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Effective Performance of Surge Arrester in EHV and UHV Lines



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Abstract In modern power system whenever failures take place, it interrupts power supply and sometimes cause system outages. Lightning and switching over voltage are one of the reasons for power system failure. Over voltage due to natural lightning is most hazardous phenomenon which can cause severe damages which results in system outage. Natural lightning stroke when discharges through the system equipment, few thousands of Ampere current flows through the entire system. Hence, system voltage level increases extremely high above the system voltage. The power system must be capable to withstand and protected against such over voltages. There are many different protection schemes for lightning surges are adopted out of that surge arresters (SA) are most commonly used for protection against lightning surges. From different types of surge arresters, metal oxide surge arrester (MOSA) has best non-linear characteristics. In this paper, performance evaluation of MOSA on 765 kV single circuit line is taken into consideration. Effect of location of MOSA from power transformer terminal is analyzed with respect to location of lightning strikes. Also, effect on transmission line voltage and effect of tower footing resistance is also considered. Modeling of all line parameters and surge arrester and their simulation is done using EMTP-RV program and its results are discussed in detail.

Keywords Over voltage · Surge arrester · Lightning stroke

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1 Introduction

There are millions of lightning strikes takes place in nature across the globe. Lightning phenomenon is natural and cannot be avoided. For the overhead lines (OHLs), there is high risk of lightning, which cause the failure and outages of the system. Lightning stroke generates traveling waves in the transmission lines, which causes over voltages in the system. Such lightning over voltage damages the system insulation. Hence, disturbances in transmission line due to lightning strikes needs to be mitigated. The increase in power demand rises the new levels of transmission voltages, which increase the lightning hazards of the line. The study of insulation co-ordination of switchgear and equipment of substation at Extra High Voltage (EHV) are very important, since the selection of insulation dominates the cost and safety of equipment and switchgear [1]. As for ultra high voltages (UHV) are installed at larger height and have large spans thus have more exposure for lightning strikes. Thus, it is important to protect the EHV and UHV transmission lines. In the electrical power system for the protection of surges many different protection elements are used. For 765 kV lines, there are effects of switching and lightning surges. For lightning surge protection, shielding wire, ground wire, and surge arresters are used [2]. For substation equipment like transformers surge arrester are most common in use. There are many different types of arresters are there in system. Out of all metal oxide, type arresters are most common in use (MOSA). Arrester used in transmission line are known as line surge arrester (LSA). For OHL's protection the insulation plays an important role, the BIL of the line is important aspect for lightning strike performance on OHLs. LSA is connected between line and ground of tower. For improvement in lightning surge mitigation and to know the protection margin in insulation performance of surge arrester must be studied. A study has been carried out to investigate the over voltages occurring due to switching and lightning, which affects an Air Insulated Substation (AIS) [1]. MOSA is the main measure to limit the over voltage of lightning invasion wave in high voltage substation. MOSA directly determines the lightning impulse insulation level of substation equipment and the lightning protection safety of equipment [3]. Over voltage in the power system is a voltage that can only be retained for a limited time [3]. Lightning has fast front wave and slow tail wave. According to IEC: 60060 standards, the lightning voltage waveform is 1.2/50 μ s and lightning current waveform is 8/20 μ s [4]. This standard wave of lightning is presented on transmission line for the experiments.

Here the different components have modeled and simulated. A transmission line of 765 kV of certain length is considered in this paper. With this line, total system of 765 kV including substation, lightning model is used. For simulation, EMTP-RV program is used. To analyze the increase in voltage due to lightning the above software is used. In this paper, analysis of the lightning strike on ground wire by simulation have been carried out. The obtained results of the simulation are discussed in this paper.

2 Methodology

UHV power lines as its large distributed capacitance, more easily lead to over-voltage generator self-excitation, while faster and higher over-voltage process [5, 6]. With the construction of high voltage transmission lines, over-voltage surges problem will become more prominent.

For the evaluation of surge arrester performance, it is connected at three different locations at substation from transformer. The location of the surge arrester has been considered as 5 m, 10 m and 20 m from transformer HV terminal. The location of lightning strike has been considered at distance of 20 m, 500 m and 1000 m from the transformer HV terminal. The waveform of the surge current of 50 kA and 100 kA is considered as $8/20 \mu\text{s}$. The effect of lightning strike on shield wire at different location is simulated using EMTP-RV software. The over voltage across arrester is computed in the software for the different location. Then position of arrester is changed and effect of lightning strike on the system has been analyzed and so on for different position of arrester has been analyzed. The performance and effect of surge arrester has been analyzed. The surge on the line due to lightning has been computed in simulation, this transient analysis has been done through the EMTP-RV program. For analysis, modeling of different parameters of system should be taken into account. Simulation details and simulation results are given further in Sects. 3 and 4, respectively.

