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LIMITATION OF SWITCHING OVERVOLTAGES BY USE OF TRANSMISSION LINE SURGE ARRESTERS

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SUMMARY

This report describes the use of transmission line arresters on EHV lines in order to limit switching surge overvoltages. Overvoltages profiles along sample lines are given for a number of cases and for different number of installed arresters along the lines. In addition energy requirements on the station and transmission line arresters are given. A polymer-housed arrester suitable for line switching surge control is presented.

KEY WORDS

Surge arrester - Energy - Switching - Overvoltages - Polymer

1 INTRODUCTION

For long EHV lines, pre-insertion resistors traditionally are used to limit switching overvoltages. As a "second-line-of-defence", surge arresters usually are located at line-ends in the stations. A trend in recent years has been to try to find alternatives to the pre-insertion resistors by more active use of arresters or by controlled switching [1,2,3,4,5,6]. However, efficient limitation of the overvoltages along the lines by surge arresters has first been possible with the introduction of high-energy polymer-housed surge arresters that permit easy installation out on the lines. Extra "mini-substations" are not needed for the installation of the arresters since they can be installed directly in the towers. This use of transmission line arresters, TLA, offers a robust and efficient alternative to pre-insertion resistors since the arresters can be located along the lines at selected points to obtain the required control of the overvoltage profile along the lines.

2 550 KV LINES - SIMPLIFIED MODELLING

2.1 Statistical analysis of line overvoltages

The effect of transmission line arresters was investigated by statistical surge overvoltage analysis using EMTP (DCG/EPRI version 3.0, [7]) on cases illustrated in Figure 1. A 550 kV transmission line, 100 to 300 km, was considered with standard reference parameters as per ANSI C37.06-1987. A ground fault close to the receiving end of the line was assumed followed by tripping of the line breaker at the sending end of line and thereafter a three-phase reclosing operation.

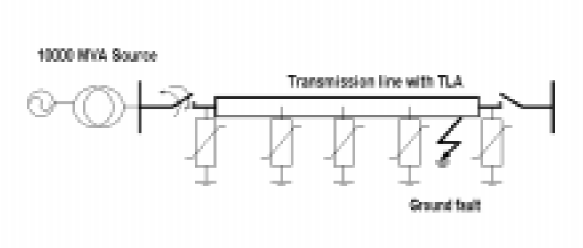

Figure 1: *Basic scheme for statistical analysis on 550 kV lines*

The closing angles of the breaker poles were allowed to vary stochastically and the statistical spread of closing times amongst the three poles was included as well.
A standard deviation, σ, of 0.6 ms, for the spread between the poles was used with a truncation at 3*σ. The average closing time was varied randomly during one cycle of power frequency voltage.

In all cases 396 kV rated arresters with a protection level of 783 kV (1.74 p.u.) at 2 kA were assumed.

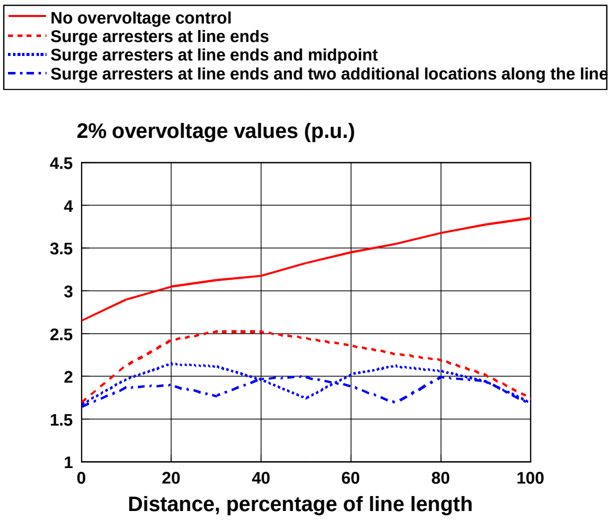

Figure 2: *2% overvoltage values, line to ground, for 100 km line with different measures to control switching surge overvoltages.*

The overvoltage profiles along the lines, 2% overvoltage values, are given in Figures 2 to 4 for 100 to 300 km lines and for the four cases considered as follows:

- without any overvoltage limitation
- surge arrester at line ends only
- surge arresters at line ends and midpoint
- surge arresters at line ends and at 30% and 70% of line length.

