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Reduction of the double-circuit flashovers on a 400 kV overhead line

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SUMMARY

Double circuit flashovers may cause very severe system disturbances when taking place on some critical double-circuit lines of an electrical network. Line arresters offer an efficient solution to protect these specific lines against double circuit outages due to lightning.

This paper will study, on a double-circuit 400-kV line, the protection provided by line arresters against double circuit outages due to lightning. The efficiency of several configurations of line arresters will be compared. For that purpose, the double-circuit lightning flashover rates of the line with and without line arresters will be calculated using a newly developed software which includes a three-dimensional electro-geometric model and is able to take into account the random nature of lightning. This software automatically launches EMTP-RV (restructured version of EMTP) for analyzing fast front overvoltages impressed on line insulation. The energy stressing the line arresters will also be calculated in order to evaluate the risk of failure of the line arresters due to excess energy absorption.

Furthermore, the effects of several other parameters such as the tower footing resistances, the lightning withstand voltages of insulator strings as well as the protective levels of line arresters will also be investigated.

KEYWORDS

Lightning, flashover, energy duty, continuity of service, transient calculation, line surge arrester.

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1 Introduction

This paper is devoted to the protection against lightning of a double-circuit 400 kV line, which is essential for the utility because its absence of service might lead to severe stability problems. Single phase reclosing is used and each circuit is managed separately, therefore the priority of the protection of the line is to avoid simultaneous multi-phase flashovers on both circuits.

The line is protected with 2 sky wires but a significant number of the line towers are located on rocky areas where it is not feasible to obtain sufficiently low grounding resistances to avoid multi-phase flashovers (see Figure 1). So it has been decided to use line arresters and several questions needed to be answered especially regarding the technology (gapped or gapless), the rated voltage and the class of the arresters to be used. It is also necessary to determine the towers and the phase where arresters need to be installed.

This paper presents some elements of the study conducted by RTE and EDF R&D in order to answer these questions. It starts with a brief presentation of the methodology applied to evaluate the lightning flashover rate of the line. Then, after a description of the configuration of the line, it presents a study of the influence of the characteristics of arresters and of the configuration of line arresters on the flashover rate. The paper ends with considerations regarding energy duty of the arresters.

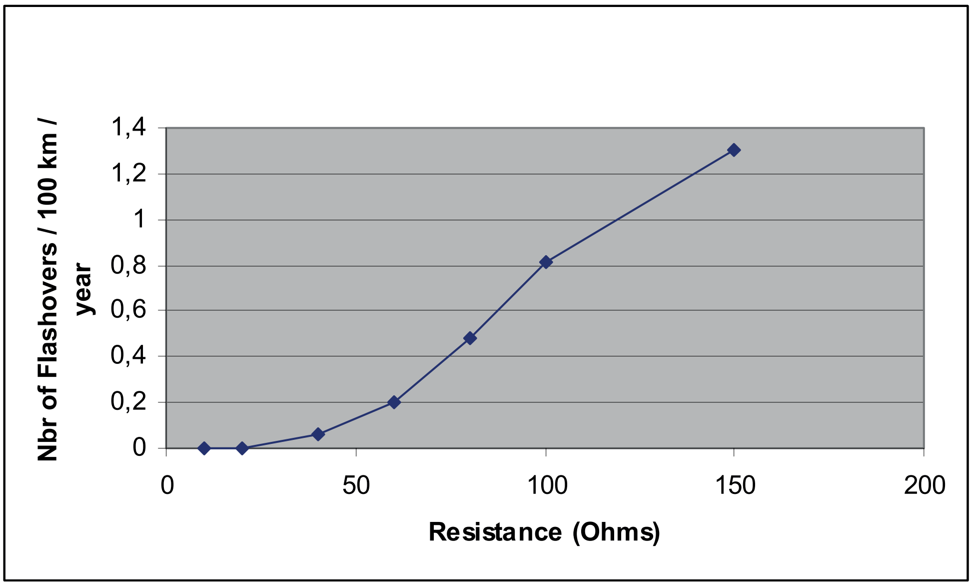


Figure 1 : Multiphase flashover rate of one circuit of the line considered in this study when it is not protected by line arresters.

