A STUDY OF LINE ARRESTERS APPLICATION ON HV TRANSMISSION LINES LOCATED IN HIGH RESISTIVITY SOIL AND HIGHLY EXPOSED TO LIGHTNING

Júnio C. C. Viana[1] and Ivan J. S. Lopes[2*]
[1]Dalben Consultoria,
[2]Universidade Federal de Minas Gerais,
Belo Horizonte, MG - BRAZIL
*Email: ivanlopes@ufmg.br

Abstract: The paper investigates the energy capability of ZnO line arresters installed along transmission lines for lightning performance improvement purposes. The electromagnetic transient simulations are performed using PSCAD. A 230kV line case study is presented comparing the arresters energy levels when arresters are installed in every tower and when they are installed only in a few selected towers. A cost-benefit analysis is performed and the results show that, for lightning strikes to towers (back-flashover outages), when arresters are installed in every tower, their energy capability has to be higher than when they are installed in selected towers. The use of a smaller number of line arresters with lower energy capability allows a reduction in the overall cost of the system at an acceptable lightning performance level. The study shows that, for lines where some lightning related outages is acceptable, the installation of line arresters in a few selected structures is a good solution from both technical and economical points of view.

1 INTRODUCTION

Lightning related outages of transmission lines are responsible for approximately 65% of all transmission line outages in Brazil [1-3]. The search for more beneficial solutions for such a problem is mandatory especially on the light of the new standards and regulations to increase the overall power system reliability level.

To fight the lightning performance problem, it is well known that the application of ZnO line arresters is a good solution [4-9]. However, there is a lack of conclusive studies on the energy capability of these arresters, mainly when installed in highly exposed lines where, generally, the soil has high resistivity levels. The reported line arresters field performance has been very good [1, 2, 4-6], and in many cases their installation is the only solution left. However, the more the arresters installation is needed, the more stressed they are, and their energy levels increases as well. Therefore, a better understanding of line arresters behavior in this situation is needed considering that they are tested for specific and well defined voltage and current waveshapes [10].

In this paper, the line arrester energy level is investigated. The system modeling is discussed, taking into account its different parts such as tower sketch and span, grounding resistance and shield wires, as well as the lightning magnitude and striking point. In the second part, the results of a 230kV line case study in which the lightning performance and the energy capability of the arresters is evaluated on the light of two different scenarios.

2 SYSTEM MODELING

The system under study is presented in Fig. 1. Lightning current injection points are the tower or the shield wire at mid-span. The system was modeled, and PSCAD [11] was used for the simulations. Figure 2 shows a schematic representation of the system at PSCAD. The transmission line model proposed by Cigre and used in literature [12, 13] was used. It consists of several non-transposed sections of three-phase transmission lines with frequency dependent parameters. The number of spans was adjusted to be long enough to have no influence on the results. Five adjacent towers on each side of the striking point were considered in the simulations.

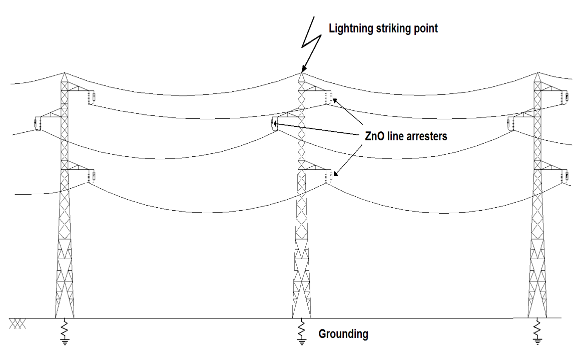

Figure 1: Elements of the system to be modeled

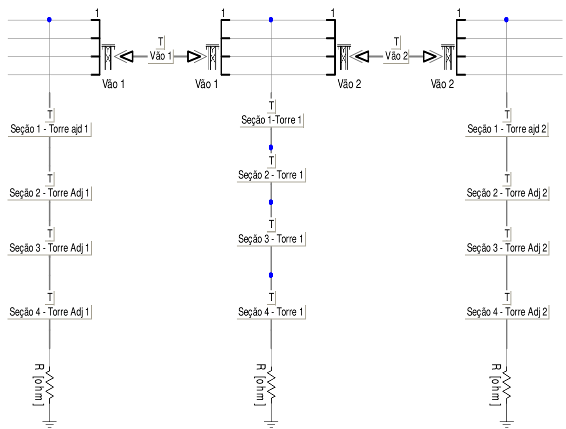

Figure 2: Schematic representation in PSCAD of the transmission line model (one adjacent tower in each side).