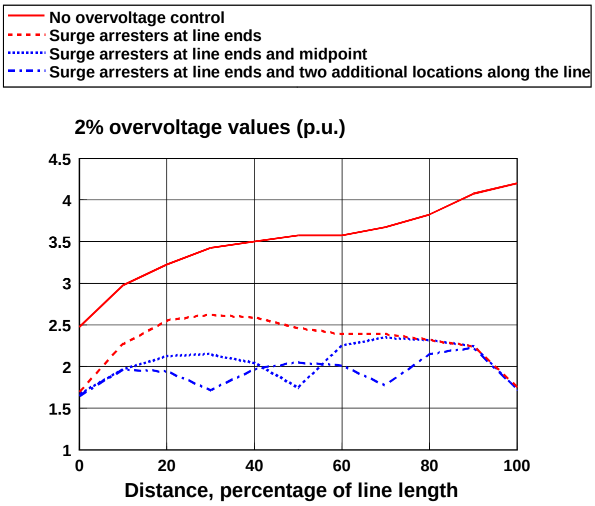

Figure 3: *2% overvoltage values, line to ground, for 200 km line with different measures to control switching surge overvoltages.*

As seen from the Figures 2 to 4, with a reasonable number of arresters, it would be possible to obtain an average overvoltage (2% value) of approximately 2 p.u. along the entire line. Furthermore, if reclosing is performed from one end of the line only, the line arresters could preferably be concentrated towards the receiving end of the line. The effect of such a location is shown in Figure 5.

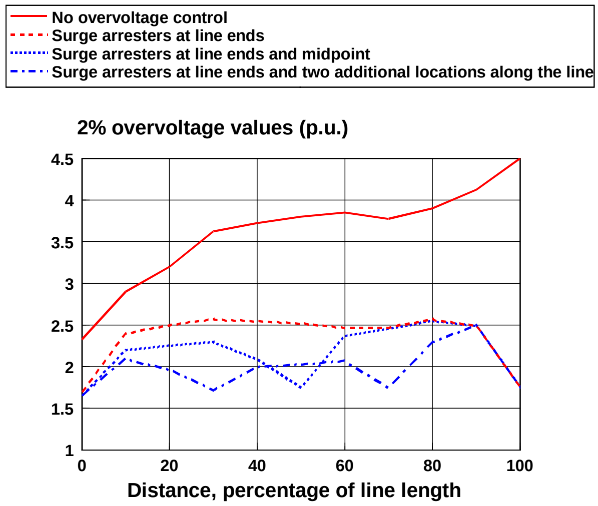

Figure 4: *2% overvoltage values, line to ground, for 300 km line with different measures to control switching surge overvoltages.*

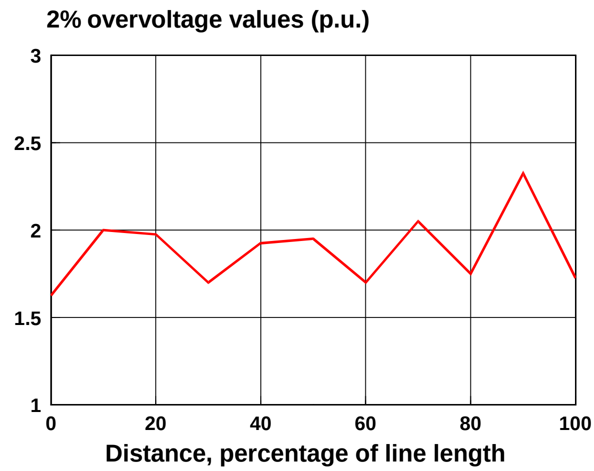

Figure 5: *2% overvoltage values, line to ground, for 300 km line with 3 arresters along the line, concentrated towards the receiving end.*

2.2 Arrester energy demands

In Figure 6, maximum arrester energies are given for the different statistical analysis. With no use of additional line arresters, the energy requirement for a 300 km long line results in Class 5 arresters as per IEC, which also is commonly used. With additional line arresters located along the line the energy stresses on the station arresters are reduced. In addition, the energy requirements for the arresters out on the line due to switching surges only correspond to Class 3 as per IEC.