2 Methodology used to evaluate the flashover rate

The methodology we have applied to evaluate the lightning flashover rate has been presented into details in [1]. It includes the following steps :

1) Application of the electro-geometric model to determine the number of lightning strokes impacting each element of the line and the probability density function of these strokes ;
2) EMTP-RV simulations of the electromagnetic transients due to lightning strokes impacting the line ;

3) Evaluation of the flashover rate of the line segment under consideration. The stochastic nature of lightning is taken into account and the results of the previous stages are included.

The software requires splitting the segment of line into elements (section of sky wires, section of phase conductors, etc.) which will be considered separately in the flashover calculation. Only one point of impact is considered when performing the EMTP-RV simulations. It is supposed that overvoltages due to a lightning stroke impacting an element do not change significantly with the position of the point of impact inside the element.
Different types of flashovers are distinguished : total flashover rate or multi-phase flashover rate of the line and of each circuit of the line, etc.

3 Description of the configuration

A 400 kV double circuit line is considered. The line is protected by 2 sky wires. All the towers of the line are of the same type but their height can be different. It has been decided to conduct the study considering only one tower configuration because differences between towers are limited. The following table presents the position of conductors at towers and in the middle of the span.

Type of conductor	Height at tower (m)	Height at midspan (m)	Horizontal distance to the axis of the tower (m)
Phase 1 -circuit 1	20.6	12.6	-10
Phase 2 – circuit 1	26.1	18.1	-17
Phase 3 – circuit 1	33.1	25.1	-4
Phase 1 – circuit 2	20.6	12.6	10
Phase 2 – circuit 2	26.1	18.1	17
Phase 3 – circuit 2	33.1	25.1	4
Sky wire 1	42.2	36.2	-9.6
Sky wire 2	42.2	36.2	9.6

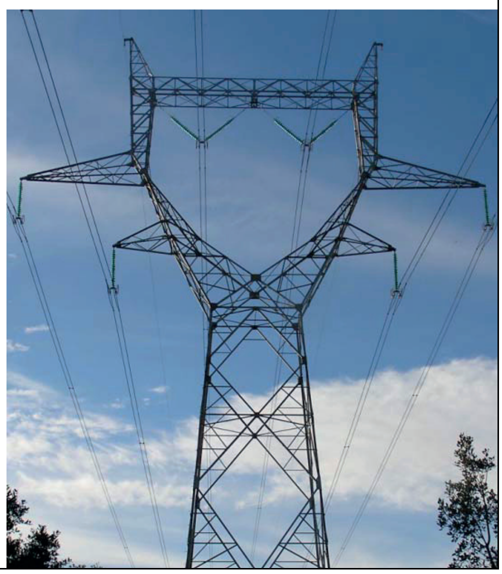


Figure 2 : Position of conductors at towers and in the middle of spans.

The length of the spans is 400 m and the lightning withstand voltage of the insulator strings is 1425 kV. The ground flash density is equal to 1.2 / km^2 / year.
In this paper the flashover rate has been calculated for different configurations of arresters, considering that the line is homogenous (all the towers and all the span are identical) in order to evaluate the effect of specific parameters on the flashover rate.

4 Influence of the characteristics of arresters on flashover rate

Since the early eighties RTE has been using gapped arresters. The main advantage of gapped arresters is that they allow the operation of the line even in case of failure of the active part of the arresters, but for the line considered in this paper the use of gapless arresters is considered because of clearance constraints at towers. In this paragraph we compare gapless and gapped arresters in terms of flashover rate reduction. We study also the influence of the residual voltage of arresters on flashover rate.

4.1 Gapped or gapless arresters

A configuration with arresters on both external phases of one circuit of the towers is considered (see Figure 3 below).