For the towers, a single-phase transmission line model, also available in PSCAD, was used [14,15]. The model, proposed by Bergeron, has been used by other authors in similar studies [12, 14]. The tower surge impedance and travel time were calculated accordingly for each case under study [16]. The tower grounding system was modeled as a constant resistance and the soil ionization effect was neglected. Figure 3 shows a schematic representation of tower representation at PSCAD.

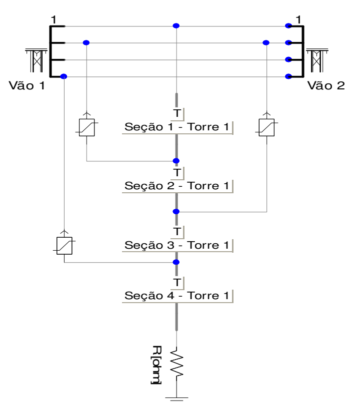

Figure 3: Schematic representation in PSCAD of the tower, grounding and arrester model.

For the arresters, the model available in PSCAD was used. The input data for the model is the arrester rated voltage and its "*VxI"* curve. This model is based on Pinceti and is derived from a model recommended by IEEE [17]. The energy on the arrester was calculated by using a meter available in PSCAD that integrates the product between the voltage and the current on the element over a period of time. Finally, the insulator strings were not considered as they have little influence on the results according to other authors [12-14, 18, 19].

The lightning current waveform was considered triangular with front time varying from 1.0 to 2.0µs and fall time 50 µs. The 60Hz system voltage was not taken into account.

For validation purposes, the results obtained with the presented model were compared with other results available in the literature, and thorough sensitivity analysis of the model was performed. More details on the model validation are presented in [20].

3 CASE STUDY

Two complementary studies about the same system were performed: in the first study, the lightning performance of a transmission line was evaluated using IEEE Flash software [16]. The line performance improvement was then considered. In the second part, the model presented in Section 2 was used to evaluate the energy capability of the arresters. The basis for the simulations was the lightning performance study of the first part. Two different situations were considered for the arresters energy evaluation: case 1 – line arresters installed in every tower; case 2 – line arresters installed only in selected towers.

The system considered for the case study was a 230kV, 89 km long transmission line, single circuit with one conductor per phase. A total of 171 towers, average height 22.5m, were considered. A typical tower sketch is shown in Fig. 4. The average span along the line was 523m and the ground flash density was considered 8.1disc./km^2.year

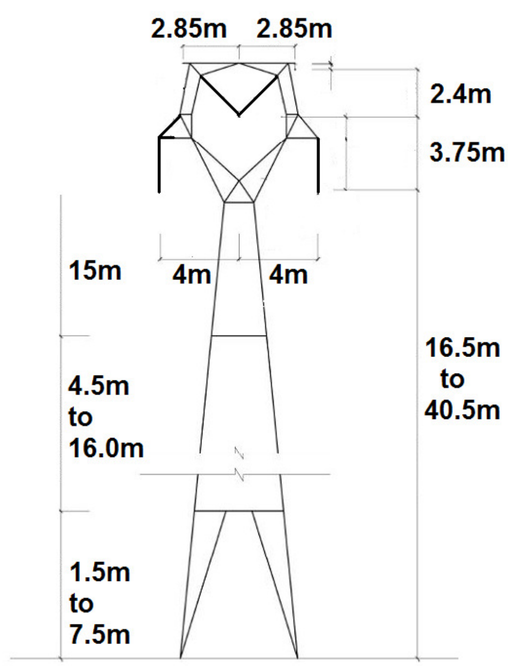

Figure 4: Typical tower sketch

For lightning performance evaluation purposes, the line was divided into 3 sections of approximately 27km with 57 towers in each section. Figures 5 to 7 show the distribution of towers footing resistance along each line section.

