Calculation of Lightning-Induced Voltages with RUSCK's Method in EMTP Part II: Effects of Lightning Parameter Variations

J.P.Silva
Departamento de Ciências Exatas
Universidade Federal de Lavras
P.O Box 37, 37200-000, Lavras, MG
Brazil
joaquim@cpdee.ufmg.br

A.E.A. Araújo
Departamento de Engenharia Elétrica
Universidade Federal de Minas Gerais
Av. Antônio Carlos, nº 6627, 31270010
Belo Horizonte, MG-Brazil
araujo@cpdee.ufmg.br

J.O.S. Paulino
Departamento de Engenharia Elétrica
Universidade Federal de Belo Horizonte
Av. Antônio Carlos, nº 6627, 31270010
Belo Horizonte, MG-Brazil
josvaldo@eee.ufmg.br

Abstract-**This paper discusses the effects of the following parameters on the return stroke and on the characteristics of the induced voltage: propagation velocity, peak value, front steepness, time to half-value and distance between the striking point and the line. The main purpose of this study is to point out the effects of parameter variations on the wave shape of the induced voltage on an experimental distribution line due to rocket triggered lightning flashes.**

Keywords: Lightning Parameters, Induced Voltages, Wave shapes, Rusck's Theory.

I. INTRODUCTION

The mechanisms which influence the induced voltage on overhead lines from nearby lightning strokes have been reported by many researchers in the last decades [1], [2], [3], [4], [5], [6]. There are many parameters which have great importance for the amplitude and wave shapes of lightning induced voltages.

Triggered lightning flashes make it possible to measure many characteristics of the triggered return stroke, that are very similar to natural subsequent return strokes [7], [8], [9], [10], [11]. These characteristics are useful to simulate these phenomena and predict a range of values of expected induced voltages.

As presented in the first part of the paper [12], the wave shape of the induced voltage is influenced by various parameters, such as propagation velocity, front time, time to half-value, amplitude peak and distance between the striking point and the line [1]. This part of the paper evaluates the modification of amplitude and waveforms as a function of the variation of the parameters involved.

II. METHODOLOGY

The system configuration is the same as used in part 1, (see Fig. 1)[12]. The most significant characteristics of the lightning stroke current associated with triggered lightning flashes were varied to study possible discrepancies between the measured value and the simulated value.

To get the database, a data acquisition program was used, since no speed measurements or statistics on current wave shape parameters are available [13]. Almost all values were the same as in [14]. The exception is the front time to return stroke nº 9313-2, where Jankov's work presents a front time of 2.5µs. The return stroke velocity of 100m/µs was adopted to make comparisons with Jankov's work easier [14]. This topic will be discussed later in the stroke velocity variation section. Table I present the necessary data for this study.

Table I
Lightning Stroke Current Characteristics – Base Case

Stroke nº	I_o (kA)	t_f (µs)	t_h (µs)	v (m/µs)
9305	23	1.5	45	100
9306	37.5	1.75	45	100
9313-2	9.75	1.0	40	100

Where:

I_o = stroke current magnitude, in kA;
t_f = front time, in µs;
t_h = time to half-value of the stroke current, in µs;
v = return stroke velocity, in m/ µs.

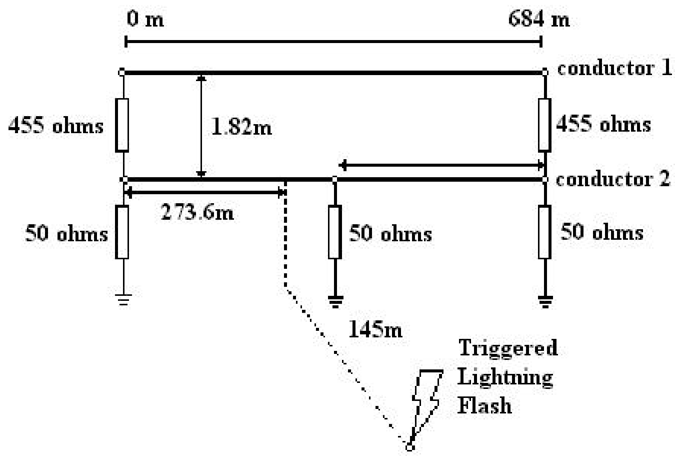

Fig. 1.Phase conductor 1 and neutral conductor 2, and discharge configuration.