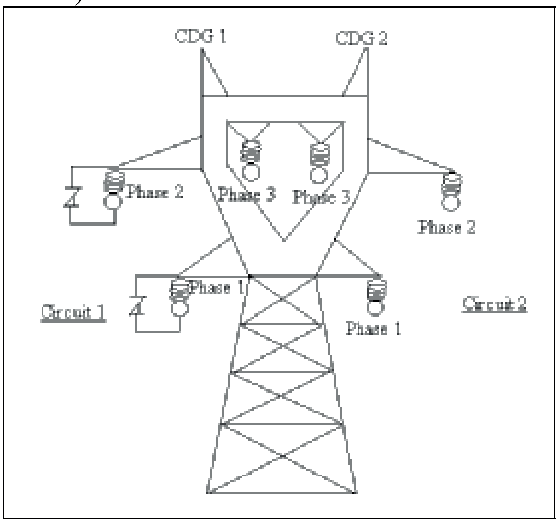


Figure 3 : Tower with line arresters installed on both external phases of circuit.

The gapless arresters have a residual voltage of 900 kV for 40 kA. The gapped arresters are constituted of an active part of residual voltage 630 kV for 10 kA and of a gap whose lightning impulse withstand voltage is 1 100kV.
The multiphase flashover rate of circuit 2 not protected with line arresters is calculated versus the grounding resistance of towers for both types of arresters and a comparison between both results is presented in Figure 4. We can see that the type of arresters does not have a strong influence on the flashover rate.

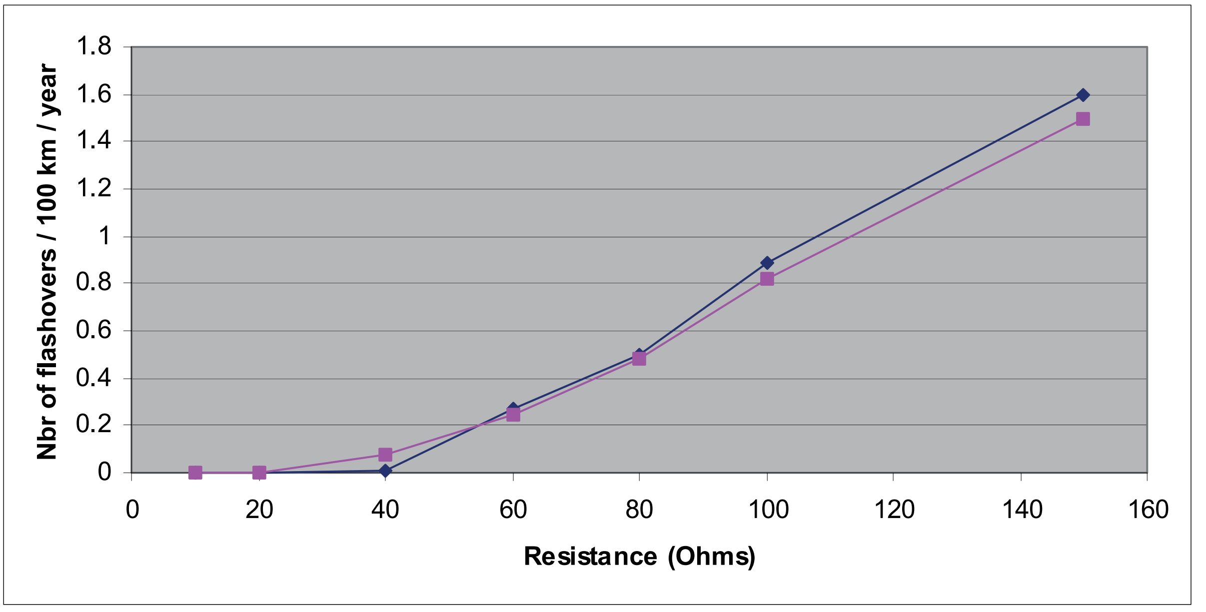


Figure 4 : Multiphase flashover rate of circuit 2 not equipped with line arrester when both external phases of circuit 1 are protected by line arresters (gapped arresters -■- , gappless arresters -◆-).

4.2 Modification of the rated voltage

The increase of the rated voltage of arresters allows the diminishing of the stress applied to arresters due to lightning overvoltages, but arresters with a higher rated voltage present the disadvantage of requiring more space in towers.