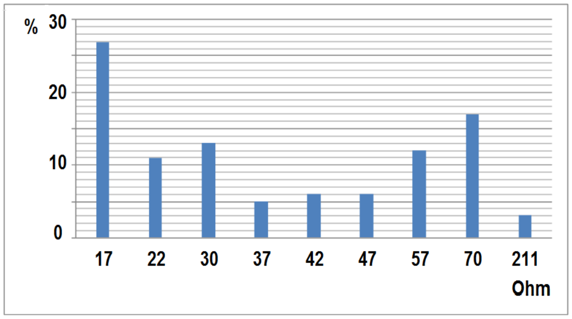

Figure 5: Distribution of tower footing resistance along section 1.

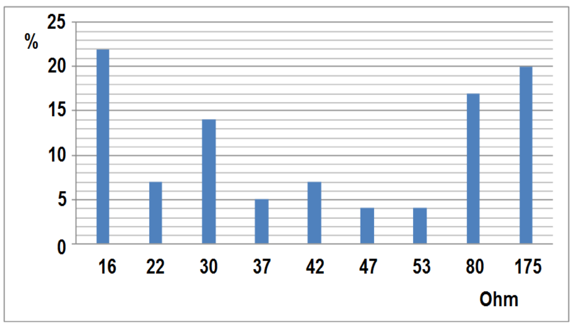

Figure 6: Distribution of tower footing resistance along section 2.

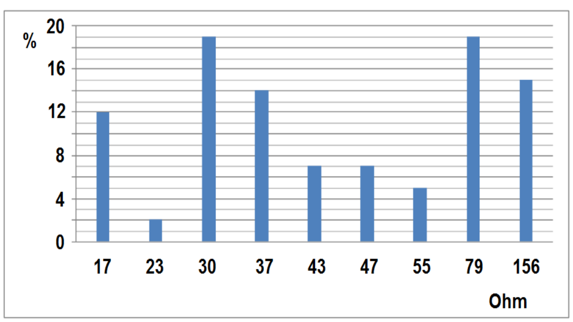

Figure 7: Distribution of tower footing resistance along section 3.

3.1 Lightning performance estimation

Using IEEE Flash (Version 1.81), the line lightning performance was evaluated. The results showed that the line is effectively shielded; that is, all the line outages will be due to back-flashovers only. Table 1 shows the outages expected for each section.

Table 1: Back-flashover outages for each line Section before arresters installation

Line Section	Ng (disc./km^2.ano)	Outages/100km.year
1	8.1	7.12
2		12.56
3		11.41
Average:		10.3

As seen, with the presented footing resistance distribution and without arresters, the line is expected to present a poor lightning performance. To improve the performance to a target of 2 outages per 100km per year, which is a maximum accepted number of outages for this voltage level, line arresters installation should were considered.

The lightning performance, considering the arresters installation, was evaluated, with Flash, by replacing the footing resistance of the towers where the arresters would be installed by a low resistance (R = 0,01 Ω) since, from the performance point of view, such a low ohmic value, as well as the line arrester installed, eliminates the back-flashover outage in such a tower.

Starting with the highest footing resistance towers (R > 100 Ω), the target of 2 outages per 100km per year was achieved by considering the installation of arresters in every tower where the footing resistance was greater than 50 Ω for Sections 1 and 2, and greater than 45 Ω in Section 3. Doing so, a total of 76 towers altogether will have arresters installed in each phase. The new performance estimation for the 3 sections is shown in Table 2. As seen, the arresters installation in the selected 76 towers will reduce the line outage rates by 70 %, 85% e 82% for Sections 1, 2 and, 3 respectively. Considering the overall lightning performance, a 78% reduction in the outages is expected.

