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LINE SURGE ARRESTERS ENERGY DUTY CONSIDERATIONS

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SUMMARY

This Paper presents Line Surge Arrester [LSA] energy duty considerations. Shielded and unshielded lines are considered. LSA current shapes are computed and presented for both line designs. Energy duties for the first and for the subsequent strokes are presented.

There is a big difference in the energy duties for the LSA installed on the shielded and on the unshielded lines. LSA installed on the unshielded line are much more stressed than LSA on the shielded line.

Statistical distribution of LSA currents is computed and presented in the form of the cumulative frequency distributions. Sigma slp software is used for the all simulations. LSA current distributions are presented for the different tower footing resistance values and for the different line designs.

Several single stroke case studies are also performed in order to present different LSA current shapes. It is indicated that single stroke hitting transmission line usually produce operation of more than one LSA.

KEYWORDS

Line lightning performance, Line surge arrester, Tower footing resistance, Shielded line, Unshielded line

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1. INTRODUCTION

The use of line surge arresters for the quality of service improvement has increased over the last decade [1], [2], [3], [4]. Line surge arresters (LSA) are mainly used for the transmission line lightning performance improvement and for the reduction of double circuit outages on double circuit lines [5]. Many line surge arresters are in service today and substantial service experience has been accumulated.

In the selection of the line surge arrester (LSA) for the line lightning performance improvement it is very important to determine arrester energy duty. LSA energy duty depends on many factors, like: line design, lightning data in the region where line will be operating, tower footing resistance, LSA installation configuration, LSA design, …

LSA are differently stressed on the shielded and on the unshielded line. In the case of the shielded line a large fraction of the lightning stroke current will be diverted to the ground through the shield wires and transmission line towers. In the case of the unshielded line, the majority of the lightning strokes will terminate on the phase conductors. When lightning stroke hits directly phase conductors, all energy related to the particular stroke has to be discharged by LSA.

In this paper LSA energy duties for the shielded and for the unshielded lines are considered. LSA current shapes are presented for these two line designs.

Statistical distribution of LSA current peaks is computed by the use of sigma slp software. The corresponding distributions are presented for the shielded and for the unshielded lines.

2. LINE SURGE ARRESTER CURRENT SHAPES

LSA energy duty is mainly related to the lightning stroke parameters (peak, shape, polarity, multiplicity), LSA installation configuration, line design (shielded or unshielded), tower footing resistance and stroke location.

When lightning stroke hits shield wire or tower top (in the case of the shielded line) lightning stroke current is diverted along shield wires, tower construction and tower footing resistance. When LSA are installed on the shielded line then only a fraction of the lightning stroke current is flowing through LSA. In addition, LSA current tail time is shorten than original lightning stroke tail time (duration of LSA current surge is shorter than the duration of the original lightning stroke).

Situation is completely different in the case of the unshielded lines equipped with the LSA. When lightning stroke hits directly the phase conductor the energy related to the lightning stroke has to be discharged through the line surge arresters installed on the stricken phase conductor. The most stressed are the LSA, which are close to the place where lightning terminates. In general, LSA installed on the unshielded lines are much more stressed than arresters on the shielded lines. LSA currents on the unshielded lines have higher currents peaks and the longer durations.

When the lightning stroke hits phase conductor in the case of the shielded line (shielding failure), duration of the LSA current is similar to the duration of the LSA currents in the case of the unshielded lines, but current peaks are lower (shielding failures happen for the low amplitude lightning strokes).

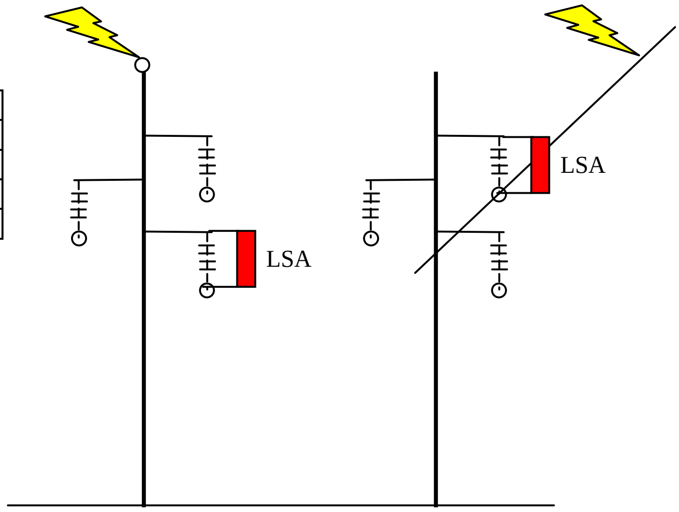
In order to compare LSA current shape for different line design (shielded and unshielded) 123 kV lines are considered. Line general data is given in Figure 1 (unshielded line has only three conductors - no shield wire - conductor No 4).

Line insulation critical flashover voltage for both lines is 550 kV. IEC Class II polymer housed line surge arresters are used. LSA rated voltage is 108 kV. In the case of the shielded line LSA were installed on the bottom phase conductor, while for the unshielded line LSA were installed on the top phase conductor.

