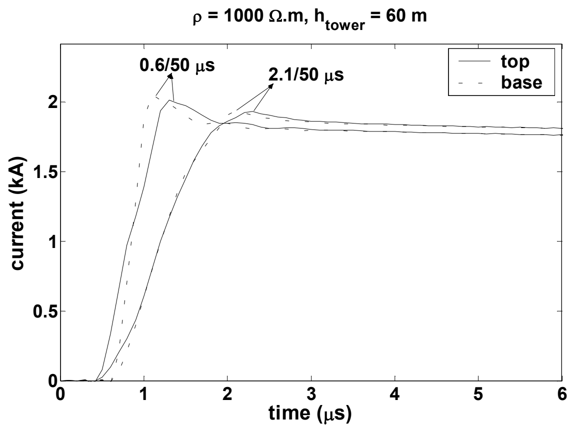

Figure 5: Comparison of current wave at tower top and base, assuming a dynamic behavior for channel parameters.

The results leads to the conclusion that for short instrumented towers, such the ones of Morro do Cachimbo, South Afrika and San Salvatore stations, the current wave measured at the tower top or at its base would practically be the same one. Therefore, the general idea that measurements at the tower base would generate larger amplitudes is not consistent.

This results contradicts the findings of Melander [2], but seems quite reasonable in the perspective of the electromagnetic propagation theory.

Due to the relevance of the results, the authors decided to expand the evaluations to some other situations, as following commented.

For the first evaluation, the same conditions of the second step (ii) were assumed, but the tower was supposed to be 250m high. The results of simulations are shown in Figure 6. As it is shown, the current profile is quite different for the waves measured at tower top and base. While the "base" wave at base has a smooth variation of its front, the reflection is very explicit for the "top" wave. Nevertheless, the current amplitudes are very similar. Only for the fast wave, the peak value of "top" wave is about 10% larger.

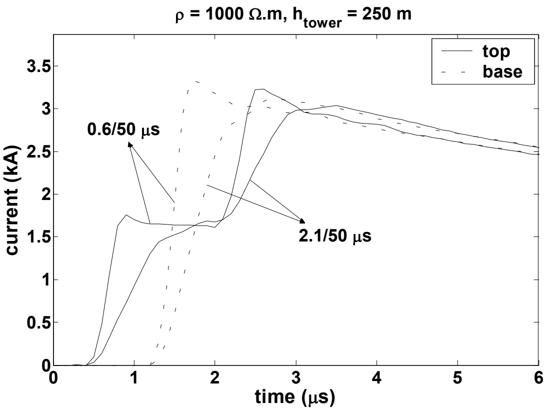

Figure 6: Comparison of current wave at tower top and base, assuming a dynamic behavior for channel parameters for a 250m high tower.

Also some situations considered in simulations reported in literature were evaluated for a short tower (60m) [4]:

(i) the current is injected directly at tower top by an ideal current source and the presence of a lightning channel is not considered; (ii) the current is injected directly at tower top by an ideal current source but a lightning channel is connected to tower top, assuming 2 m equivalent radius for corona sheath and R= 0.56 Ω/m. Figure 7 shows the results of model application for a fast and a slow current wave.

The results denotes that only for the assumption that no lightning channel is connected to the tower while current is being injected, there is a substantial difference between the current waves at the tower top and base. Even though, such difference is really significant for the fast wave. The assumption of current injection directly at tower top could be reasonable for subsequent strokes as the attachment is very close to the tower in this case. Nevertheless, the absence of a lightning channel corresponds to a non-realistic representation of the current establishment process. Therefore, in all developed evaluations, the only case that the current waves at tower top and base are substantially different for short towers is not representative of the physical process involved in the current establishment.

4. Conclusions

This work presented evaluations about the influence of the current sensor position on the contamination of lightning current waves for measurements taken at short instrumented towers.

The results denoted that the current waves measured at top and base of the tower are quite similar, when typical values of lightning current wave front are employed. For representative conditions assumed for lightning channel, the amplitude of such waves are practically the same. The only difference is a moderate increase of wave front slope for the current measured at tower base.

These results were naturally expected by the authors for short towers. The measurements taken at Morro do Cachimbo Station indicates that the median Td10 value is around 7μs for first strokes and 0.9μs for subsequent ones. [5]. Even without applying elaborated models, only based in basic electromagnetic theory, it is not difficult to conclude that, for short towers (60m) and not-so-fast current waves, the contaminated current wave at the top and base should be very similar, once the transit time along the tower is around 0.2μs. For first strokes it is natural not to expect any influence on current amplitude, though for subsequent ones a slight difference could be expected. Also the increase of the wave front slope was a reasonable expectation, once the wave reflected at tower base is added with no delay to the incident wave.

Therefore, the difference on median peak values for negative lightning currents determined from database obtained by measurement at short towers in different parts of the world should not be attributed to the position of the sensor along the tower, as it is very commonly assumed.

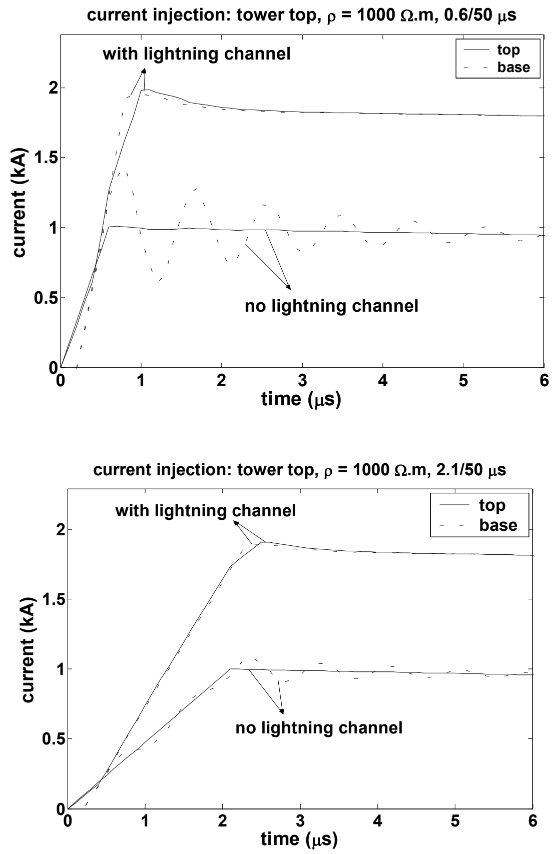

Figure 7: Comparison of current wave at tower top and base: current injected directly at the tower top.

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