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Optimal Location of Surge Arrester for Protection of 220kV Transmission Line Against Lightning Over Voltages Using EMTP-RV Software

Shaswat Dwivedi [1], Anil S. Khopkar [2], Hemang Tailor [3]
[1] The Maharaja Sayajirao University of Baroda, Vadodara, India
[2] Electrical Research And Development Association (ERDA), Vadodara, India
[3] The Maharaja Sayajirao University of Baroda, Vadodara, India

ABSTRACT: Natural Lightning strikes are the main cause of over voltages in the power system. Such lightning over voltages can damage the system insulation if sufficient protections are not provided to the system. In the power system ground wire or shield wires are placed on top of the transmission line tower for the protection of transmission lines against lightning strikes. Surge arresters are also connected in the system for the protection against lightning strikes which protect the system by not allowing surge voltage beyond the permissible limit. Hence, study of lightning surges, location of surge arrester and its rating selection is very crucial parameters. For transmission system equipment lightning surge and switching surges have impact on its insulation system. For protection of the system against such over voltages, Surge Arresters (SA) are connected. In this paper study on overhead transmission line of 220 kV is taken under consideration. Analysis of lightning on 220 kV transmission line is performed and its effective ness are computed with different location of surge arrester and location of lightning strikes. Effect of tower footing resistance, Magnitude of surge voltage on primary side of transformer, transferred voltage on secondary winding is computed and presented in this paper. Further effect of surge with at various locations from the transformer with and without surge arrester is computed in EMTP-RV software and results are discussed in details. Modelling of lightning study is performed using EMTP-RV software.

KEYWORDS: lightning, over voltage, Surge Arrester, EMTP-RV

I. INTRODUCTION

Lightning is natural phenomenon where charge discharges through the huge global capacitor. Basically, there are two types of lightning discharges occurs in nature, cloud-to-cloud and cloud-to-ground. When lightning strikes on transmission line it generates surge voltage on the line. This surges generates over voltage on power system equipment. This may damage the system insulation and cause system outages, and sometimes damages the power system equipment. Thus, surge arresters are employed for over voltage surge protection. Nowadays gap less surge arrester constructed by Zinc oxide elements are used due to its non-linear characteristics. Metal oxide surge arrester (MOSA) is most common in use type for arrester in power system. Other types of arresters such as gaped and externally gapped lightning arrester (EGLA). MOSA are constructed using different MOV (Metal Oxide Varistor) blocks to provide nonlinear voltage-resistance characteristics. For improvement in lightning surge mitigation and to know the protection margin in insulation performance of Surge Arrester must be studied. MOSA is the main measure to limit the over-voltage of lightning invasion wave in high voltage substation.

Here the analysis of 220 kV transmission line is considered. From the aspect of Indian grid scenario, 220 kV lines covers 44% of overall transmission lines [1]. From this it is important to analyze lightning on 220 kV lines. As these overhead lines (OHL’s) are prone to lightning strike, thus the overvoltage cause by the lightning can be minimized. Which lead to reduction in outages caused by lightning and in order to provide unobstructed power supply, it is essential to study Lightning generated over voltages and its mitigation.

This paper analyses the effect of MOSA on 220 kV line, when lightning strikes the ground wire. Here different components have been modelled for the performance analysis of the line. For simulation, EMTP-RV program is used. To analyse the increase in voltage due to lightning the above software is used. In this paper performance analysis of 220 kV TL when lightning strike on ground wire by simulation have been carried out. The effect of MOSA, its location from the protective equipment, distance of lightning strike from MOSA and protective equipment have been analysed. The impact of lightning on different phases has been evaluated [2]. For the simulation TFR (tower footing resistance) static and non-uniform both the models are used [3]. The effect of transferred surge from primary winding of transformer to secondary winding has also been analysed and discussed in details. The obtained results of the simulation are discussed in this paper.

II. SIMLUATION

Different models are simulated as per standard [4] using EMTP-RV software to derive optimal location of surge arrester in the system. This software is one of the frequently used for transient and surge analysis of the power system. Modeling of different parameter are given below. Modeling of circuit is done as per Fig 1, which shows the methodology of this paper.

A. *Lightning stroke*

Lightning discharge is taken as current source. It is the current source is directly modelled on the transmission line connected on ground wire. For this line, the rise in voltage in the grounding system is according to $U = R \cdot i$ and the voltage produced in phase conductor $U = L\frac{di}{dt}$. The steepness of waveform is given by rate of change of current with respect to time i.e., $\frac{di}{dt}$, which is rise time of impulse current wave. The waveform utilised is 1.2/50 µs as per Standard CIGRE guideline.