Shielded line conductor data:

Cond No	x (m)	y(m)	r (mm)	Sag(m)
1	2,5	22,7	8,54	8,6
2	-3	20,5	8,54	8,6
3	3,5	18,3	8,54	8,6
4	0	28,9	4,5	7,6

Tower height:	28,9 m
Tower surge impedance:	184,7 Ω
Line span:	305 m
Tower footing resistance:	40 Ω
Soil resistivity:	1200 Ωm



a) Shielded line b)Unshielded line

Figure 1 - Shielded and unshielded 123 kV lines

In order to compare LSA current shapes, two lightning strokes are considered in the study:

a) Lightning stroke, which has median parameters from the first stroke distributions for negative downwards flashes [7]
b) Lightning stroke, which has median parameters from the subsequent stroke distributions for negative downwards flashes [7]

Stroke parameters are presented in Table 1.

Table 1 - Parameters of the strokes used in the study

	I_0 (kA)	t_f (μs)	t_t (μs)
First Stroke	31,1	3,83	77,5
Subsequent stroke	12,3	0,67	30,2

I_0 - Stroke peak (kA)
t_f - Stroke front time (μs)
t_t - Stroke tail time (μs)

In the case of the shielded lines lightning strokes are applied to the tower top, while for the unshielded line strokes are injected to the middle of the span (top phase conductor) - Figure 1.

Line surge arrester current shapes for the shielded line are presented in Figure 2. From this Figure we can see that the arrester current peaks are not so high, compared to the peaks of the original lightning strokes (more that ten times lower compared to the original lightning strokes).

It is also important to note that the durations of the arrester currents are much shorter than the durations of the original lightning strokes (almost four times shorter than the original lightning stroke).

The associated energy duties of LSA for this studied case are given in Table 2 (7,7 kJ and 0,6 kJ respectively). The energy capability of the considered LSA is 450 kJ.

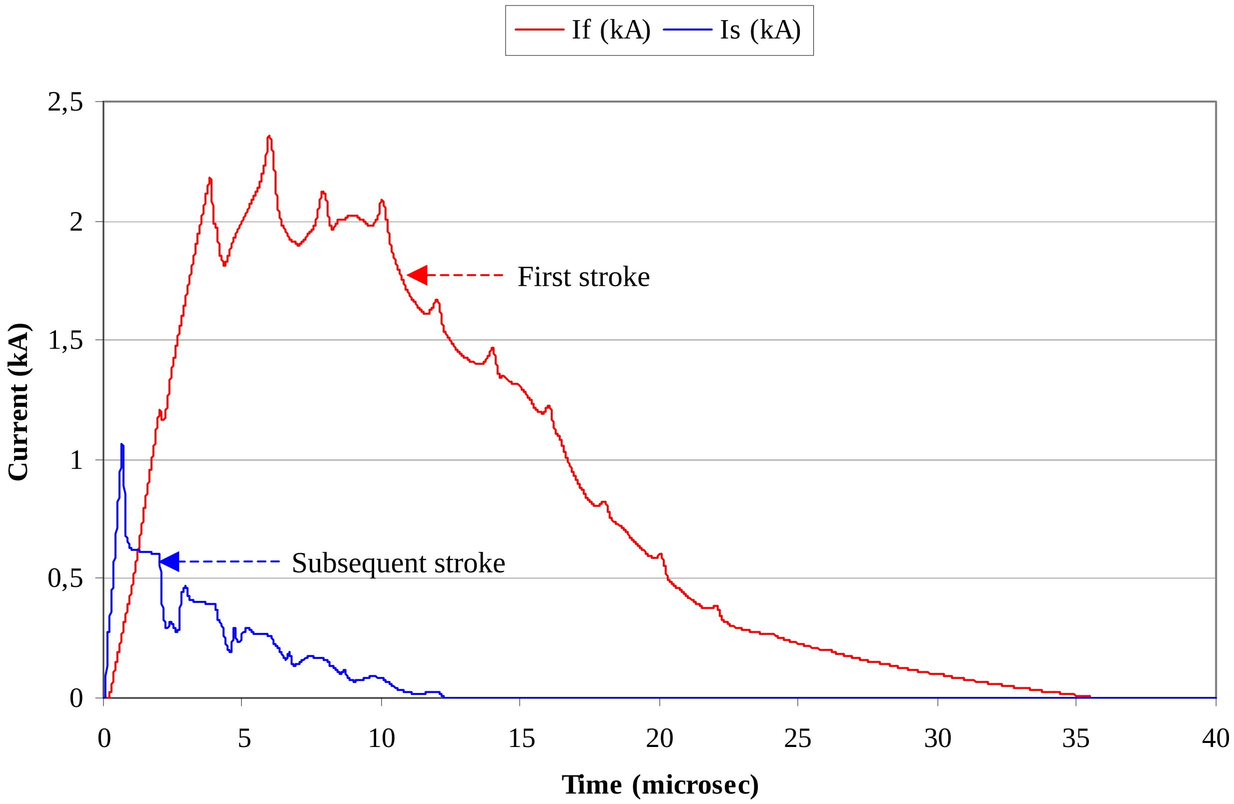


Figure 2 - Shielded line: Arrester current for the first and for the subsequent stroke

Line surge arresters current shapes for the unshielded line are presented in Figure 3. From the presented results we can see that surge arrester current peaks are much higher than in the case of the shielded line (for the same original lightning strokes).