3 Simulation

Nowadays, many researchers widely use EMTP-RV software for simulating power system and its transient analysis [7]. The various design parameters and circuit used for simulation is given in Fig. 1.

3.1 Lightning Parameters

Lightning is taken as a huge source of current. In modeling of lightning, surge of current source is applied on line. When lightning strikes the overhead lines, the rise in voltage in the grounding system is according to $U = R \cdot i$ and the voltage produced in phase conductor $U = L \text{ di/dt}$. And the rate of rise of surge given as di/dt , it gives the steepness of the surge waveform, more the steepness more the stress on insulation and protection system. For lightning surge CIGRE model is used.

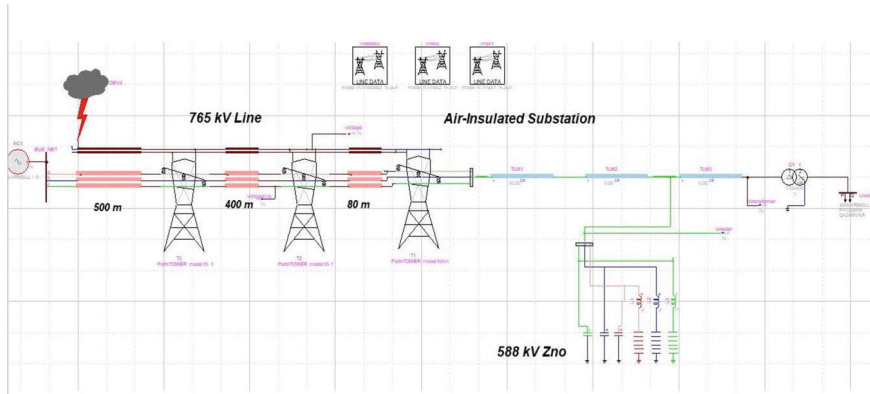


Fig. 1 Simulation diagram

3.2 Arrester Model

Arrester for overhead lines are MOSA's, with non-linear resistors constructed from zinc-oxide (ZnO) blocks [1]. ZnO has good non-linear voltammetry characteristic. The Metal Oxide surge arrester's representation is notably different when it comes to fast front transients [1]. For modeling of arrester, both types of surges on the line must be taken into account. As above lightning is fast front transient, so for analysis of it on arrester, proper model of it must be selected. Here for simulation ZnO blocks are used. Proper arrester properties are given to these blocks. The case of arrester on all the phase is being analyzed. For analysis IEEE model of arrester is being utilized [13]. In the analysis the rating of arrester considered is 588 kV. Two types of ZnO blocks used and various data of these blocks are given in Table 1.

3.3 Arrester Selection

Objective of selecting any lightning arrester is to select the lowest rated surge arrester such that it gives complete protection of the insulation of any equipment. The lightning arrester with the minimum rating is selected since it gives the greatest margin of protection for the specific insulation in level. The higher the rating of arrester, greater the arrester's ability to survive in the power system, but it decreases the protection margin which it gives for a particular insulation level [1].

Table 1 I-V characteristics of surge arresters A0 and A1

I(kA)	Value of A0	Value of A1
0.000002	1.8762	1.5023
0.1	2.2223	1.8462
1	2.4231	2.0423
2	2.5108	2.1485
4	2.5962	2.2223
6	2.6262	2.2523
8	2.6977	2.2985
10	2.7415	2.3285
12	2.7831	2.3423
14	2.8408	2.3723
16	2.8846	2.3885
18	2.9562	2.4023
20	3.0300	2.4185

Adapted from [9, 14]

3.4 Arrester Data

In the data of arrester, many different ratings are considered. For a 765 kV line rating of arrester ranges between 555 kV and 690 kV. Arrester nominal discharge current is 20 kA. Residual voltage is taken as 1020 kV–1530 kV.

3.5 Tower Modeling

For modeling of tower, many parameters are to be calculated. Surge impedance, height of tower, velocity of propagation of traveling wave, are need to know for analysis. The design parameters considered are given in Table 2, Adapted from [8, 10, 11, 15]. Velocity of propagation is taken as 80% of velocity of light, i.e., $3e8$ m/s.

