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INSTALLATION OF LSA ON A 400 KV DOUBLE-CIRCUIT LINE IN RUSSIA

L. STENSTRÖM[1], J. TAYLOR, F. PERSSON
ABB AB
High Voltage Products
(Sweden)

N.T. OSIPTSOV
Main Electric Networks of North-West
(Russia)

SUMMARY

Necessary information for making decisions regarding installation of LSA in a double circuit 400 kV line running between substation Vyborgskaya in Russia and substations Yullikyalya and Kyumi in Finland are discussed. Lightning discharge energy requirements for LSA have been calculated and the risk for single- and double-circuit lightning related faults with and without arresters has been estimated as a function of tower footing resistance. The decisions regarding ultimate number and location of arresters along the line are described and the type and technical data of the arresters selected are given. Furthermore the measuring system used to monitor lightning surges through the arresters is presented as well as the experience from the installation and the 3 years of service.

KEYWORDS

Line surge arresters, Lightning protection, Arrester energy requirements, Arrester monitoring

lennart.o.stenstrom@se.abb.com

1. INTRODUCTION

Application of line surge arresters in northern countries has historically been a quite rare occurrence due to the relatively low ground flash density in these countries. On the other hand, prevailing poor grounding conditions could make it difficult and very costly to ensure sufficiently low tower footing resistances to avoid too frequent flashovers even at a low ground flash density. In addition, the expectations from buyers of electrical power are changing and what previously may have been an acceptable outage rate is now no longer tolerable. This becomes particularly the case when consumers and network owners become aware of what could be achieved with modern surge arresters applied on the lines. Of course, this in turn puts very high demands on the reliability of the arresters themselves, both mechanically and electrically, in order not to introduce new reasons for outages due to arrester malfunctions. The report describes the installation of LSA on a 67 km long 400kV line in Russia, of which 42 km is double-circuit. The line constitutes an important connection link between Russia and Finland, which is why a low outage rate is extremely important and double-circuit faults in particular must be avoided. The line runs between substation Vyborgskaya in Russia and substations Yullikyalya and Kyumi in Finland. Previous experience shows roughly 4 faults per year for the line with 2 faults in average per circuit. Target rate was set at maximum 0.5 fault per 100km and year. Tower footing resistances along the line are very high at many locations. The installation in 2004 was preceded by a careful analysis of possible arrester stresses with respect to lightning energy as well as analysis of necessary number of arresters to achieve the target reduction of outage rate.

2. ARRESTER ENERGY CONSIDERATIONS

When installing a great number of arresters along a transmission line it is vital to ensure that the current and energy capability of the arresters is sufficiently high so that the arrester failure rate does not exceed the target outage rate. Both shielding penetration and strokes to shield wires and towers must be considered.

2.1. Calculation model

A line section with 17 double circuit towers with one 400 kV circuit positioned on each side of the towers was modelled in the EMTP. An average span length of 350 m was used between the towers. Both the circuits were modelled with their 2 conductor phase bundles as well as the two overhead shield wires. Across each phase insulator voltage controlled switches were used to model flashover. Polymer-housed surge arresters with rated voltage of 360 kV were assumed to be connected to all 3 phases in one of the circuits. The electrical data for the arresters is given in Table 1. The model of the arresters comprised the non-linear voltage-current characteristics for 8/20 μs current impulses and a compensation circuit in series to model the arrester response to steeper surges. Connection leads and length of arresters were accounted for by inductances.

Table 1. Electrical data for 420 kV line surge arrester.

Rated voltage kVrms	IEC line discharge class	Lightning discharge capability as per IEC [8] (Annex N)	Protective level in kVpeak at lightning current with wave shape 8/20 μs			
		kJ	5kA	10kA	20kA	40kA
360	3	1440	804	846	931	1046

2.2. Lightning strokes to towers or shield wires

The value of ground flash density, Ng, was not accurately known for the area. Two values of Ng were therefore used, 2.9 and 1 respectively, which were considered to well cover the actual range. For Ng=2.9 the number of flashes per km of line per year was calculated to 0.9 and for Ng=1 the corresponding figure was 0.3; adopting the methods outlined by CIGRE [1]. The intended number of arresters to be installed along the line was around 100, which meant that approximately 12 km of the line would be protected by LSA. To estimate the risk for the arresters to be overloaded the MTBS

(Mean Time Between Surge) for the line arresters could be calculated for lightning surges of different probability of occurrence from the equation [5, 6]:

$$MTBS = \frac{1}{(p \times N)}$$

where N is the number of flashes per year to the line section with arresters and p the probability that a lightning flash has a total charge and current exceeding a particular value.