Table 2 - Arrester energies W (kJ)

	Shielded line W (kJ)	Unshielded line W (kJ)
First Stroke	7,5	83,2
Subsequent stroke	0,6	15,8

The duration of the arrester currents is also much longer than for the shielded line case (being very close to the durations of the original lightning strokes).

The corresponding arrester energy duties are 83,2 kJ for the first stroke and 15,8 kJ for the subsequent stroke (Table 2). These values are much higher than in the case of the shielded line.

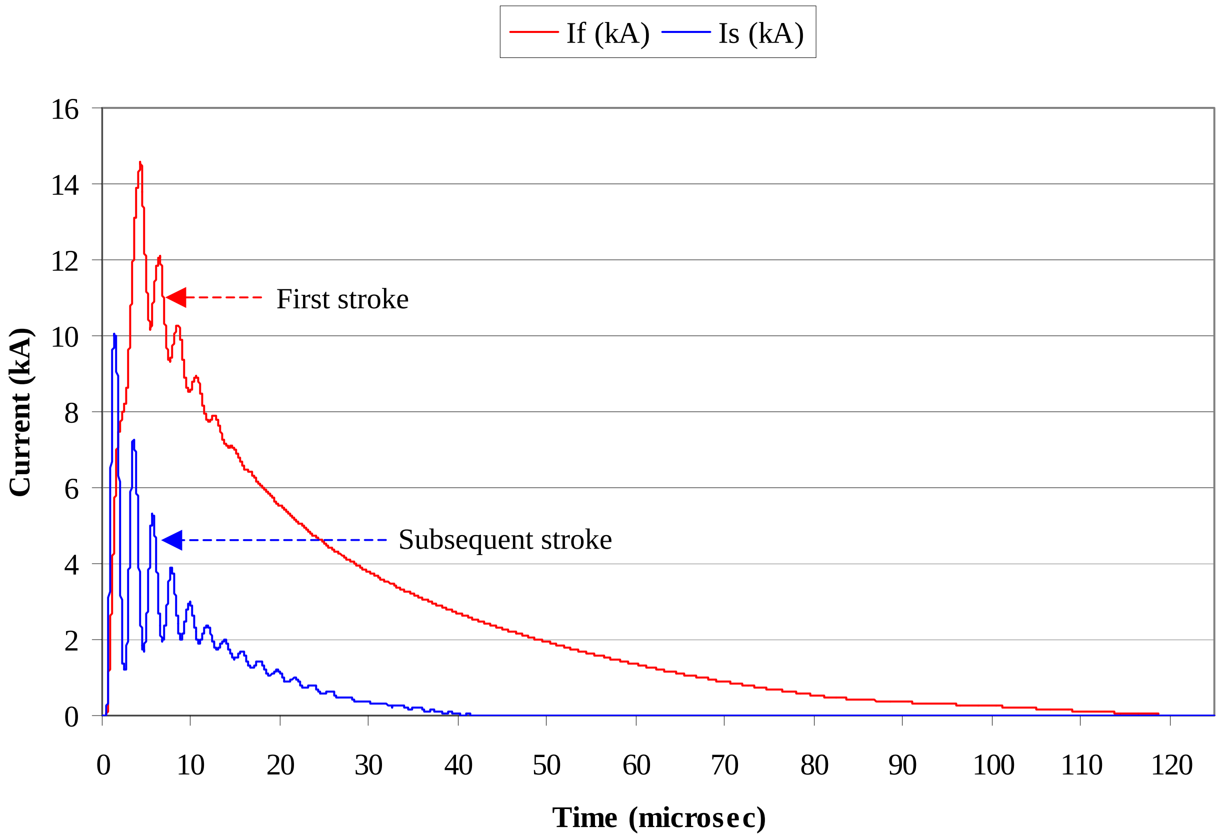


Figure 3 - Unshielded line: Arrester current for the first and for the subsequent stroke

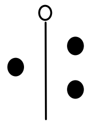
3. STATISTICAL STUDY OF LINE SURGE ARRESTER CURRENTS: SHIELDED LINE

Statistical distributions of LSA current peaks are computed using sigma slp software. Shielded line design corresponds to the previously presented line. Tower footing resistance was varied from 10 Ω to 100 Ω. For each studied case the total number of 1000 statistical simulations is performed. Two lines CIGRE stroke distribution, modified for the flat ground, is used.