III. ANALYSIS OF THE EFFECTS OF THE LIGHTNING PARAMETER VARIATION

Considering the system's configuration presented in Fig.1, the method described in the companion paper [12], and the data from Table I, the influence of some characteristic parameters associated with the triggered return stroke on the amplitude and wave shape of the induced voltages (V_{ind}) is studied.

A. Effect of return stroke velocity variation

In this section, the value of return stroke velocity was varied, keeping the values of I_o, t_f, t_h, and v the same as those in Table I. The results at a point perpendicular to the lightning stroke, close to the middle of the line, are shown in Table II.

For this system's configuration, it can be seen that increasing the velocity of the return stroke, the amplitude of the induced voltage decreases and the front steepness of the induced voltage wave shape increases. Fig. 2 shows the results of induced wave shapes for lightning flash nº 9305. For the cases of Flash nº 9306 and 9313-2 the same behavior was observed.

It is worth mentioning some of the values of triggered lightning flash velocities adopted in the literature are : 130m/µs was used in [1], [3], 100m/µs was used in [14], and 120m/µs was adopted in [13].

Table II
Induced voltage as a function of the stroke velocity

Velocity (m/µs)	60	90	100	120	130	150	180
V_{ind} (kV) Flash nº 9305	51.0	49.2	48.4	46.8	46.3	45.0	43.1
V_{ind} (kV) Flash nº 9306	82.1	77.5	75.9	72.6	71.0	68.4	65.2
V_{ind} (kV) Flash nº 9313-2	21.9	21.8	21.7	21.6	21.4	21.5	21.6

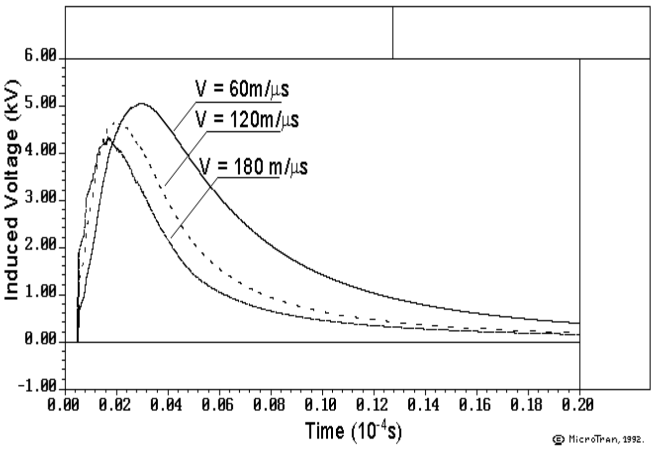

Fig. 2.Induced voltage as a function of velocity, Flash nº 9305

The average value of 120m/µs is presented in [15], [16], [17], and values between 100 - 130m/µs were presented in [18]. Considering these values for return stroke velocity, the maximum relative error between measurements and the EMTP-Rusck method is 10%.

Fig.3 shows the wave shapes for lightning flash 9305 as a function of the most usual values of return stroke velocity.

B. Effect of amplitude peak of return stroke current

Table III gives the results for the effects of the amplitude peak variation, using data from Table I. Since this numerical data is not published, it was necessary to get this data directly from the wave shape [13].

The results for this configuration show that the induced voltage amplitude is proportional to the return stroke current. Despite these variations, presented here only for the purpose of representing possible discrepancies between the measured and digitized values, the relative error between measurements and EMTP-Rusck stays lower than 10%.

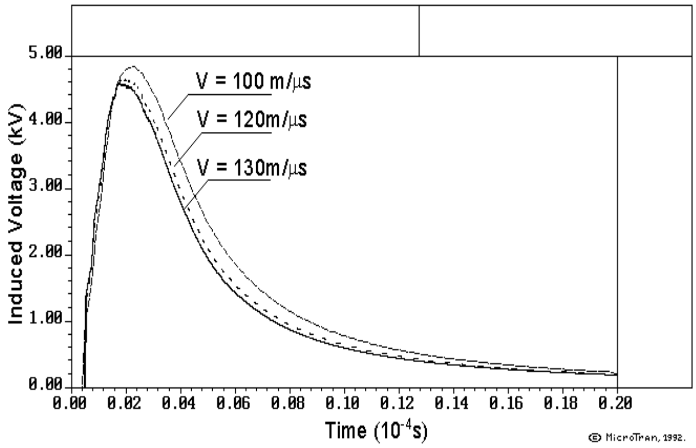

Fig 3 Induced voltage for the most usual velocities (100, 120 and 130m/µs) – Flash nº 9305