Furthermore, the total flash charge was selected to cover multiple strokes. Three probability values were selected equal to 0.002, 0.005 and 0.01 respectively. From the statistical distribution of total charge of negative flashes [2, 4] these probabilities correspond to total flash charges of 134.1, 101.2 and 78.6 As respectively. Corresponding current amplitudes with the same probability of occurrence were calculated as per [1] to 190.1, 158.2 and 136 kA respectively. Current impulses with the required value of charge and amplitude were constructed. Front time and steepness for the impulses were calculated as median values for the statistical distributions based on the current amplitude. The 3 current impulses were injected in the tower top of the centre tower of the modelled line section. The calculations were performed with tower footing resistance of 600 and 170 ohms which covered the range of tower footing resistance where LSA were intended to be used. Five towers on each side of the centre tower were given the same tower footing resistance as the centre tower. The non-linear performance of the tower footing resistance taking into account soil ionization was modelled for the centre tower. The result is given in Table 2 where corresponding figures for the MTBS are given for Ng =2.9 and 1 and for a total line section of 12 km with LSA. For other values of Ng the MTBS could be recalculated accordingly. As seen from Table 2 the coupling factor as well as the instantaneous value of the power frequency affects the amount of arrester energy.

Table 2. Arrester energies and MTBS for lightning strokes to towers or shield wires.

Current impulse "probability"	MTBS		Tower footing resistance	Arrester energy in kJ					
	Ng=2.9	Ng=1		Top phase,R		Middle phase,S		Bottom phase,T	
				Phase angle R-phase		Phase angle R-phase		Phase angle R-phase	
	years	years	(Ω)	30°	210°	30°	210°	30°	210°
0.002	46	139	600	168	56	151	165	87	240
0.005	19	56	600	148	30	141	114	78	194
0.01	9	28	600	119	18	107	84	56	159
0.002	46	139	170	128	16	105	83	57	161
0.005	19	56	170	105	9	83	57	43	129
0.01	9	28	170	77	5	59	43	26	104

Table 3. Arrester energy due to shielding failures.
*) No flashovers in unprotected system.

Tower footing resistance centre tower	Tower footing resistance adjacent towers	LSA in adjacent towers	Arrester energy
ohm	ohm		kJ
600	600	Yes	207
170	170	Yes	231
100	100	Yes	246
20	20	Yes	289
20	600	Yes	314
20	600	No*)	983

2.3. Shielding penetration within the protected section

Applying classical electrogeometrical theory yields that the line is effectively shielded with a low probability for shielding failures. However, for Ng=2.9 a shielding penetration rate of 0.175 per 100 km per year to one of the two circuits is estimated. Maximum current for shielding penetration is calculated to 22.5 kA. Taking into account the entire line length with double circuit of 42 km this yields 0.07 shielding failures per year. Selecting a MTBS of 25 years results in a surge probability of 1/(25*0.07) = 0.57. From [2, 4] corresponding flash charge is calculated to 6.3 As. An impulse with charge 6.3 As and amplitude 22.5 kA and with front steepness and front time calculated as median values for the statistical distributions based on current amplitude was constructed. The current impulse was injected in the top phase in the centre tower of the line section model. The tower footing resistance of the centre tower and adjacent towers was varied. The result of the calculations is shown in Table 3. For shielding penetration the most severe case is with the arrester in a tower with low footing impedance in contrast to the case for strokes to tower structure or shield wires for which the highest arrester stress is obtained for highest footing impedance. Note that the tower footing resistance of 20 ohms is selected as an extreme case since LSA, in general, are not considered to be installed in towers with such low values of tower footing resistance.