For each statistical case the highest LSA current peak is extracted. The cumulative frequency distributions of the highest LSA current peaks are presented in the following tables:

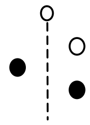
Table 3: All three phase conductors LSA installation configurations [LSA 1,2,3]
Table 4: Middle and bottom phase conductors LSA installation configurations [LSA 2,3]
Table 5: Bottom phase conductor LSA installation configurations [LSA 3]

Table 3 - Shielded line: Cumulative frequency distributions of LSA Currents
Arrester configuration LSA 1,2,3 [All three phase conductors]



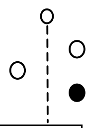
	LSA Current cumulative frequency distributions (%)					
R_T (Ω)	$I_{1\%}$ (kA)	$I_{2\%}$ (kA)	$I_{5\%}$ (kA)	$I_{10\%}$ (kA)	$I_{25\%}$ (kA)	$I_{50\%}$ (kA)
10	3,36	2,75	1,62	1,10	0,61	0,29
20	6,65	4,88	2,78	2,00	0,95	0,49
30	8,91	6,86	3,83	2,84	1,33	0,65
40	10,93	8,21	4,66	3,45	1,71	0,80
50	11,52	9,22	5,38	3,99	2,05	0,92
60	12,33	9,94	6,06	4,43	2,35	1,05
70	12,97	10,51	6,53	4,80	2,57	1,65
80	13,49	10,97	6,89	5,08	2,74	1,26
90	13,92	11,34	7,17	5,29	2,92	1,34
100	14,29	11,68	7,39	5,51	3,07	1,45

Table 4 - Shielded line: Cumulative frequency distributions of LSA Currents
Arrester configuration LSA 2,3 [Middle and bottom conductor LSA installation]



	LSA Current cumulative frequency distributions (%)					
R_T (Ω)	$I_{1\%}$ (kA)	$I_{2\%}$ (kA)	$I_{5\%}$ (kA)	$I_{10\%}$ (kA)	$I_{25\%}$ (kA)	$I_{50\%}$ (kA)
10	3,89	3,04	1,82	1,23	0,66	0,31
20	7,75	5,43	3,41	2,37	1,08	0,55
30	9,61	7,55	4,51	3,32	1,57	0,75
40	10,91	8,61	5,35	4,05	2,01	0,93
50	11,64	9,48	6,02	4,58	2,44	1,12
60	12,17	10,33	6,63	4,97	2,74	1,28
70	12,66	10,86	7,10	5,35	3,00	1,41
80	13,13	11,08	7,53	5,66	3,15	1,54
90	13,50	11,28	7,86	5,75	3,31	1,63
100	13,86	11,48	7,96	6,00	3,47	1,73

Table 5 - Shielded line: Cumulative frequency distributions of LSA Currents
Arrester configuration LSA 3 [Bottom conductor LSA installation]



	LSA Current cumulative frequency distributions (%)					
R_T (Ω)	$I_{1\%}$ (kA)	$I_{2\%}$ (kA)	$I_{5\%}$ (kA)	$I_{10\%}$ (kA)	$I_{25\%}$ (kA)	$I_{50\%}$ (kA)
10	4,53	3,65	2,10	1,36	0,70	0,34
20	8,16	6,69	4,00	2,80	1,26	0,62
30	10,12	8,20	5,21	3,92	1,95	0,88
40	10,81	9,51	6,40	4,65	2,56	1,15
50	11,59	10,04	6,90	5,14	2,98	1,43
60	11,91	10,08	7,56	5,77	3,25	1,63
70	12,61	10,16	7,95	6,08	3,48	1,77
80	13,14	10,37	8,23	6,59	3,71	1,93
90	13,80	10,82	8,51	6,69	3,85	2,05
100	13,75	11,22	8,68	6,89	4,04	2,21

It is important to note that for the less than all phase conductors LSA installation configurations [for LSA 2,3 and LSA 3] and for the high values of the tower footing resistance insulation flashovers happen on the conductors without LSA.

If we take 2% values for the comparison purposes then we can conclude:

The maximum 2 % LSA current peaks are lower than 12 kA [for all studied LSA installation configurations and for the different tower footing resistances].

2 % LSA current peaks increase with the increase of the tower footing resistance.

For the lower values of the tower footing resistance, there are no insulation flashovers and LSA currents are lower for more LSA installed [stroke current is better shared through more LSA installed on the same towers].

Each lightning stroke hitting the line usually produces the operation of several LSA. As indicated before for each lightning stroke hitting the line the maximum LSA current for all installed LSA is extracted. In Figures 4 and 5 LSA current shapes are presented for the stroke hitting tower top and the stroke hitting the phase conductor [shielding failure].