Table 2: Back-flashover outages for each line Section after arresters installation

Line Section	Ng (disc./km^{2}.year)	Outages/100km.year
1	8.1	2.17
2		1.94
3		2.11
Average:		2.07

The lightning performance evaluation has shown that, for line under study, it is possible to reduce the outages from 10.3 to 2.07 by installing line arresters in 76 towers (19 arresters in Section 1, 25 in Section 2 and 32 in Section 3). Therefore, the results show that, it is possible to improve, to a reasonable level, the lightning performance of the a transmission line even when line arresters are installed in a few selected towers.

Table 3: Towers selected for arresters installation

Towers at which arresters installation (3 phases) is recommended				
Section 1	Section 2		Section 3	
3	60	100	115	146
9	61	105	116	153
17	62	106	117	155
19	66	107	119	156
23	67	108	121	157
24	68	112	123	158
25	69	-	124	159
27	70	-	126	160
28	71	-	127	161
29	72	-	128	163
30	75	-	132	165
36	76	-	134	166
38	79	-	136	167
39	88	-	137	-
40	89	-	139	-
42	90	-	140	-
43	93	-	141	-
44	96	-	144	-
45	98	-	145	-

3.2 Arresters energy calculation

From the lightning performance study, the arresters energy capability was evaluated considering a lightning discharge striking the tower top in 2 different scenarios: case 1 – line arresters installed in all phases of the 171 towers; case 2 – line arresters installed in all phases of the selected 76 towers discussed in the previous section.

For the PSCAD simulations, a lightning discharge 200kA peak value, 2.0x50µs striking the tower top was considered in every tower along the line. In each case, 3 subsequent strikes with 40% of the peak value of the first strike were considered.

The tower surge impedance was calculated and its value was Zt = 202,6 Ω. The line arresters characteristics were taken from a manufacturer website [38]: rated voltage (Vn) = 192kV, energy capability = 5,1kJ/kV; Rated current (In) = 10kA. Considering the arrester rated voltage, its maximum energy capability is 979kJ.

Tables 4 and 5 show the maximum energy capability in calculated at each arrester for both cases. Figures 8, 9 and 10, compares the maximum energy capability at the 76 towers for cases 1 and 2.

Table 4: Energy capability of each arrester installed along the line (Case 1):