Table 2 Parameter of tower design

Parameter of tower	Value
Height	99 m
Diameter of bottom	15.5 m
Footing impedance	2Ω

Table 3 Line parameters

Parameter	Value
No. of circuit	1
Conductor type	Bersimis
Conductor per phase	4
Insulator length	4.8 m
Span length	1 km
Conductor diameter	33.56 mm
BIL	1950 kVp
Shielding angle at tower	– 8.0
OHGW diameter	11.10 mm

3.6 Line Modeling

In modeling of line various parameter are considered which are given in Table 3, Adapted from [8, 14]. Modeling of phase conductor, tower footing resistance, height of tower and span of transmission line. As above the single circuit parameter are considered. For phase conductor (cardinal) DC specific resistance is 0.045 ohms/km. and for OHGW DC specific resistance is 3.605 ohms/km.

3.7 Substation Design

MOSA is the main measure to limit the over voltage of lightning invasion wave in UHV AC substation, which directly determines the lightning impulse insulation level of substation equipment and the lightning protection safety of equipment [3, 10, 12]. For BIL selection of station IEC standards are used. For the design of substation power transformer and various equipment are modeled [9]. A substation of 765 kV/400 kV is taken into account. HV side transmission line is taken for analysis of in this paper. Ratings of transformer is taken as 315 MVA. And the load connected to it is taken as R-L-C. Location of arrester is taken with respect to the station transformer.

4 Results and Discussion

As stated above different position of arrester is being simulated with respect to the lightning at certain distance on the line on the 765 kV side. The effect on voltage due to lightning is being observed. Disturbance in voltage wave at the incoming at transformer terminal in all the phase is observed and analyzed. These are the values of ZnO blocks which are used for IEEE modeling of arrester. Table 3 describes the non-linear characteristics of the arrester. This shows the I-V characteristics of both

the blocks. Placement of arrester is done at 5m, 10m and 20m distance from the power transformer (Tables 4 and Table 5).

At all this position lightning surge effect and its impact is studied. For these position lightning strikes at three different locations. Lightning current of 50–100 kA are considered.

The above two observation shows that for these two values of current, value of over voltage (OV) for different phase and different distance of lightning strike comes out to be different.

Table 4 Observation data for 50 kA lightning current

Distance of Lightning strike from Transformer	Voltage across each phase in kV due to lightning Surge of 50 kA			
	Location of surge arrester from transformer			
	Phase	5 m	10 m	20 m
1000 m	Phase A	443.81	499.87	502.47
	Phase B	450.27	450.47	451.17
	Phase C	460.87	460.77	459.47
500 m	Phase A	444.77	444.57	445.07
	Phase B	500.67	500.68	502.17
	Phase C	521.27	520.97	521.57
20 m	Phase A	660.67	673.67	664.17
	Phase B	912.67	910.37	910.87
	Phase C	882.87	881.87	883.87

Table 5 Observation data for 100 kA lightning current

Distance of Lightning strike from Transformer	Voltage across each phase in kV due to lightning Surge of 100 kA			
	Location of Surge Arrester from Transformer			
	Phase	5 m	10 m	20 m
1000 m	Phase A	680.37	689.47	689.77
	Phase B	599.67	599.27	604.07
	Phase C	565.37	561.17	566.67
500 m	Phase A	656.37	754.27	713.07
	Phase B	614.77	614.07	613.07
	Phase C	795.77	794.57	795.27
20 m	Phase A	626.67	814.67	804.67
	Phase B	791.97	778.27	777.37
	Phase C	905.37	909.77	911.67

So, for the value of arrester (588 kV) it gives good value for 50 kA current lightning strike and also that the surge arrester in different phase at different position from power transformer shows different effect, but for same phase the shows minute change according to position of arrester. The highest value of OV is seen if the lightning strike at 20 m from the HV terminal of transformer. For 100kA the highest value seen when lightning strikes at 20 m from Transformer HV terminal and also the phase A shows highest OV. It is to be noted that in all the cases of 50 kA and 100 kA lightning surge, the voltage appears in the system is less than the residual voltage of surge arrester. Hence, system is well protected against the lightning surges. These figures (Figs. 2 and 3) show the impact of lightning current at 500 m on the voltage wave at transformer. Figures 4, 5 and 6 shows effect of lightning on different phases of transformer during lightning strikes at 500 m.

This shows the impact on different phase of transformer. From Table 4, among all phases, phase C has the highest OV while phase A has the least. Similarly, for 100 kA surge shown in Table 5 over voltage is highest for phase C. The reason for this is shielding effect of ground wire is least for the phase at the bottom of the tower.