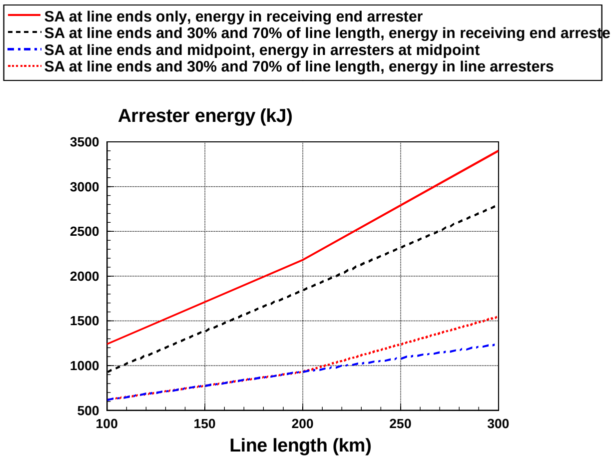

Figure 6: *Maximum arrester energies for different number of arresters as function of line length*

3 420 KV COMPENSATED LINES

3.1 Statistical analysis of line overvoltages

When a shunt-compensated line is switched off, the line-side voltage starts to oscillate with a frequency determined by the line capacitance and the shunt reactor inductance with, normally, only a weak damping. Since the line voltages oscillate with a frequency which differs from the power frequency, the voltages across the open breaker poles show a low-frequency beat phenomena as illustrated, in Figure 7, for a 420 kV, 300 km long line with 30% compensation at each end of the line.

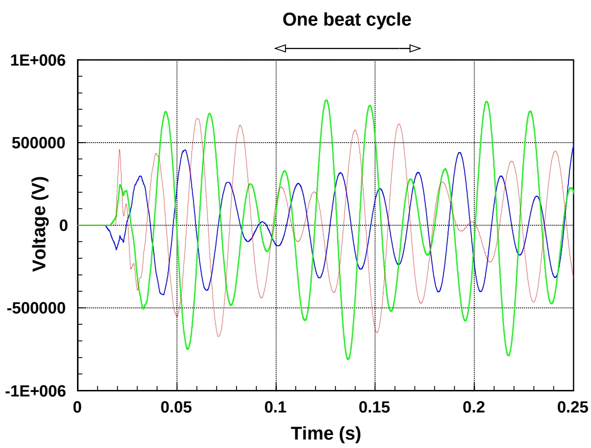

Figure 7: *3-phase voltages across breaker poles after disconnection of 420 kV, 300 km shunt-compensated line with previous ground fault.*

If the breaker closing time is uncontrolled, the reclosing after a fault on the line occurs randomly during the beat oscillation, which means that reclosing could occur against low or high voltage across the breaker. However, even if controlled closing is adopted, aiming at closing to occur at a beat minimum, it is a very complicated task to accurately control the closing to occur at the optimum close target. In real life too, the beat minimum may not be as pronounced as shown in the example. Different numbers of reactors, for example, may be connected to the line etc.

For a statistical study, the reclosing must be varied randomly during one complete cycle of the beat oscillation, which necessitates a great number of simulated breaker operations. The basic scheme used for an analysis is shown in Figure 8.