Tower #	R (Ω)	E (kJ)	Tower #	R (Ω)	E (kJ)	Tower #	R (Ω)	E (kJ)
1	18	73.59	39	129	293.65	77	27	146.62
2	16	44.31	40	57	218.05	78	16	65.17
3	70	217.86	41	42	163.07	79	96	205.22
4	45	192.52	42	83	255.27	80	42	166.84
5	35	153.50	43	74	265.61	81	16	50.00
6	37	152.91	44	64	255.51	82	37	150.66
7	30	123.71	45	103	259.01	83	42	172.90
8	22	87.90	46	16	38.87	84	32	134.45
9	84	233.15	47	18	55.06	85	28	110.40
10	21	66.57	48	33	135.95	86	45	145.65
11	21	97.96	49	29	125.77	87	29	110.31
12	19	88.23	50	32	136.23	88	205	334.26
13	17	46.37	51	23	92.05	89	125	335.43
14	17	53.57	52	19	64.26	90	73	265.50
15	17	55.61	53	20	67.56	91	42	139.48
16	48	188.90	54	18	53.27	92	22	78.88
17	54	214.67	55	17	68.50	93	57	194.90
18	41	185.65	56	15	58.65	94	34	148.86
19	66	220.32	57	36	126.75	95	37	165.30
20	27	108.44	58	34	132.55	96	73	221.14
21	38	123.43	59	23	90.38	97	16	47.21
22	24	119.82	60	56	220.57	98	83	224.83
23	70	235.57	61	87	303.93	99	24	130.31
24	70	257.93	62	294	357.22	100	219	287.65
25	86	247.31	63	46	191.92	101	21	72.83
26	22	81.95	64	16	41.67	102	15	38.50
27	71	227.69	65	39	125.63	103	24	88.45
28	71	253.16	66	93	265.88	104	11	23.56
29	62	240.90	67	68	249.55	105	441	352.01
30	58	222.0	68	74	246.12	106	157	394.77
31	40	151.17	69	53	230.68	107	195	396.59
32	24	72.95	70	118	313.41	108	119	315.54
33	26	28.53	71	118	326.67	109	23	75.42
34	20	83.38	72	110	279.23	110	16	53.31
35	26	85.81	73	18	64.10	111	21	101.06
36	50	192.54	74	20	68.62	112	72	226.60
37	49	195.90	75	54	203.42	113	49	174.16
38	53	222.40	76	52	205.98	114	34	161.30
Tower #	R (Ω)	E (kJ)	Tower #	R (Ω)	E (kJ)	Tower #	R (Ω)	E (kJ)
115	224	341.26	134	144	267.75	153	48	180.44
116	150	343.07	135	40	180.20	154	36	193.98
117	80	258.15	136	83	268.99	155	69	254.16
118	27	111.84	137	93	253.47	156	250	372.24
119	156	273.02	138	19	74.03	157	168	355.99
120	36	117.32	139	54	200.77	158	74	284.42
121	66	206.28	140	76	252.70	159	80	266.32
122	15	61.45	141	52	196.20	160	98	267.11
123	236	287.10	142	17	42.26	161	46	174.22
124	49	208.06	143	35	170.03	162	23	86.66
125	44	199.35	144	298	335.05	163	137	265.63
126	183	317.11	145	51	242.96	164	45	146.00
127	64	263.97	146	76	195.26	165	45	205.78
128	89	258.25	147	16	44.74	166	121	299.63
129	39	160.53	148	33	129.91	167	74	256.88
130	33	115.59	149	39	167.15	168	27	113.81
131	25	74.95	150	37	150.30	169	11	19.93
132	53	183.18	151	18	59.30	170	38	126.84
133	16	69.37	152	40	145.16	171	31	174.10

Table 5: Energy capability of each arrester installed along the line (Case 2):

Section 1			Section 2			Section 3		
Tower #	R (Ω)	E (kJ)	Tower #	R (Ω)	E (kJ)	Tower #	R (Ω)	E (kJ)
3	70	70.49	70	118	294.29	127	64	218.92
9	85	74.19	71	118	288.89	128	89	205.13
17	54	98.01	72	110	214.91	132	53	122.51
19	66	173.16	75	54	146.11	134	144	205.32
23	70	174.78	76	52	151.61	136	83	212.78
24	70	223.51	79	96	102.42	137	93	201.59
25	86	198.53	88	205	161.94	139	54	164.01
27	71	196.80	89	125	216.81	140	76	218.21
28	71	219.07	90	72	189.26	141	52	151.89
29	62	214.38	93	57	137.15	144	298	254.97
30	58	195.78	96	73	160.09	145	51	152.33
36	50	93.67	98	83	155.20	146	76	107.44
38	53	187.78	100	219	178.52	153	48	88.73
39	129	204.69	105	441	194.71	155	69	214.47
40	57	204.68	106	157	263.81	156	250	351.60
42	83	232.54	107	195	287.06	157	168	350.39
43	73	225.70	108	119	205.90	158	74	276.0
44	64	173.53	112	72	141.64	159	80	126.78
45	103	123.57	115	224	303.04	160	97	253.85
60	56	85.64	116	150	328.43	161	46	152.95
61	87	195.44	117	80	227.38	163	137	223.12
62	293	253.04	119	15	223.24	165	45	160.22
66	93	202.35	121	66	157.69	166	121	273.75
67	68	213.75	123	236	241.84	167	74	124.61
68	74	216.55	124	49	181.64			
69	53	205.36	126	183	269.63			

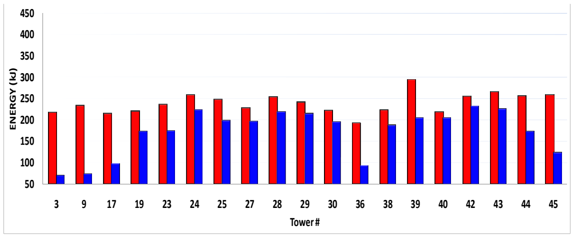

Figure 8: Arrester energy capability: case 1 (red) versus case 2 (blue) for arresters in Section 1.