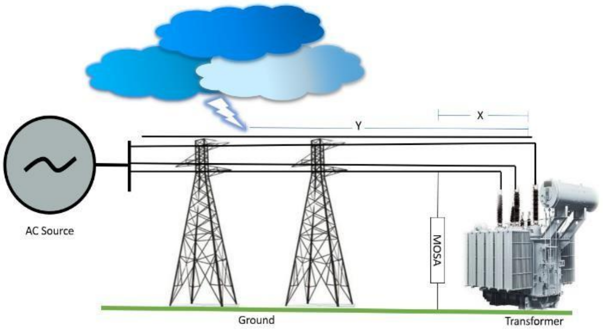

Fig1: Simulation of line

B. *Tower modelling:*

Though the tower is equipped with power lines and ground wire we calculated impedance of tower alone. A multistorey model of tower is modelled.

$$Z_t = 60\left(\ln \frac{H}{r} - 1\right) \tag{1}$$

$$r = \left(\frac{r_1 h_1 + r_2 h_2 + r_3 h_3}{2H}\right) \tag{2}$$

$$H = \sum_{i=1}^{3} h_i \tag{3}$$

$$R_i = \frac{-2Z_t \ln\sqrt{\gamma}}{h_1+h_2+h_3} h_i \text{ , i=1..3} \tag{4}$$

$$R_4 = -2Z_t \ln\sqrt{\gamma} \tag{5}$$

$$L_i = \frac{\alpha R_i 2H}{V_i} \text{ , i=1..4} \tag{6}$$

Where,

Z_t: Tower impedance in [Ω], H: Tower height in [m], R_i: Resistances of sections in [Ω], L_i: Inductances of sections in [mH], γ: Attenuation coefficient, α: Damping coefficient, v_i: propagation velocity, R_f: tower footing resistance [5]. Its modelling is shown in Fig 3 [6]. Lightning strike on ground wire of tower is considered. This strike is simulated as per [7].

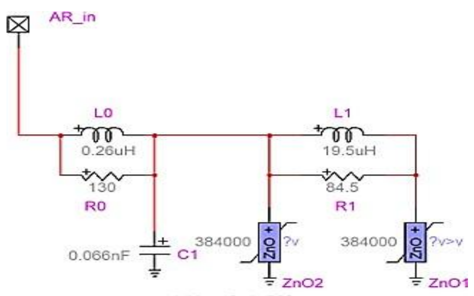

Fig. 2: Frequency dependent IEEE model of arrester

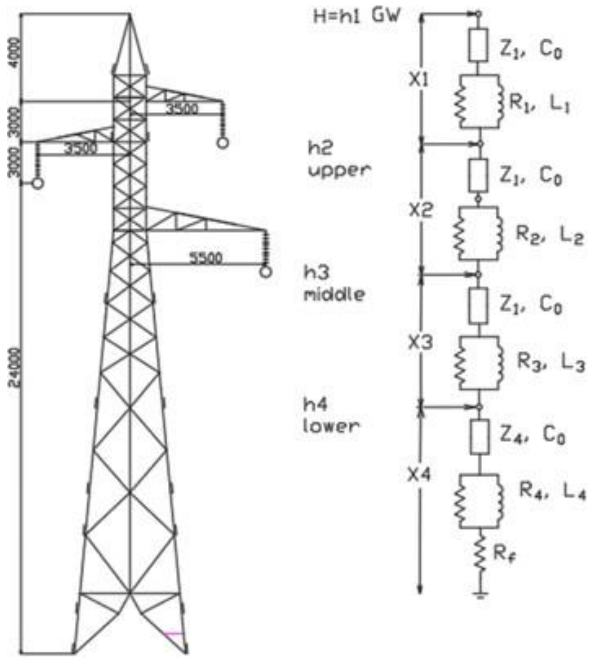

Fig3: modeling of tower as multi storey model

C. *Arrester modelling*

For modeling, MOSA's are used for analysis and modelled the same. ZnO has good non- linear voltammetry characteristic. The Metal Oxide surge arrester's representation is notably different when it comes to fast front transients [8]. For the purpose of mitigating over-voltage resulting from lightning strikes on the ground wire of a studied 220 kV D/C transmission line, the MOV type IEEE frequency dependent surge arrester model introduced in [5,9] was employed. Calculation of parameter from [10]:

$$L1 = 15\left(\frac{d}{n}\right) \mu H \tag{7}$$

$$R1 = 65\left(\frac{d}{n}\right) \Omega \tag{8}$$

$$L0 = 0.2\left(\frac{d}{n}\right) \mu H \tag{9}$$

$$R0 = 100\left(\frac{d}{n}\right) \Omega \tag{10}$$

$$C0 = 100\left(\frac{n}{d}\right) pF \tag{11}$$

Where: d = height of arrester; n = no. of parallel MOV blocks here height considered is 2.6 m and two parallel blocks are used as in IEEE frequency dependent model as shown in Fig2. For the same parameter calculated are shown in Table-I