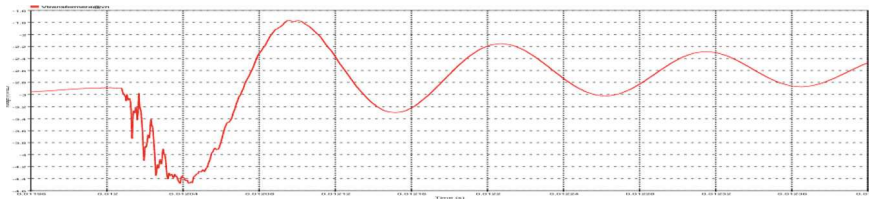


Fig. 2 Output waveform for 50kA strikes at 500 m for transformer phase A

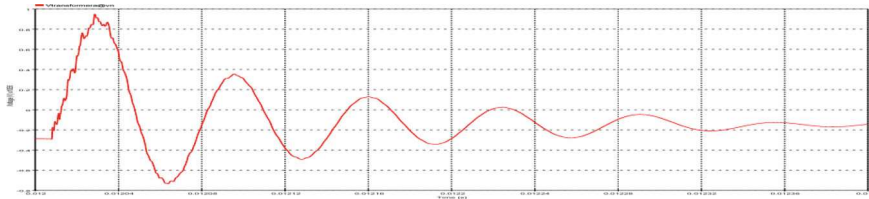


Fig. 3 Output waveform for 100 kA strikes at 500 m for transformer phase A

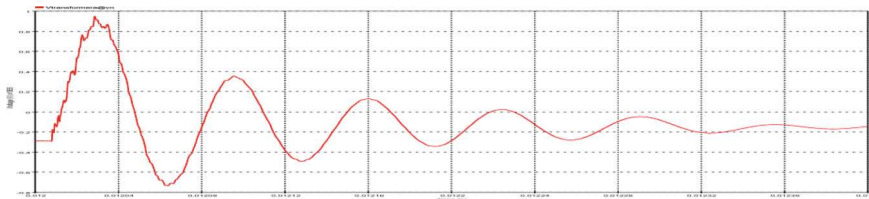


Fig. 4 Surge voltage across phase A of transformer during lightning at 500 m

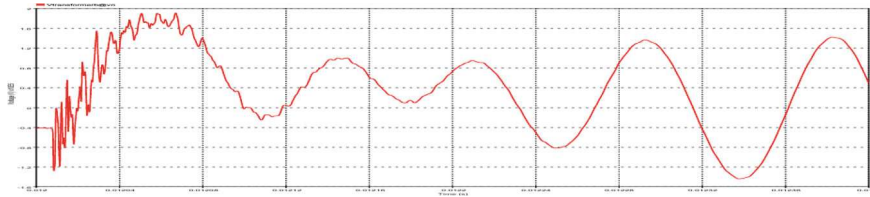


Fig. 5 Surge voltage across phase B of transformer during lightning at 500 m

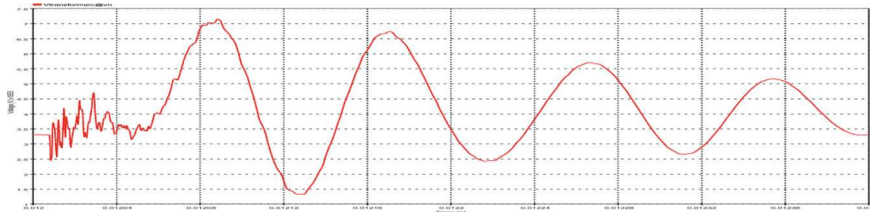


Fig. 6 Surge voltage across phase C of transformer during lightning at 500 m

The best shielding effect of arrester is seen when arrester connected in in all phases at incoming of transformer. For the lightning strike at the nearest point, i.e., the first tower at substation then arrester must be placed near to the transformer. But for the lightning strike at some distance (distance 500–1000 m) the best overall position of arrester is 10 m from the transformer. Hence, to protect all the possibilities of lightning surges, arrester can be kept near to the transformer.

5 Conclusion

This simulation analysis results shows the effective performance of surge arrester during lightning surges for UHV lines and systems. All the observed data show that the selected ratings of surge arrester is suitable system for the surge current magnitude of 50–100 kA. Surge arrester subsided the over voltage and does not allow the voltage to increase beyond system insulation level (BIL). The optimal position of arrester comes out to be the 5 m for 50 kA lightning surge and for the 100 kA surge. Thus, the analysis of lightning to be done for the position of placement of arrester in the substation. The study results are useful for the utility engineers and system design engineers to decide the optimal location of surge arrester.

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