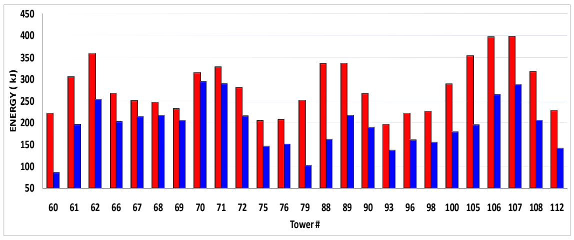

Figure 9: Arrester energy capability: case 1 (red) versus case 2 (blue) for arresters in Section 2.

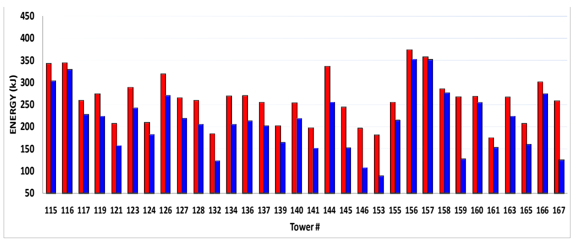

Figure 10: Arrester energy capability: case 1 (red) versus case 2 (blue) for arresters in Section 3.

As seen, in all 3 line sections, when arresters are installed in all phases of all towers (case 1), their energy capability is higher than when they are installed in selected towers (case 2). This can be explained by sucessive current wave reflections due to the arresters located in every tower. In all cases, the arrester energy capability is well below the chosen arrester maximum capability (979 kJ). For case 1, the maximum arrester capability is 397kJ at tower 107. In this case, a 2.1kJ/kV arrester would be enough. For case 2, this maximum value is 352kJ at tower 156 and corresponds to 1.8kJ/kV arrester. It is important to mention that these results are for a 200kA lightning current which is an event with very low probability of being reached. For most towers a 0.5kJ/kV arrester would be enough in most cases.

3.3 Cost-benefit analysis

In terms of the number of arresters and their costs, for case 1 a total of 513 arresters are needed, while for case 2 only 228 arresters are to be used. Therefore, only considering the number of arresters, a 56% reduction is possible. Another point to consider is the arrester energy capability. Only to illustrate, the difference between a 7.5kJ/kV arrester and a 4.5kJ/kV arrester of the same voltage is about 45%. The use of a small number of number of arresters implies in an overall reduction in the system price not only by the number of arresters, but also by also the price of each arrester.

4 CONCLUSIONS

The improvement of lightning performance of a transmission line by applying ZnO arresters along its length is a good solution and the reported line arresters field performance has been very good. In this paper, the energy capability of the line arresters installed in towers with a high footing resistance was investigated. The arresters energy calculation was performed using PSCAD.

A case study was presented and a 230 kV transmission line was considered. The 171 tower footing resistances varied from 11 to 441 Ω, with a high average value.

The line lightning performance was estimated using Flash software. Starting with a poor performance estimation, arresters installation was considered and a target of 2 outages/100km.year was set. The maximum energy capability of the arresters was calculated for 2 cases: arresters installed in every tower (no lightning outages) and arresters installed in selected towers (2 outages / 100km .year).

The results of the simulations show that, for lightning discharges striking the tower, the greater the number of towers with arresters next to the tower stricken by lightning, the greater the energy level at the arrester at such a tower. Therefore, if arresters are installed only in a few selected towers, their energy capability is lower than if they are installed in every tower, reducing the overall system price at an acceptable outage rate of the line. The cost may be even smaller if lower energy capability arresters can be specified.

The overall results obtained with the present study show that, for lines where a certain number of lightning outages is acceptable, the installation of a reduced number of arresters along the line can be considered as an interesting solution from both economical and technical points of view.

5 ACKNOWLEDGMENTS

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