Table I: Arrester parameter calculated

Parameters	*Values*
R0 (Ω)	129.40
R1 (Ω)	84.11
L0 (µH)	0.2588
L1 (µH)	19.41
C (pF)	77.2797

Rating of arrester is taken as 192 kV, by considering MCOV to be 152 kV.

D. Line parameters

For this study various line parameter considered are given in table:2. Modelling of phase conductor, tower footing resistance, height of tower and span of transmission line are given in table II. [5,10] As above the single circuit parameter are considered.

Table II: Line parameters

Parameters	***Values***
No. of circuit	1
Conductor type	Zebra
Conductor per phase	2
Insulator length	2.24 m
Span length	62 km
Conductor diameter	28.6 mm
BIL	950
System	4-wire, Y- connected
Ground wire type	Weasel
Ground wire diameter	7.77M

III.METHODOLOGY

Here the impact of arrester connected on primary side of the transformer in the intermediate substation at different location is considered. its impact on the secondary side of transformer is also assessed. The case of without arrester is taken as the base case. The lightning current of 20 kA and 40 kA are considered. Its impact for different location of lightning (Y {from fig 1}) from the transformer is studied. The effect of lightning strike for different current magnitude of 20 kA and 40 kA has been simulated for the non uniform TFR. The location of lightning strike form transformer and its effect with various position of surge arrester (X {from fig 1}) has been evaluated. The impact of different value for static TFR is analysed.

To check the impact on secondary, transformation ratio has been calculated. The results of simulation have been evaluated and compared with basic insulation level of the system.

IV. RESULTS AND ANALYSIS

The observed data for the system are considered in different cases. Different cases for lightning strike current, arrester position, footing resistance are studied and measured. Observation of different arrester position at different lightning strike current are simulated by considering the parameter defined in the section-2. Here six cases are considered as mentioned in table III

Table III: Cases considered

Sr.No.	***Cases***	***Description***
1	*Case 1*	Nominal case (without arrester),
2	*Case 2*	Analysis of 20 kA lightning current on system
3	*Case 3*	Analysis of 40 kA lightning current on system
4	*Case 4*	Analysis of 20 kA lightning current for 10 Ω and 40 Ω TFR
5	*Case 5*	Analysis of 40 kA lightning current for 10 Ω and 40 Ω TFR
6	*Case 6*	Analysing effect of arrester on secondary of transformer

Case1:

This case is considered for study and comparison purpose only. This shows rise in phase voltages when arrester is not connected as shown in Fig4. This will be the reference for the following cases.

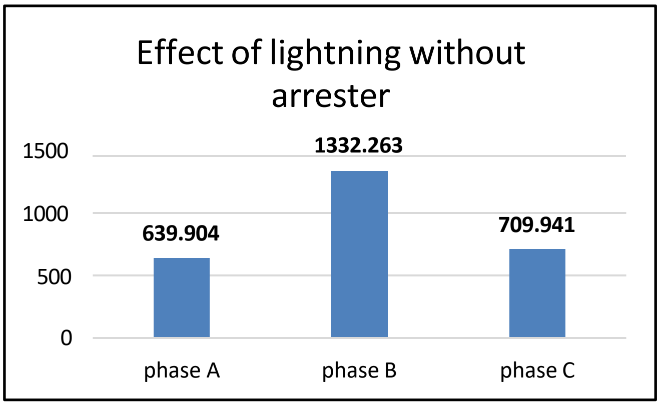

Fig. 4: Effect of lightning on each phase

Case-2

This case analyses the effect of arrester position for rise in voltage of all three phases of 220kV transformer winding. Impact of the same is shown in Fig5. For different distance of lightning strike voltage is recorded in Table IV.

Case-3

This case is similar with case2 just the lightning current changes to 40 kA. Its impact is shown in Fig6. The data of this for different lightning strike distance is shown in Table V.

Case-4

In this case analysis of TFR of different value analysed for different position of arrester for 20 kA lightning current. Analysis of this is shown in Fig7. Observed data for this is in Table VI, 20 kA row.