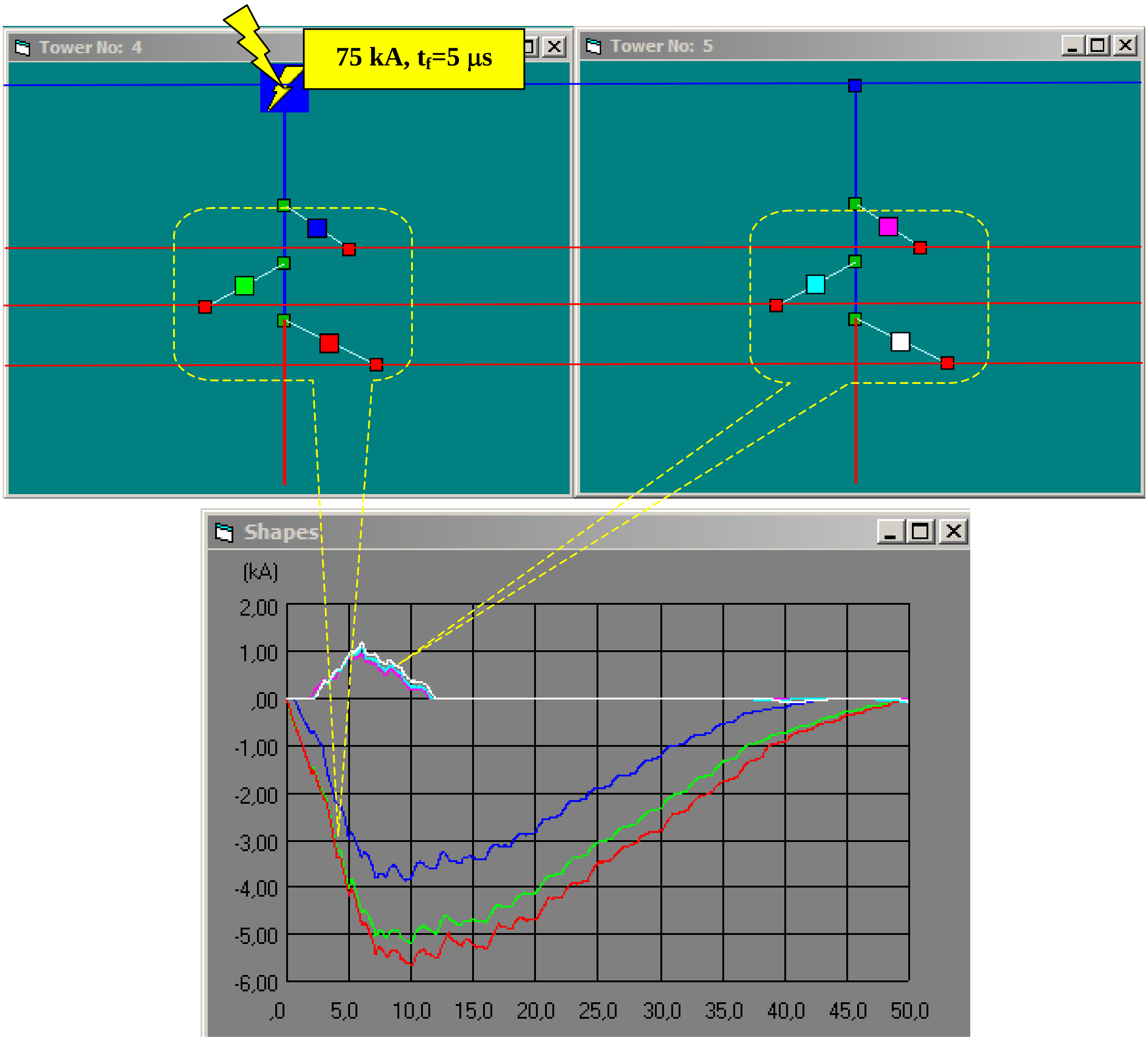


Figure 4 - LSA current shapes: Shielded line > Stroke to the tower top
Stroke current peak 75 kA and stroke front time of 5 µs
Tower footing resistance 30 Ω

In Figure 4 lightning stroke having current peak of 75 kA, front time 5 µs and tail time of 75 µs hits tower top of the shielded line. Tower footing resistance is 30 Ω [soil resisitivity 900 Ωm].

This stroke produces operation of the LSA on the struck tower but also operation of the LSA on the neighbouring towers.

From the presented shapes we can see that LSA currents tail times is around 25 µs.