In the same configuration of arrester installation as in the previous paragraph the multiphase flashover rate of the circuit 2 (without arrester) is calculated versus grounding electrode of towers, for arresters of rated voltage 330 kV and rated voltage 360 kV (see annex 1).

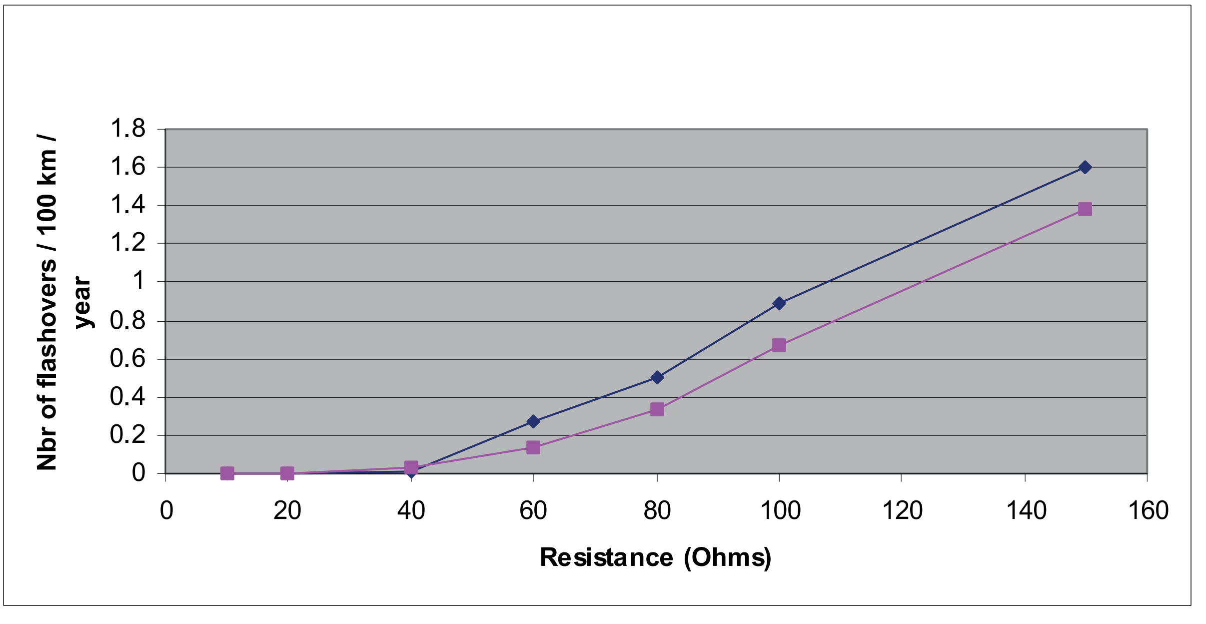


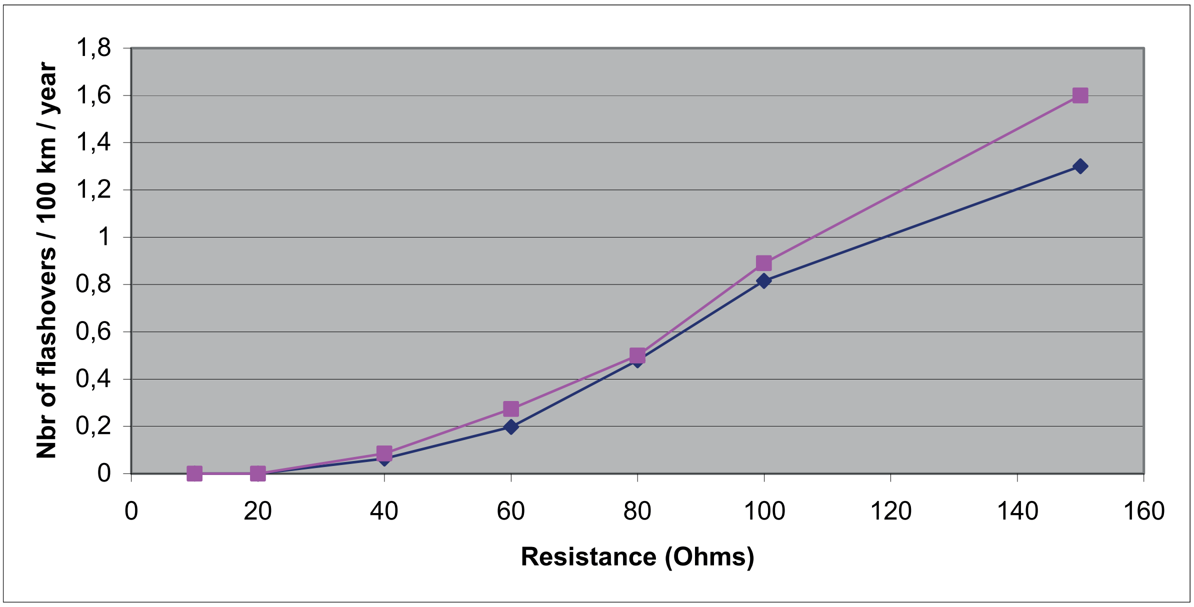
Figure 5 : Multiphase flashover rate of circuit 2, when both external phases of circuit 1 are protected by line arresters of rated voltage 330 kV (-◆-) or rated voltage 360 kV (-■-) .