2.4. Summary of energy stresses

The energy stresses calculated for the LSA in the double-circuit line were well below the lightning discharge capability of 1.44 MJ for the selected arrester type. For lightning strokes to towers or shield wires the arrester energy is low even taking into account strokes with very low probability and MTBS in the range of the technical lifetime of the arresters. For shielding failures a significant energy may be obtained. However, compared with the capability of the selected arrester the safety margin is considered sufficient.

3. CALCULATION OF RISK OF INSULATION FLASHOVER WITH AND WITHOUT ARRESTERS

A number of computer calculations were performed to investigate the risk of flashover of line insulators during lightning events. Cases with and without arresters in all 3 phases of one of the circuits were considered. To model the lightning overvoltage withstand of the line insulators, flashover models based on voltage-time curves were used, assuming a LIWL of 1490 kV. The same model of a line section and towers as in paragraph 2.1 was used. The tower-footing resistance was varied from 20 to 600 ohms. A lightning stroke was injected in the top of the centre tower of the modelled line section. The lightning current was modelled as a double-exponential impulse with a concave front, with varying values of amplitude and maximum steepness. The amplitude and steepness of the current impulses were varied in such a way that limiting curves could be established as shown in the examples in Figure 1. In total 108 current impulses with different amplitudes and steepness were applied for each case in order to cover the whole statistical distribution of lightning strokes. In addition the phase angle of the power-frequency voltage was varied in steps of 30 electrical degrees. In total 1296 calculations were made for each value of tower-footing resistance. Combined values of stroke current amplitude and steepness above the limiting curve will cause flashover of a line insulator. The corresponding risk of flashover can be estimated by taking into account the statistical distribution of stroke current amplitudes and steepness and applying the method described in [9]. Furthermore the average value is taken for the 12 calculations with different phase angles. The result of the risk calculations is shown in Figure 2.

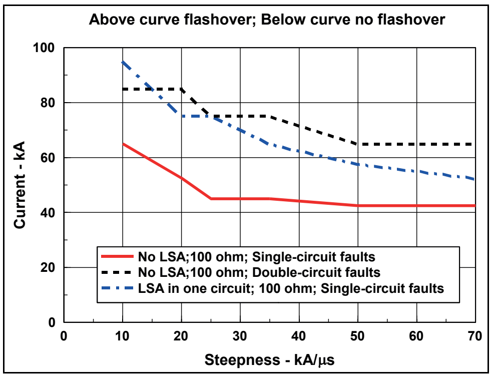

Figure 1. Limiting curves for the case with 100 ohm tower footing resistance

The total number of flashovers at a tower with a particular footing impedance is estimated as the number of lightning strokes per km line per year times the span length times 0.6 [3] times risk of flashover per lightning stroke as per Figure 2. For the complete transmission line the total risk is calculated as the sum of the risk at each tower. If arresters are located in one of the circuits at a tower the risk for double-circuit faults is practically eliminated; only the risk for single-circuit faults in the unprotected circuit remains. By making the calculations in a spreadsheet format, the most efficient solution for locating a specific number of arresters could easily be determined. For instance all towers with footing resistance above a selected value, e.g. 250 ohms, could be equipped with arresters. The efficiency in using a particular number of arresters could be exemplified in Figure 3. Arresters in this case are located at the towers with highest footing impedances. With LSA in all phases in one circuit single-circuit faults only occur in the unprotected system.

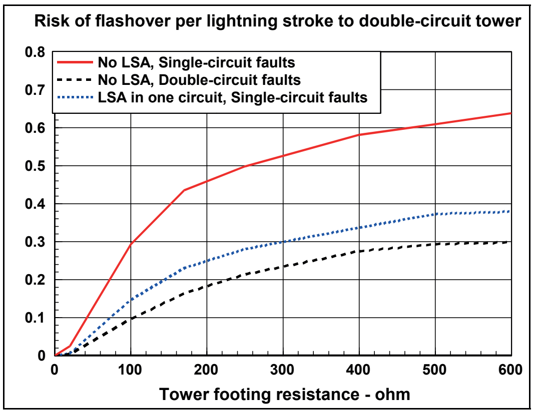

Figure 2. Risk of flashover per lightning stroke as function of tower footing resistance.