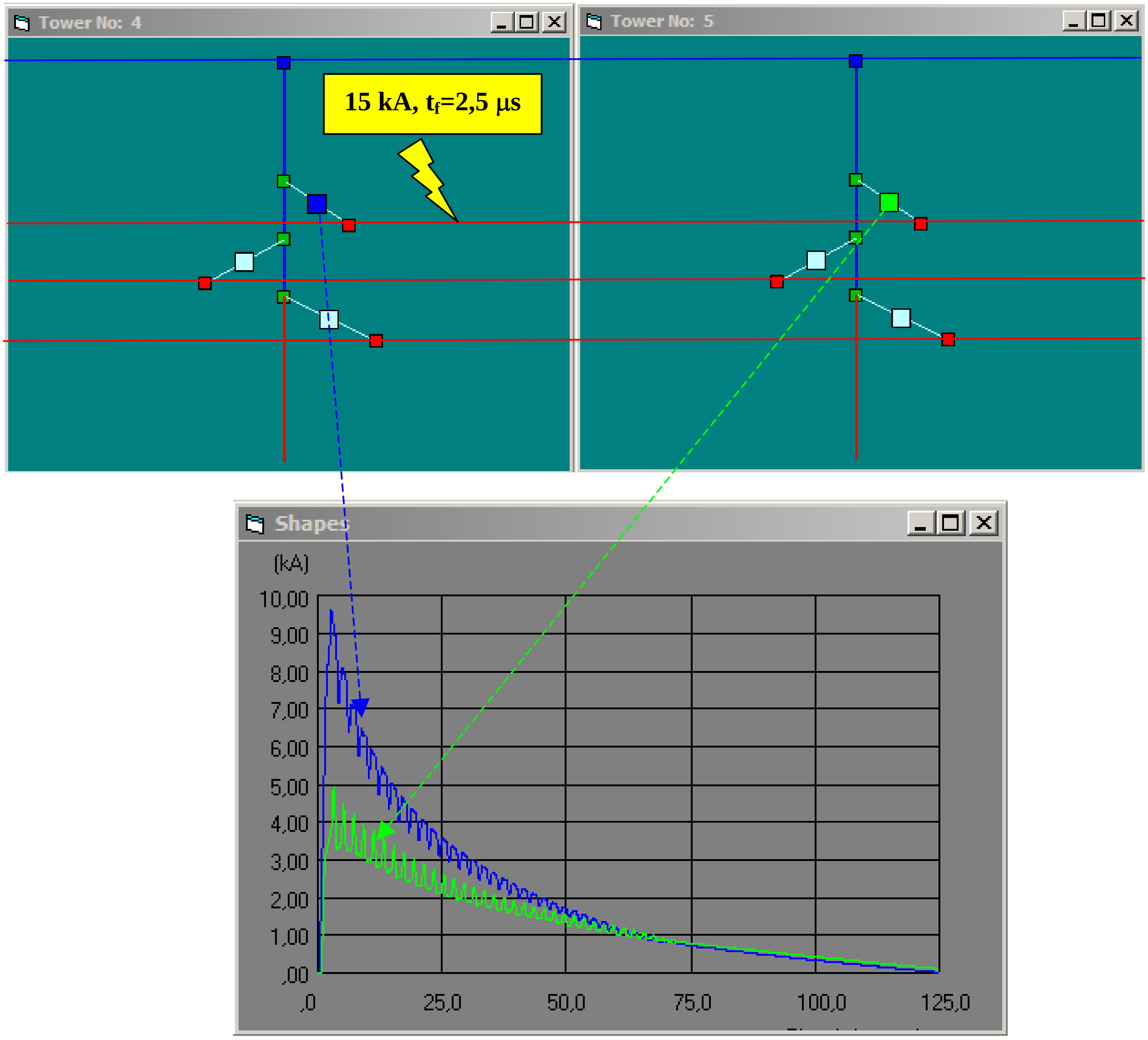


Figure 5 - LSA current shapes: Shielded line > Stroke to the top phase conductor
Stroke to the 1/4 of the span length
Stroke current peak 15 kA and stroke front time of 2,5 μs
Tower footing resistance 30 Ω

4. STATISTICAL STUDY OF LINE SURGE ARRESTER CURRENTS: UNSHIELDED LINE

The unshielded line used for the simulations is the same as that one used before but with the removed shield wire. LSA surge arresters are installed on the top and on the middle phase conductors.

Tower footing resistance was varied from 10 Ω to 100 Ω. For each studied case the total number of 1000 statistical simulations is performed. Two lines CIGRE stroke distribution, modified for the flat ground, is used.

For each statistical case the highest LSA current peak is extracted. The cumulative frequency distributions of the highest LSA current peaks are presented in Table 6.

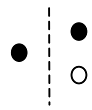


Table 6 - Unshielded line: Cumulative frequency distributions of LSA Currents
Arrester configuration LSA 2, 3 [Top and middle conductor LSA installation]

	LSA Current cumulative frequency distributions (%)					
$R_T(\Omega)$	$I_{1\%}$ (kA)	$I_{2\%}$ (kA)	$I_{5\%}$ (kA)	$I_{10\%}$ (kA)	$I_{25\%}$ (kA)	$I_{50\%}$ (kA)
10	48,94	39,08	31,84	24,11	13,93	3,83
20	47,36	38,15	31,16	23,61	13,86	5,46
30	46,23	37,29	30,07	23,23	13,92	6,34
40	45,41	36,66	30,02	22,95	13,90	6,93
50	45,86	36,15	29,44	22,66	13,83	7,20
60	45,38	36,02	29,10	22,41	13,79	7,44
70	45,02	36,32	29,45	22,19	13,79	7,56
80	44,73	36,05	28,95	21,99	13,72	7,66
90	44,49	36,08	29,14	21,88	13,67	7,75
100	43,98	35,76	29,57	21,87	13,60	7,80

From the presented results we can see that 2 % LSA maximum currents might be close to 40 kA. LSA currents are slightly reduced with the increase of the tower footing increase because:

- With the increase of the tower footing resistance less current is flowing through the tower footing resistance and more current has to be diverted through LSA.
- For the high values of the tower footing resistance insulation flashovers may happen on the bottom conductor [reducing current through the LSA].