The Figure 5 above shows that the rated voltage of the arresters used on circuit 1 has a limited effect on the multiphase flashover rate of circuit 2.

5 Study of different configuration of arresters

5.1 Arresters installed on the external phases of circuit 1

With two line arresters of rated voltage 360 kV installed on the external phases of circuit 1 and the multiphase flashover rate of circuit 2 is compared to its value when the line is not protected by line arresters. By avoiding any multiphase flashover on circuit 1 this configuration allows to keep on circuit always in service.



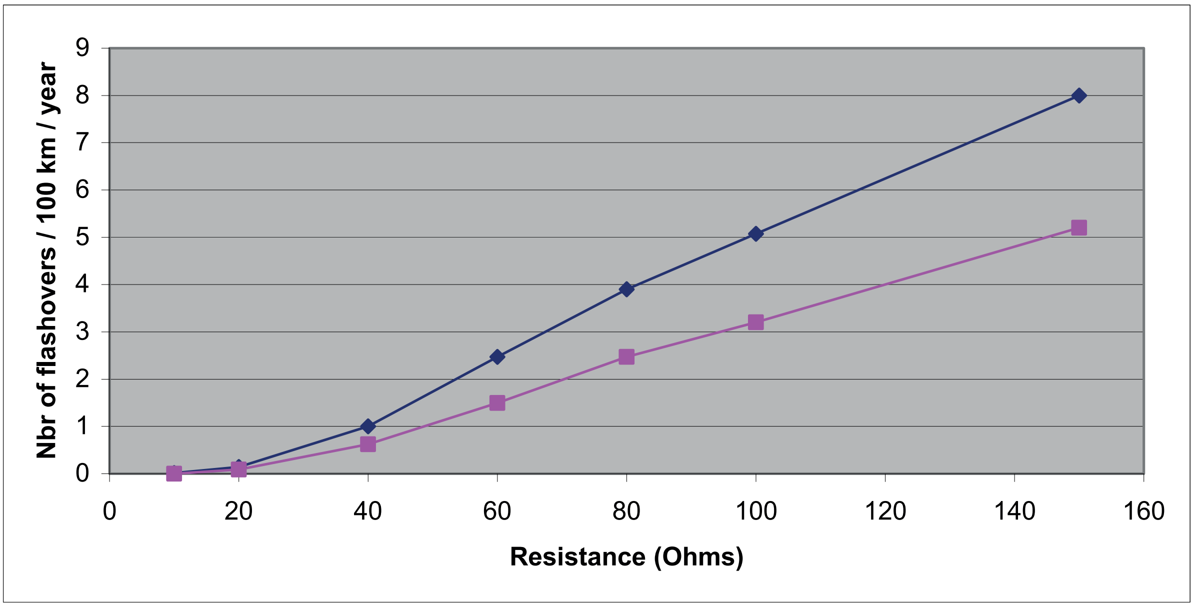


Figure 6 : (Higher Graph) Multiphase flashover of circuit 2, when the line is without arresters (-◆-) when line arresters are installed on the external phases of circuit 1 (-■-). (Lower Graph) Total flashover rate of circuit 2, when the line is without arresters (-◆-) when line arresters are installed on the external phases of circuit 1 (-■-).