Case-5

Similar analysis as per case-4 is done for the lightning current taken as 40 kA. Its analysis shown in Fig8. The observed data in Table VI, 40 kA row.

Case-6

Here analysis of effect of arrester position connected in primary (i.e.,220kV) on secondary (i.e.,66kV) for both 20 kA and 40 kA lightning current. Measured data for this is in Table-VII effect is shown in Fig 9.

Table IV: observation for 20 kA lightning current

Distance of lightning strike (Y)	**Arrester position (X)**	**Voltage when lightning current is 20kA (kV)**		
		Phase A	**Phase B**	**Phase C**
0.02km	***5m***	246.06	500.653	243.502
	10m	269.493	543.624	277.352
	20m	265.255	548.435	271.874
1.02km	***5m***	479.019	404.287	389.915
	10m	484.855	403.131	405.26
	20m	543.112	570.486	541.381
21.02km	***5m***	444.362	352.435	373.375
	10m	444.891	352.634	374.662
	20m	443.731	352.233	373.335
41.02km	***5m***	436.741	347.766	363.585
	10m	437.064	347.913	363.881
	20m	437.769	347.872	363.919

Table V: observation for 40 kA lightning current

Distance of lightning strike (Y)	**Arrester position (X)**	**Voltage when lightning current is 40kA (kV)**		
		Phase A	**Phase B**	**Phase C**
0.02km	*5m*	532.383	514.879	483.125
	10m	567.013	555.054	505.942
	20m	560.554	574.618	483.812
1.02km	*5m*	538.719	465.133	507.367
	10m	581.067	484.472	533.306
	20m	550.702	478.971	474.461
21.02km	*5m*	479.845	389.782	414.117
	10m	485.607	389.563	414.96
	20m	494.823	395.119	419.789
41.02km	*5m*	471.909	382.03	401.906
	10m	474.72	384.187	406.784
	20m	478.857	388.981	410.114

Table VI: Observation of TFR

Lightning current	**Arrester position(X)**	**Voltage when TFR (kV)**	
		10ohms	**40ohms**
20kA	*5m*	436.929	437.725
	10m	437.252	438.058
	20m	437.958	438.78
40kA	*5m*	472.091	472.912
	10m	474.909	475.768
	20m	479.048	479.917

Table VII: effect of arrester and lightning strike on secondary

Distance of lightning strike (Y)	**Arrester position (X)**	**Voltage at lightning current (kV)**	
		20 kA	**40 kA**
1.02km	*5m*	40.529	46.223
	10m	41.109	46.496
	20m	41.202	46.678
21.02km	*5m*	42.8	40.511
	10m	43.88	43.113
	20m	42.818	40.476
41.02km	*5m*	41.43	40.17
	10m	42.554	40.183
	20m	40.292	40.166