In Figures 6 and 7 LSA current shapes are presented for the stroke hitting the phase conductor and tower top.

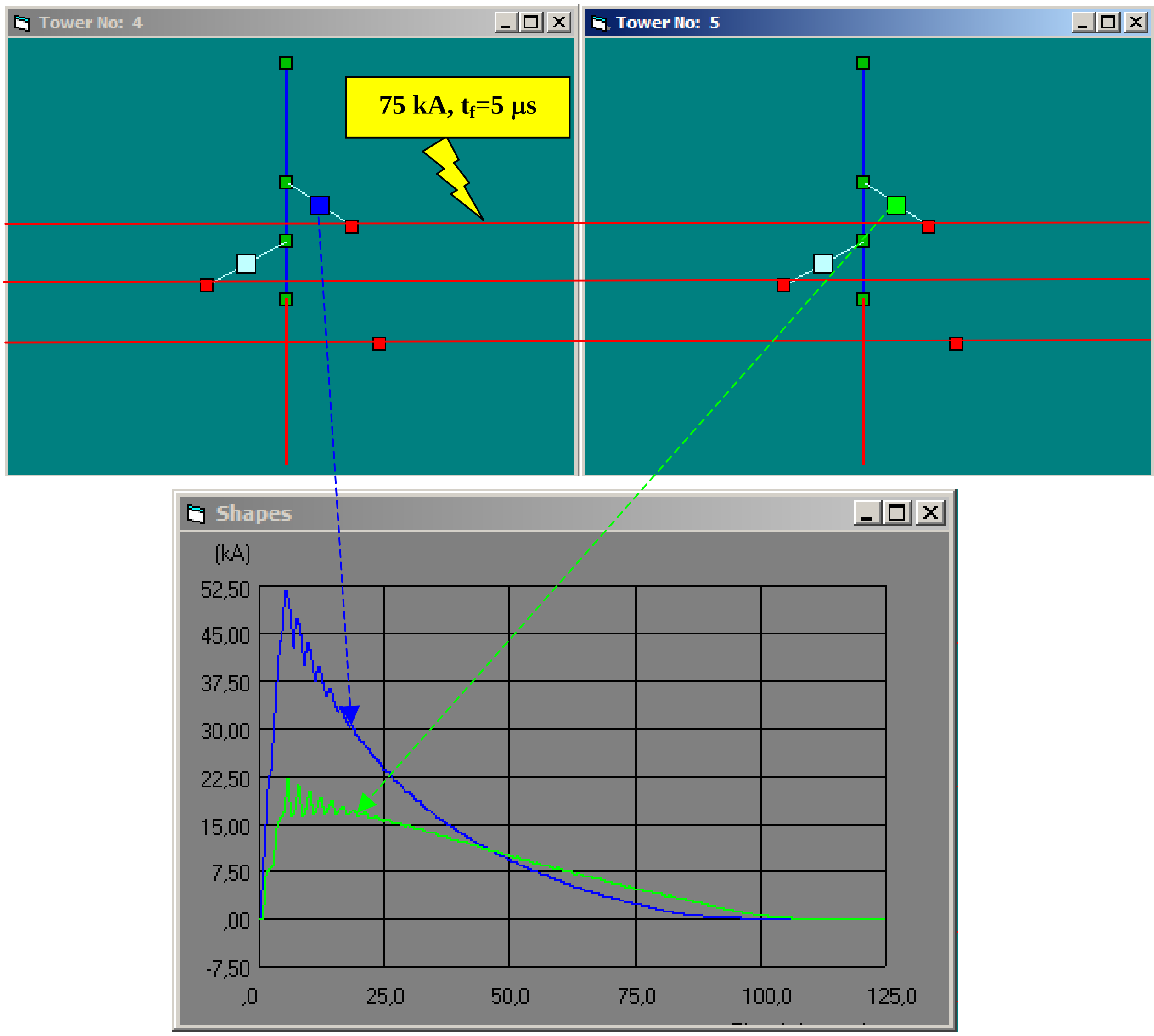


Figure 6 - LSA current shapes: Unshielded line > Stroke to the top phase conductor
Stroke to the 1/4 of the span length
Stroke current peak 75 kA and stroke front time of 5 μs
Tower footing resistance 30 Ω

In Figure 6 lightning stroke having current peak of 75 kA, front time 5 μs and tail time of 75 μs hits top phase conductor. Tower footing resistance is 30 Ω [soil resisitivity 900 Ωm]. Stroke distance is one quarter of the span length. LSA current shapes for the top LSA are presented.