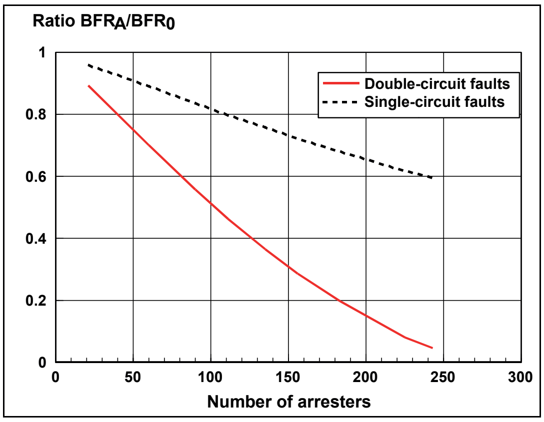

Figure 3. Relative improvement with LSA for Ng=1. BFR_A is backflashover rate with LSA and BFR_0 is backflashover rate without LSA.

3.1. Installation strategy – number of towers

Based on the calculations it was decided to install a total number of 102 surge arresters in one of the two circuits (Linke 2) on 41 selected towers and an additional 6 arresters in the other circuit (Linke 1) on two towers identified as “trouble towers” (Figure 5) with respect to lightning related faults. The locations of the arresters were assessed to optimize their effect on total outage rate; selected basically on magnitude of tower-footing resistance and experience from earlier lightning incidences. Arresters were ultimately installed in all 3 phases on the Linke 2 circuit at 27 selected towers, whilst 13 towers had only one or two phases of the Linke 2 circuit protected by arresters and two specific towers had both Linke 1 and Linke 2 circuits protected.

4. MECHANICAL CONSIDERATIONS AND INSTALLATION PRACTICE

In addition to electrical concerns the mechanical strength of the arresters and installation hardware must match requirements to avoid mechanically related failures as well. Furthermore, considering the installation height of the arresters a possible overloading should not result in dangerous bursting of hard arrester pieces.

Figure 4. Installation of LSA

The arresters were hung on the conductors close to the towers and easily installed by hand with the aid of rope winches and internal-combustion engine drive (Figure 4). The hardware was selected from standard, readily available equipment and by employing a moment-free coupling the mechanical forces could be reduced greatly. A disconnecting device was fitted in series with the arresters. Installation examples are shown in Figures 5 and 6. The high tensile strength of the arresters allows for applying a patented solution with weights under the arresters in order to limit swing during heavy wind. However, after review this was not considered necessary in this case.

The arresters themselves have the ZnO blocks housed in series-connected “modules”, which are of an open-cage design formed of fibreglass loops placed on yokes at each end, together with special fibres wound around the module. This arrangement prevents any large pieces from bursting out of the cage through the housing at severe short-circuit conditions. This is particularly important in this case with the arresters located in high towers. The assembly is furthermore kept under heavy compression to maintain good contact between the ZnO blocks up to the specified short-term cantilever load, which for this application with suspended mounting assists equally against permanent tension load. Where deemed necessary – notably at the line connection and disconnecting device – special configurations were used to minimize mechanical stress on joints.

Figure 5. "Trouble tower" with arresters. installed in both circuits and in all 6 phases.

Figure 6. 400 kV line arrester in bottom phase.

5. MONITORING AND FIELD EXPERIENCE

Modern day gapless surge arresters are intended to be maintenance-free and therefore, by design, do not explicitly need to be monitored. Nonetheless, there is a natural interest from the user to know the kind of surges an arrester has been exposed to and thereby make a judgement on the effectiveness of the arresters in protecting insulation and what, if any, damage the surge may have caused to the arrester itself. In a substation environment, this may be a key factor in ensuring desired continuity of supply whereby early detection of arrester deterioration can permit removal of suspect arresters before the situation becomes acute and an unplanned circuit breaker lock-out occurs. Monitoring of both surge magnitude and resistive leakage current through the arresters provides vital data to the maintenance engineer at the substation.