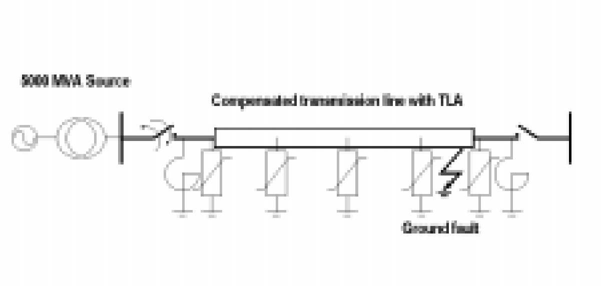

Figure 8: *Basic scheme for statistical analysis on a 420 kV shunt- compensated line. Line modelled with frequency- dependant parameters.*

The numbers of arresters along the line were varied as well as the length of the line. The compensation was in all cases set to 60%, half at each end of the line. The resulting overvoltage profiles for the different cases are shown in Figures 9 to 11.

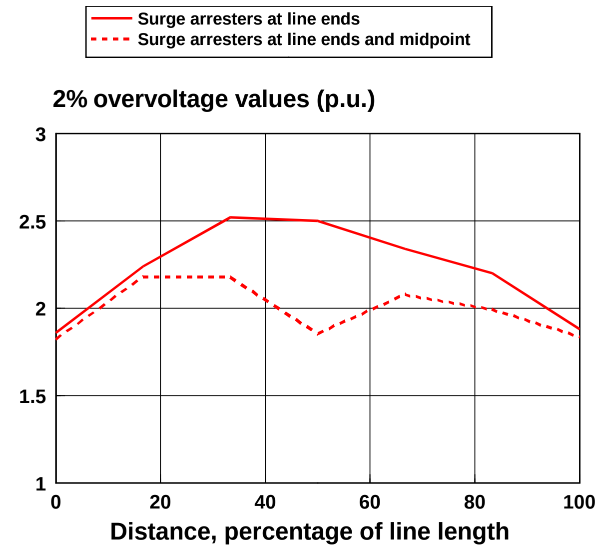

Figure 9: *2% overvoltage values, line to ground, for a 100 km line with different numbers of SA along the line to control switching surge overvoltages*

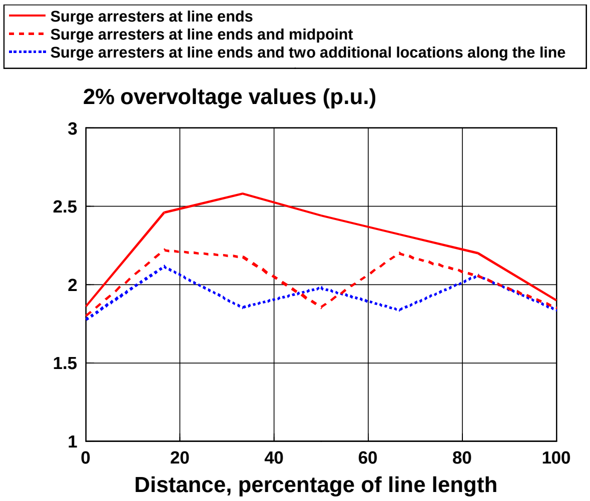

Figure 10: *2% overvoltage values, line to ground, for a 200 km line with different numbers of SA along the line to control switching surge overvoltages*

The arresters modelled at line ends and along the lines were of IEC line discharge class 4, rated voltage 330 kV, switching surge protection level at 1 kA of 644 kV (1.88 p.u.).

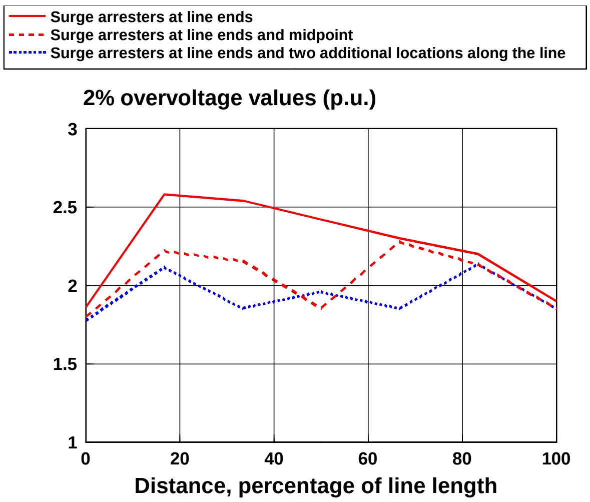

Figure 11: *2% overvoltage values, line to ground, for a 300 km line with different numbers of SA along the line to control switching surge overvoltages*