The figure above shows that the presence of the surge arresters on circuit 1 leads to a strong decrease of the total flashover rate of circuit 2 but it leads to a slight increase of the multiphase flashover rate of circuit 2, especially for high grounding resistances.

5.2 Installation of a supplementary arrester on one phase of circuit 2

In this paragraph, we consider a configuration in which 2 arresters are installed on the external phases of circuit 1, but 1 supplementary arrester is installed on the external phase of circuit 2 (see Figure 7) in order to improve the lightning performance of this circuit.

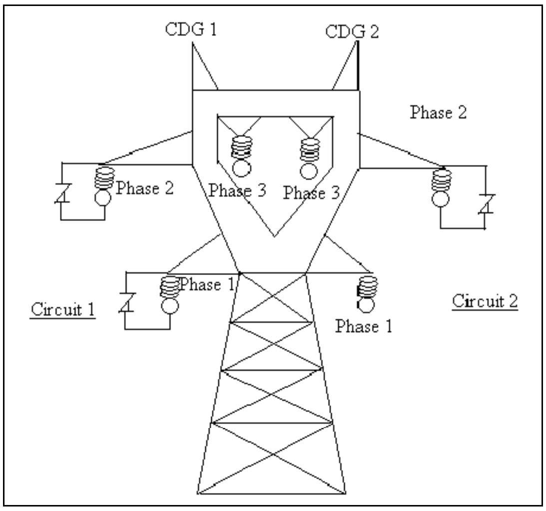


Figure 7 : Tower with arresters installed on both external phases of circuit 1 and phase 2 of circuit 2.

The figure below shows a strong decrease of the number of multiphase flashover of circuit 2 due to the presence of line arresters.

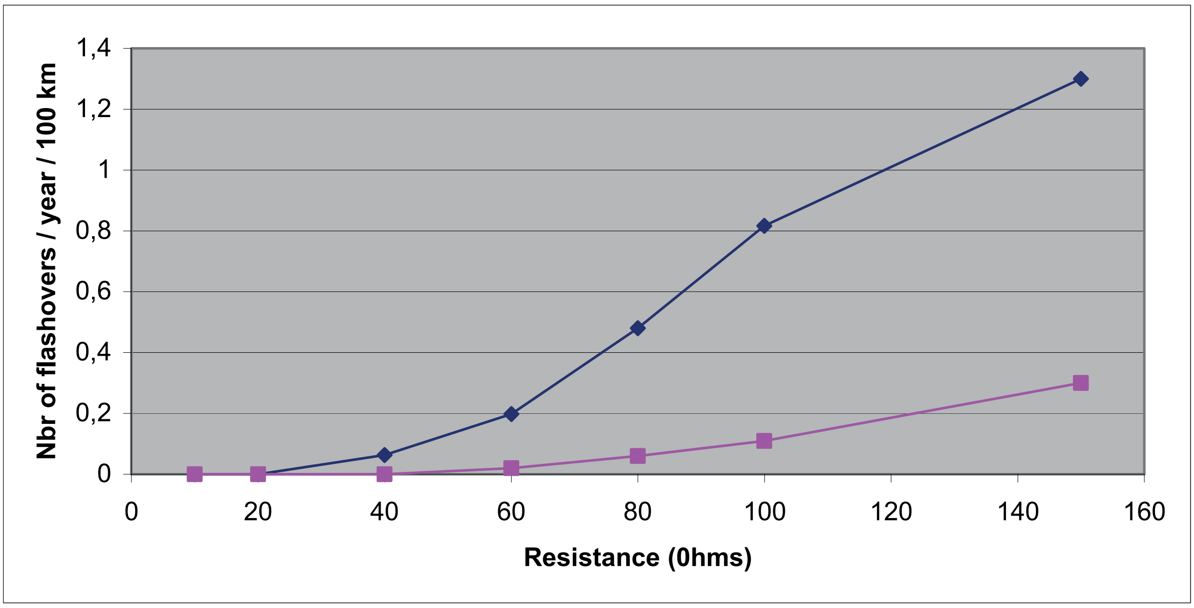


Figure 8 : Multiphase flashover rate of circuit 2, when the line is equipped with 2 arresters on circuit 1 and 1 arrester on circuit 2 (-■-) and when the line is not equipped with arresters (-◆-)).