LSA fitted with a disconnecting device do not pose the same degree of risk to system stability. In the rare event of an arrester overload, the disconnecting device will quickly and effectively remove the arrester from the circuit and an auto-reclose operation will re-establish power; if indeed a breaker trip occurs at all. Monitoring of leakage current on LSA is therefore predominantly of academic interest since, even if deterioration was detected, the outage time and cost of lost supply to replace the arrester before overload would be much greater than simply allowing it to overload and replacing it in due course during routine line maintenance. This is, of course, presuming the design is such that it can overload safely and in a controlled manner as described above. Of more practical interest to the engineer is the monitoring of surges through individual LSA along the line. During the system study phase, towers were selected for fitting with LSA in order to reduce the overall outage rate of the line as identified by a statistical representation of where lightning has struck in the past and where backflashovers may most likely occur. It is desirable to have some means of validating the selection as made, together with a way of determining if the improvement in outage rate has been due to the arresters or simply a coincidently less lightning activity in the region of the line.

The arresters were equipped with surge monitors (sensors) placed in series with the arresters at the connection point of the ground conductor in order to record number of arrester operations. Surges are grouped into the appropriate category based on current amplitude. Since it is impossible to approach the LSA to obtain a reading visually, the measured data stored in the sensors is transferred to hand held transceivers at ground level via radio communication and thereafter further on to a PC for statistical analysis. Due to the quite large distance between transceiver and sensor in this particular case with very high towers, an external hand-held antenna was used to improve the communication (Figure 7). The monitors were checked regularly and the latest attempt was in late autumn of 2007. Radio communication with all sensors was established, but few surge counts were registered. Notably, one of the "trouble towers" had been struck. The result was supported by information of relatively low lightning activity in the area during the subsequent years after installation of LSA and no outages have been reported in the arrester protected circuit nor in the unprotected. No mechanical problems have been reported either, validating the arrester and hardware selection as well as installation arrangement.

Figure 7. Communication between arrester sensors and hand-held transceiver (external antenna used).

6. CONCLUSIONS

The conclusions drawn from the project can be summarized as follows:

- Line surge arresters offer a robust, efficient and cost-effective alternative for minimising or even eliminating outages due to lightning surges along important transmission lines also in countries with low ground flash density.
- The energy requirements for LSA were mainly determined by the acceptable arrester failure risk during shielding failure.
- The energy requirement for LSA was well met by arresters of IEC line discharge class 3.
- Double-circuit line outages could be eliminated by proper use of LSA on one of the circuits.
- Mechanical strength is often a function of ZnO block size and hence energy capability. Since the mechanical demands may be decisive in many cases, a higher-energy rated arrester is automatically obtained which provides additional safety margin.
- Installation procedure and hardware must be carefully selected to minimize mechanical stress on arresters and disconnectors. The disconnecting device is often mechanically weak. Hence, the conductor connecting the arrester to ground or phase must be sufficiently long to ensure that the arrester and/or the insulator can swing unrestricted. Otherwise there is a risk that the disconnecting device may break off and appear to have electrically disconnected at a subsequent field inspection.

7. BIBLIOGRAPHY

[1] CIGRÉ Technical Brochure No. 63, "Guide to Procedures for Estimating the Lightning Performance of Transmission Lines", 1991.

[2] R.B. Anderson, A.J. Eriksson, "Lightning Parameters for Engineering Application", Electra, No. 69, March 1980.

[3] A.R. Hileman, "Insulation Coordination for Power Systems", Marcel Dekker, Inc. 1999.

[4] K. Berger, R.B. Anderson, J. Kröninger, "Parameters of Lightning Flashes", Electra, No. 41, July 1975.

[5] L. Stenström, J. Lundquist, "Selection, Dimensioning and Testing of Line Surge Arresters", presented at the CIGRÉ International Workshop on Line Surge Arresters and Lightning, Rio de Janeiro - Brazil -April 24 -26, 1996.

[6] L. Stenström, J. Lundquist, "Energy Stress on Transmission Line Arresters Considering the Total Lightning Charge Distribution", presented at the IEEE/PES Transmission and Distribution Conference and Exposition, Los Angeles, September 15-20, 1996.

[7] ABB Publ. SESWG/A 2110E, edition 2, May 1999, "PEXLINK, transmission line protection for disturbance free system operation."

[8] IEC 60099-4, Edition 2.1, 2006-07.

[9] D. Loudon et al, "A compact 420 kV line utilising line surge arresters for areas with low isokeraunic levels", CIGRÉ paper 22/33/36-08, Paris 1998