3.2 Arrester energy demands

Just as for the 550 kV non-compensated lines, the energy demands increase linearly with the length of the transmission line. In addition, the necessary energy capability is considerably lower when additional TLA are used. Comparing with IEC line discharge classes [8], from energy point-of-view, arresters fulfilling Class 3 are sufficient up to approximately 200 km if no additional TLA are used.

As TLA, Class 2 arresters would be sufficient. However, Class 2 arresters would not be able to provide the same low switching protection levels as the Class 4 arresters modelled in the analysis. Class 2 arresters may also mechanically be too weak for use on 420 kV.

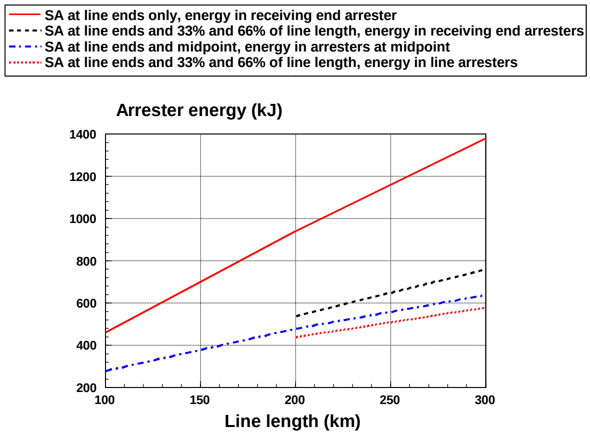

Figure 12*: Maximum arrester energies for different number of arresters as function of line length*

4 RISK-OF-FAILURE CALCULATIONS

For normally used minimum air clearances in the range of 2.7 to 3.3 m for 550 kV lines [10] corresponding to SIWL of 2.4 to 2.8 p.u.[11] and adopting the simplified method outlined in [2] the risk-of-flashover for a reclosing operation would be as per Figure 13 for 300 km line lengths and different number of arresters.

Taking a risk of 0.1 as a common target value for reclosing operations, arresters only at line ends yield a required withstand voltage of 2.7 p.u. With two additional arresters along the line, the necessary insulation level decreases to 2.53 p.u..

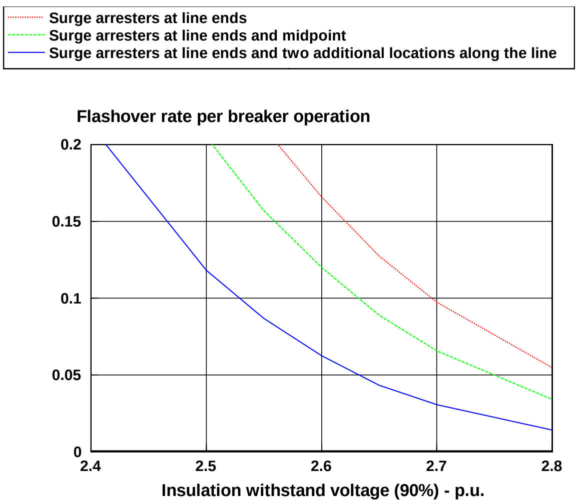

Figure 13: *Risk of flashover per breaker operation on 550 kV, 300 km line with different numbers of SA along the line to control switching surge overvoltages*

Practical 420 kV lines have minimum air clearances in the range corresponding to SIWL of 850 to 1175 kV i.e. 2.5 to 3.4 p.u.. As shown by , the lines with SIWL in the higher range could sufficiently be protected by arresters at line ends only. For lines in the lower range of SIWL the calculations indicate that additional TLA are needed if no other measures to limit switching overvoltages are used.