6 Energy duty of the arresters

In order to determine the class to be used for gapless arresters, the energy stress has been evaluated by EMTP-RV simulations. Slow front overvoltages and fast front overvoltages have been considered.

6.1 Slow front overvoltages

The simultaneous reclosing of both circuits has been studied. Simulations have confirmed that, even if the line is partially protectedby line arresters, the stress applied to line arresters is very limited and that the essential part of the energy is absorbed by the arresters installed at the end of the line to protect the breakers of the substation.
It has been concluded that slow front overvoltages are not dimensioning, when specifying the energy class of the arresters [8].

6.2 Fast front overvoltages

The most severe fast front overvoltages are due to lightning. We consider here the case of a lightning stroke impacting a tower (impacts on sky wires are less severe regarding energy stress of line arresters) and of a lightning impact on phase conductors.

Lightning strokes on towers

In order to be conservative, the following configuration is considered. Each tower has a grounding resistance of 150 Ω and there are 5 line arresters per tower.
A lightning stroke of CIGRE-concave shape is supposed to impact one tower. The time to half value of the lightning current is taken equal to 110 µs. We consider that the 50 Hz voltage is, for one phase conductor, in opposite polarity with the lightning current. Subsequent strokes are not considered.
The table below gives the energy absorbed by the most stressed arrester versus the crest value of the lightning current. We can see that the energy stressing arresters is limited to 255 kJ.

Crest value of the lightning current (kA)	Energy dissipated in the most stressed arrester of the tower (kJ).
20	8.5
50	45
100	120
150	192
170	226
200.	255

Figure 9 : Energy absorbed by the most stressed arrester, for a lightning stroke impacting the tower.

Lightning strokes on phase conductors

The application of the electrogeometric model has shown that the maximum current crest value of lightning strokes which could impact phase conductors is lower than 14 kA. In order to be on the safe side, a lightning stroke of 20 kA is considered to impact a phase conductor at a moment when the 50 Hz voltage reaches its crest value of the same polarity as the lightning current. The grounding electrodes of towers are supposed to be equal to 10 Ω. Subsequent strokes are not considered.
EMTP-RV simulations have shown that an energy level of 310 kJ is dissipated in the most stressed arrester.

Conclusion

From the results above it can be concluded that it would be appropriate to use class 2 arresters. The use of class 2 allows to take into account uncertainties related for instance to general knowledge of lightning data (time to half value of the lightning current, presence of subsequent strokes…).

7 General Conclusion

This paper has presented a study of the protection against lightning of a double circuit 400 kV overhead line protected by 2 sky wires. Line arresters are used to reduce multiphase flashovers of both circuits.

The flashover rate has been calculated for different configurations of arresters using a software based on EMTP-RV. Some general information can be obtained from this study. It was shown that the type of arresters (gapped or gapless) or its rated voltage does not have a significant effect on the multiphase flashover rate.

The installation of two line arresters on one circuit avoids the presence of multiphase flashover on that circuit and therefore eliminates the risk of simultaneously tripping both circuits of the line because of lightning. This issue is essential in the type of application considered here and the fact that, as it is shown in the paper, the presence of line arresters on one circuit does not really protect the other circuit against multiphase flashovers is less important in practical terms.

The risk of failure of arresters due to energy stress has been studied. The energy stresses due to slow front overvoltages are limited. Fast front overvoltages are more severe. However due to the presence of sky wires it is sufficient to use arresters of class 1 or 2 [8].

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Annex 1 : Characteristic of the arrester of rated voltage 360 kV