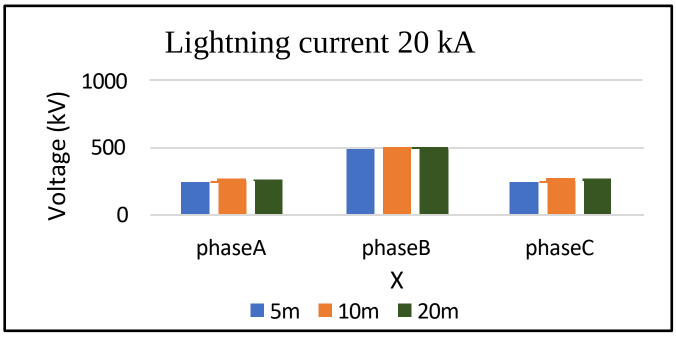

Fig5: effect of arrester position on different phase for 20kA lightning current

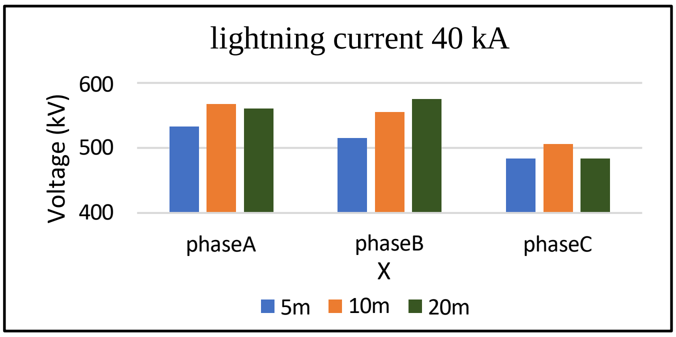

Fig6: Effect of arrester position on different phase for 40kA lightning current

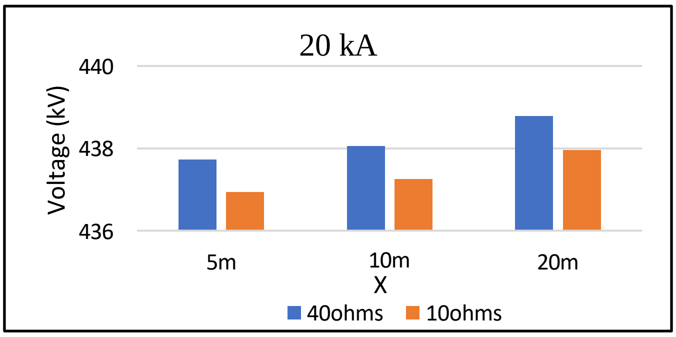

Fig7: Effect of arrester position for 20 ohms & 40 ohms TFR for 20kA lightning current

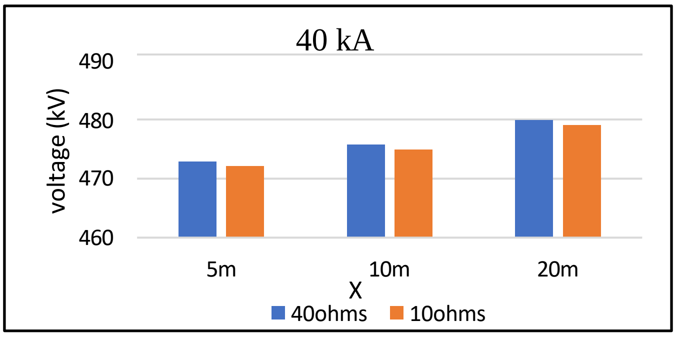

Fig8: Effect of arrester position for 20ohms & 40ohms TFR for 40kA lightning current

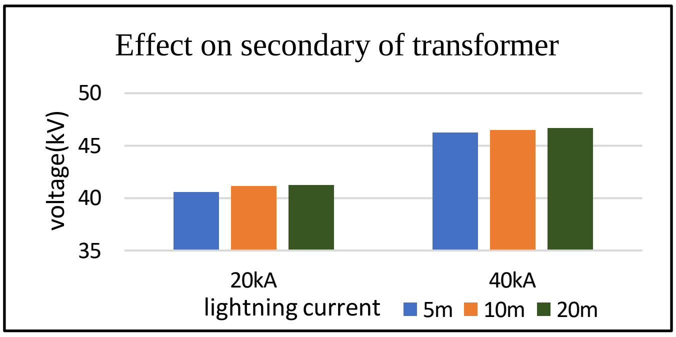

Fig9: Effect of arrester position on 220kV side on 66kV side of transformer

- It is noted that least value of voltage rise is seen when arrester placed at 5m from the in case-2 the value is 246.03 kV and for case-3 the value is 532.3 kV.
- The same is observed for all the other phases that least value when X is 5m shown in Fig 5a & Fig 5b.
- It is observed that for lightning current of 20kA (case-4) the least spike of voltage is noted when X is 5m for

both the value of TFR, for 10 ohms the value is 436.9 kV and for 40 ohms the value is 437.72 kV.

- Similarly for case-5, 472 kV for 10 ohms and for 40 ohms TFR the value is 47.97 kV.
- Case-6 the transfer of surge from higher level side to lower-level side is considered. There is small change observed in the secondary waveform. However least value observed when arrester placed at 5m from the primary of the transformer.
- The values obtained at secondary for 20 kA is 41.109 kV and for 40 kA is 46.223 kV.
- To note that all the values are less than the case-1 it shows that the impact of lightning on transformer is reduced. Thus, the analysis shows the increase in protection without increasing the rating of arrester.

V. CONCLUSION

In this paper analysis of lightning strike on 220 kV transmission line is computed with different location of surge arrester, location of lightning strikes, different value of TFR and different values of lightning current magnitude. From the results it is concluded that for different magnitude of lightning current the placement of surge arrester at 5m from the transformer shows the least rise in voltage and it is same for different phases at different current. Similarly for higher TFR the position near to transformer gives better protection margin. And also studied the lightning effect form the point of distance of strike, and observed that as the striking distance increases from transformer the overvoltage across the phases reduces. Thus, for better protection of transformer and to improve the protection margin the surge arrester should be connected near i.e within 5 m from transformer.

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