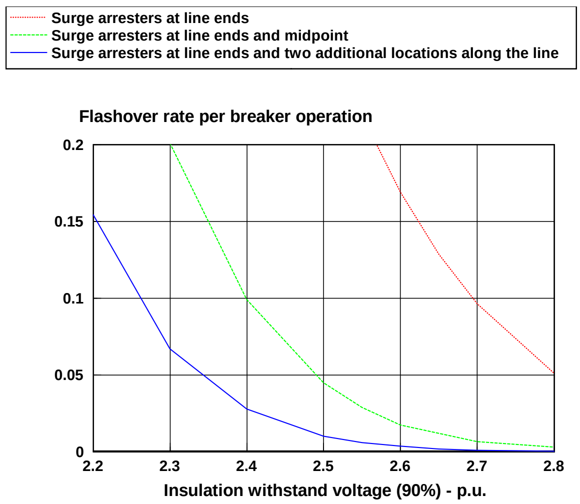

Figure 14: *Risk of flashover per breaker operation on 420 kV, 300 km line with different numbers of SA along the line to control switching surge overvoltages*

5 POLYMER-HOUSED SURGE ARRESTERS FOR TOWER INSTALLATIONS

A polymer-housed surge arrester design suitable for installations out on transmission lines is shown in Figure 15. The arrester is available as an IEC class 3 as well as a class 4 arrester. It could be mounted suspended horizontally as shown in the figure or suspended vertically, for example, from the phase conductors.

The particular arrester shown in Figure 15 was developed for a compact 420 kV line [11].

The protective characteristics of the arrester are shown in Table 1.

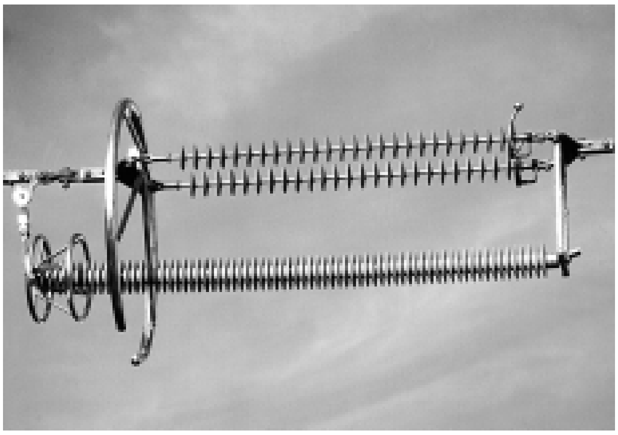

Figure 15: *Surge arrester positioned under the insulator strings in top phase of a compact 420 kV line*

Table 1: Electrical data for transmission line arrester

Rated voltage	Residual voltage vs. current amplitude			
	1 kA	10 kA	20 kA	40 kA
KV_{rms}	kV_{peak}	KV_{peak}	kV_{peak}	kV_{peak}
330	654	776	854	954

The 1 kA residual voltage is valid for switching surges and the residual voltages for 10, 20 and 40 kA for standard lightning current impulses.

The surge arrester is built-up of six separate mechanical and electrical modules connected in series. The design of each module includes an HTV silicone rubber insulator moulded directly on to the internal structure with the ZnO block column. The internal cage-style mechanical structure provides high mechanical strength and well-controlled short-circuit capability in case of arrester overloading.

The special location of the arrester in the tower has required extensive 3D electrical field calculations to determine necessary grading rings to control the voltage distribution along the arrester. The mass of the arrester including the grading rings is 128 kg or approximately one third of the mass of an equivalent arrester with porcelain housing. The creepage distance of 27 mm/kV corresponds to IEC class III.