Table III – Effects of amplitude peaks

Lightning Flash	Values Simulated in this Study					Jankov [14]	Barker et al [13]
nº 9305 I_o (kA)	21	22	23	24	25	23	23
nº 9305 V_{ind} (kV)	44.2	46.3	48.4	50.5	52.6	45.4	50.0
nº 9306 I_o (kA)	35.5	36.5	37.5	38.5	39.5	37.5	37.5
nº 9306 V_{ind} (kV)	71.9	73.9	75.9	77.9	80.0	74.6	79.0
nº 9313-2 I_o (kA)	7.75	8.75	9.75	10.75	11.75	9.75	9.75
nº 9313-2 V_{ind} (kV)	17.2	19.5	21.7	23.9	26.1	18.4	22.5

C. Effect of front time of return stroke current

The effect of front time of the return stroke current on the amplitude and wave shape of the induced voltage is presented in Fig. 4. Tables IV, V and VI give the results for return strokes nº 9305, 9306 and 9313-2 [13]. It can be observed that larger values of front time imply lower amplitude peak and smaller values of front time imply higher amplitude peak for the induced voltage wave shapes. Since the exact value of front time is unknown, this analysis tries to present the impact of small discrepancies between the real and simulated front time.

In Table IV, applying a variation of 30 % in the value of front time from the data acquisition, the higher relative error is 10.8%. In Table V, applying the same variation for the front time value, the higher relative error is 12.3%, and in Table VI applying a variation of 50% in the front time value, the higher relative error is 8.9%.

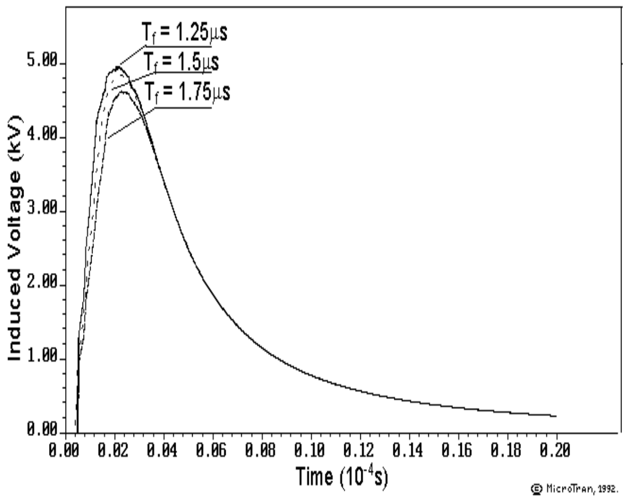

Fig.4. Effects of front time – Flash nº 9305

Table IV – Front time variation lightning flash 9305

	Values Simulated in this study					Jankov [14]	Barker et al [13]
v (m/µs)			100			100	unknown
t_f (µs)	1.00	1.25	1.50	1.75	2.00	1.50	1.50
v_{ind} (kV)	51.1	50.0	48.4	46.4	44.6	45.4	50.0

Table V – Front time variation lightning flash 9306

	Values Simulated in this study					Jankov [14]	Barker et al [13]
v (m/µs)			100			100	unknown
t_f (µs)	1.25	1.50	1.75	2.00	2.25	1.75	1.75
v_{ind} (kV)	81.5	78.9	75.9	72.7	69.3	74.6	79.0

Table VI – Front time Variation Lightning Flash 9313-2

	Values Simulated in this Study					Jankov [14]	Barker et al[13]
v (m/µs)			100			100	Unknown
t_f(µs) t_f=2.5µs	2.00	2.25	2.50	2.75	3.00	2.5	2.5
V_{ind}(kV)	18.9	18.0	17.2	16.3	15.6	18.4	22.5
t_f (µs) t_f = 1µs	0.5	0.75	1.0	1.25	1.5	2.5	2.5
V_{ind} (kV)	22.0	21.9	21.7	21.1	20.5	18.4	22.5

D. Effect of time to half- value of Return Stroke Current

Table VII shows the effect of time to half-value of the return current wave shape on the amplitude of the induced voltage. For this section, the values of time to half-value were chosen from the data in [19]. It can be observed that the variation of time to half-value of the return stroke current has little effect upon the induced voltage amplitude.