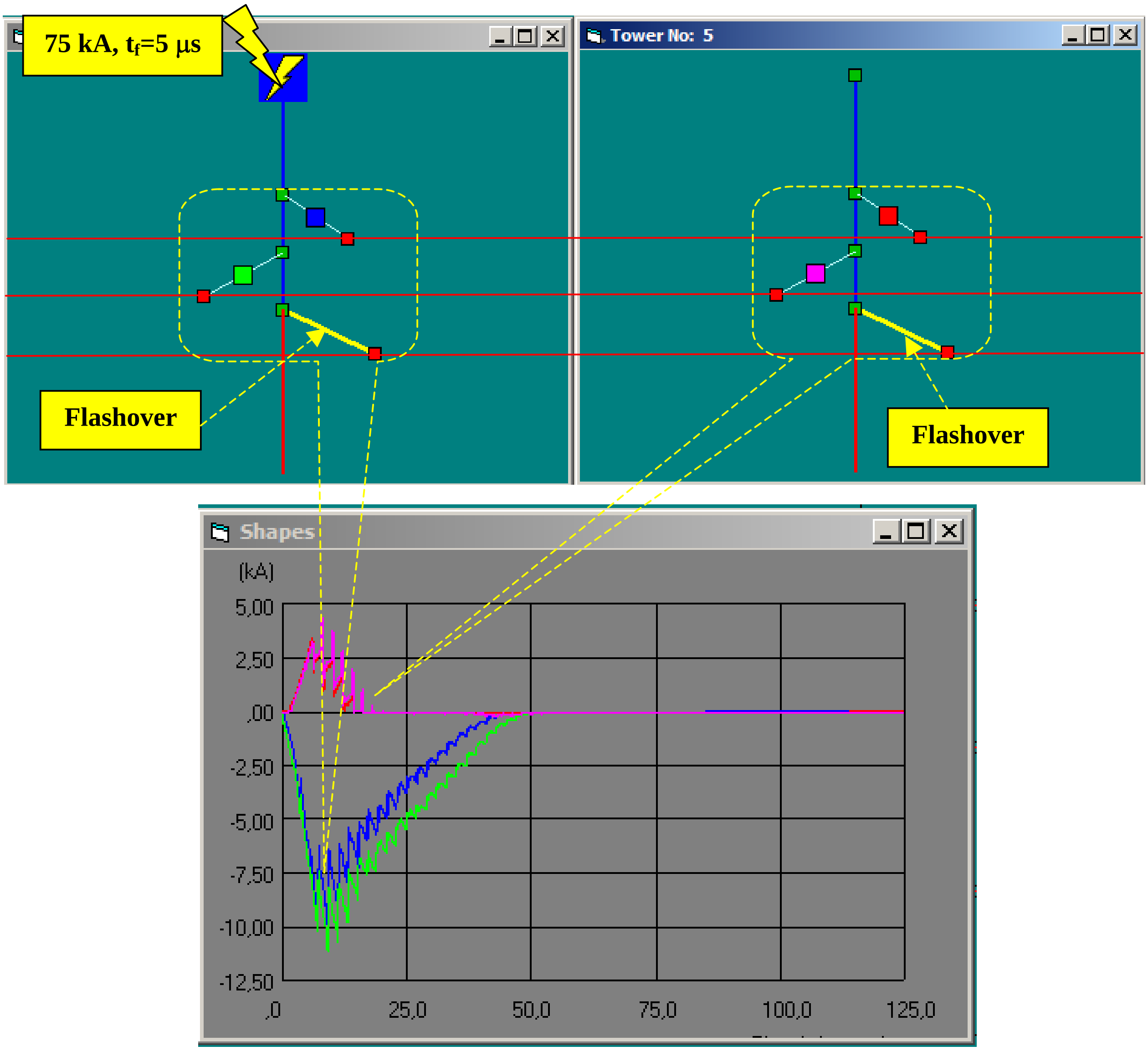


Figure 7 - LSA current shapes: Unshielded line > Stroke to the tower top
Flashover on the bottom conductor insulator
Stroke current peak 75 kA and stroke front time of 5 μs
Tower footing resistance 30 Ω

In Figure 6 lightning stroke having current peak of 75 kA, front time 5 μs and tail time of 75 μs hits tower top of the unshielded line. Tower footing resistance is 30 Ω [soil resisitivity 900 Ωm].

This lightning stroke produces also flashover on the bottom conductor of the struck tower and also flashover on the neighbouring tower.

LSA current shapes on the struck and on the neighbouring tower are presented.

5. CONCLUSIONS

1. In the design and the selection of the Line Surge Arresters, it is very important to know the shapes of the current flowing through the arresters.
2. Line Surge Arresters installed on the shielded and on the unshielded line are differently stressed. LSA on the unshielded line are more stressed than arrester on the shielded line. The main reason for this is in the difference in the arresters current shapes.
3. The shapes of the surge arrester current can be determined by the software simulations and by the field measurement.
4. Lightning stroke hitting transmission line usually produces operation of several line surge arresters.
5. In addition to the line design [shielded or unshielded] line surge arrester installation configuration and tower footing resistance influence arrester energy duty.

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