A number of tests in accordance with draft standards from IEC TC 37 on testing of polymer-housed arresters have been performed to verify the design. Some of these tests are as follows:

- Weather ageing test - 1000h salt-fog
- Tightness tests
- Short-circuit current tests
- Operating duty tests as per requirements for 10 kA line discharge class 3 arresters

In addition, a lightning energy withstand test has been carried out to determine the capability of the arrester to withstand lightning current impulses of sinusoidal shape with a duration of approximately 200µs (which is intended to cover the combined effect of multiple lightning strokes). This type of test has verified an energy capability of the arrester of at least 4.5 kJ/kV rated voltage.

To the top terminal of the arrester, a disconnecting device is connected which shall operate in the case of an arrester overloading to avoid a permanent ground fault. The disconnector has been carefully designed and tested to ensure that it functions only at arrester failure. All other possible stresses in terms of energy and current, which the arrester would withstand, will not cause a disconnector operation. It has been verified, for example, that disconnection will not take place for the following current impulses:

- 130 kA, 4/10 µs
- 3 kA, 4 ms, rectangular
- 28 kA, 200 µs, sinusoidal

6 ARRESTERS FOR 800 KV TOWERS

The use of transmission line arresters will not necessarily be limited to 420 kV and 550 kV systems only. Arrester designs that could be used on 800 kV systems already exist. A planned installation for 800 kV towers is shown in Figure 16.

The arresters are suspended mounted from the conductors, which is possible due to the low mass of the arresters. Electrical data for the arresters is given in Table 2.

Table 2: Electrical data for 800 kV transmission line arrester

Rated voltage	Residual voltage vs. current amplitude			
	2 kA*	10 kA**	20 kA**	40 kA**
KV_{rms}	kV_{peak}	KV_{peak}	kV_{peak}	kV_{peak}
588	1190	1340	1470	1610

* For switching surge ** For lightning surge

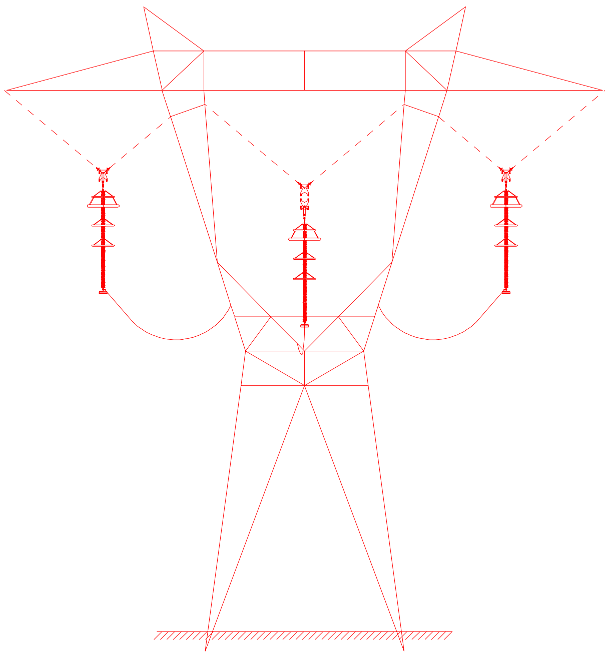

Figure 16: *Planned installation of polymer-housed arresters in a typical 800 kV tower. Arrester rated voltage 588 kV.*

7 CONCLUSIONS

- Transmission line surge arresters offer a robust and efficient alternative for limitation of switching surges along transmission lines.
- The energy requirements due to switching surges are considerably less for line arresters than for arresters located at the receiving end of the switched line.
- Polymer-housed high-energy transmission line surge arresters suitable for switching surge control are available for all EHV system levels up to and including 800 kV.
- Controlled switching for compensated lines is a complicated task. The beat minima are not always distinct and it would be difficult to determine and reach the optimum closing target during all operating conditions. Surge arresters on the other hand offer a safe and reliable alternative even if, theoretically, the resulting overvoltages will be somewhat higher.
- By the application of TLA, there would also be possibilities for compacting lines and for upgrading of existing lines.

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