Table VII- Effect of time to half-value

Lightning Flash	Values Simulated in this Study v= 100m/µs			Base case v= 100m/µs
t_f (µs)	20	30	60	45
V_{ind} nº 9305 t_f =1.5µs	47.1	48.0	48.6	48.4
V_{ind} nº 9306 t_f =1.75µs	73.9	75.3	76.2	75.9
V_{ind} nº 9313-2 t_f =1.0µs	21.2	21.5	21.8	21.7

E. Effect of striking point of the lightning flash

Fig. 5 shows the effect of striking point variation. It can be observed that the amplitude peak of the induced voltage is dependent on the distance of the striking point. Smaller distances between line and striking point produce higher amplitude values of the induced voltage.

F. Effect of Time Step used in Microtran

Fig 6 gives the results for three different time steps, used in the simulations. It can be noticed that the amplitude and the wave shape are the same for the three. There is only a small difference in the beginning of the wave shape. The entire simulation for the smaller time step of $1.0.10^{-7}$s takes only 0.5s and the entire simulation for $1.0.10^{-9}$s takes less than 30 seconds of CPU time.

G. Effect of the line discretization

In this section, the effects of section length (Δx) of the line studied are presented. For this study the line was divided into 10 sections of 68.4m each. It is possible to observe in Fig 7 that when the line is dvided into 8 sections of 85.5m, there is no difference between the two waveforms. However, this topic requires further study.

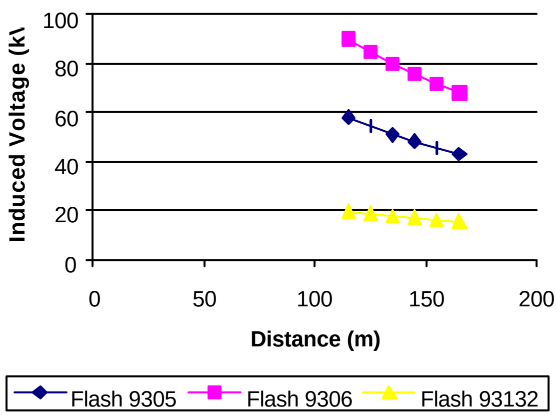

Fig. 5. Effects of striking point of the lightning flash

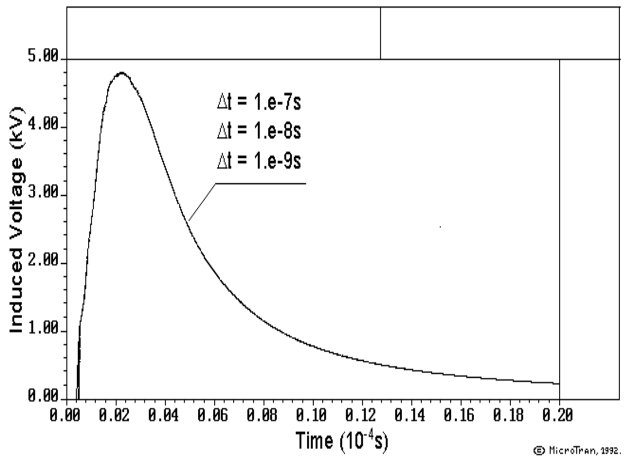

Fig 6. Time step variation – flash nº9305

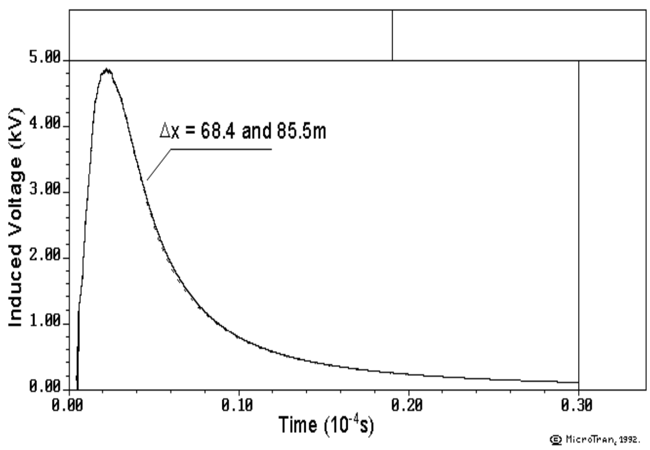

Fig.7. Discretization of the line Flash nº 9305

IV. CONCLUSIONS

The effects of various parameters on the value of induced voltages were evaluated. It is interesting to observe that these results show that the maximum difference for the value obtained from measurements is below 10%. These results indicate that the EMTP-RUSCK implementation is a powerful method to obtain the values of lightning induced voltage on lines.

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