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# Role of Metal Oxide Surge Arrester for Power System Protection Against Lightning Overvoltage

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**ABSTRACT**

Overvoltage is one of the major factors for the insulation failure in the power system. Thus, it is basic role of system designed to protect the insulation system against such voltage surges. Main reason of overvoltage in the power system is natural lightning as well as switching operations of large loads. Overvoltage generated due to switching operations are called switching overvoltage and generated due to natural lightning are called lightning overvoltage. Lightning overvoltage is very unpredictable as it does not depend on system voltage. As the overhead lines and substation equipment are exposed to open environment, it is important to protect the system against lightning overvoltage. Substation equipment such as transformer, cables, insulator etc. must be designed withstand against lightning overvoltage. Also, system must be protected from such overvoltage. Various methods such as shield wire; rod gaps and surge arresters are provided in the power system for protection against overvoltage. Surge arresters are one of the best measures for lightning overvoltage. Now, Metal Oxide Surge Arrester (MOSA) consisting of ZnO element are used in system due to its excellent nonlinear characteristics. However, location of MOSA in substation is critical and must be evaluated for its fast and reliable operation for system protection. For effective operation of MOSA, it must be grounded through lowest possible earth resistance. Also, tower footing resistance (TFR) plays important role for overvoltage magnitude. In this paper effective performance of MOSA with different TFR and different location of MOSA from equipment to be protected is analyzed. Analysis of lightning surge on different magnitude for 132 kV and 66 kV system has been evaluated and presented. The effect of MOSA on transferred voltage on secondary winding of transformer has been also computed considering effect of cable. EMTP-RV software has been used for the analysis of MOSA operations and results of the same has been presented in this paper.

**Key words:** MOSA, lightning overvoltage, lightning protection, surge transference, EMTP-RV

## 1. INTRODUCTION

In the scenario of electrical power system, system outages are needed to bring down. As it reduces the efficiency of the power supply. There are many factors which can cause the outages in the system. From which the surges are the factor which can lead to overvoltage in the system which can cause failure of equipment. Thus, to protect against surges, MOSA must have to be used. Sometimes MOSAs are present in the system but operating voltage of MOSA is not sufficient to protect equipment against overvoltage. Hence, it is important to study the system requirement for the effective operation, optimal location and correct rating of MOSA to be connected.

An overhead transmission line struck by lightning creates a large voltage across the insulator of the corresponding phase conductor, making it essential to investigate the characteristics of lightning-induced over-voltage in order to guarantee a safe and dependable power supply. Overvoltage due to lightning and switching surges have significant impact on substation design and insulation coordination of power systems. There are several methods that can be utilized to reduce lightning-induced power outages, including lowering tower footing resistance, improving line increasing the amount of insulation, installing additional ground wires on other buildings, and utilizing under-built ground wires. However, because of their low efficacy and expensive installation costs, techniques like installing ground wires on different structures and shield wires beneath buildings are not feasible. Installing line surge arresters is the most efficient way to get the best lightning performance in transmission lines, especially in regions with exceptionally high soil resistivity [1-3].

Quantifying and mitigating their impact in and around substations need to be investigated to allow determination of overvoltage levels and their probability throughout a substation. At high system voltages, it is generally more economical to use overvoltage protection versus increasing the insulation withstand level of equipment. MOSA are recognized as an effective means to protect against lightning and switching surges. They are characterized by faster action and superior energy absorption capability, in addition to suppressing follow-on AC current, allowing continuity of supply following operation [4,5].

Lightning surge are severe to the high voltage equipment for measure of it, insulation coordination must have to be set. Lightning strikes on the system cannot be specified as it the natural phenomenon thus, the protection range is to be taken into account for the computation. At line voltages of 132 kV and 66 kV the impact of lightning surges is more compared with the switching surges. As switching surges depend on the system voltage while lightning surges doesn't. Thus, it is important to protect this against lightning surges.

For line voltage of 66 kV to 11 kV and 132 kV to 33 kV is evaluated. All the data simulation is done using the EMTP-RV software. EMTP-RV is a software used for transient analysis; surge overvoltage evaluation is mostly done using this software. Effect of arrester distances on power transformer [6,7]; the one of the important equipment in the station and impact of TFR on the arrester distances is analyzed.

## 2. METHODOLOGY

For protection against overvoltage surge arrester is placement plays an important role. Here the arrester placed at the different location 2m, 4m, 6m, 8m and 10m from the power transformer and the effect of the same has been analyzed. Effect of surge transferred from primary side of transformer to secondary side has been analyzed the impact of tower footing resistance on MOSA operation has been analyzed. For above analysis lightning current of 10 kA is considered. Effect of Lightning surge on the system without MOSA on secondary side of transformer has been evaluated to understand is its effect. Lightning strike on the line at different location is computed. Impact of arrester lead length is also evaluated. For computation of the same the EMTP-RV software is utilized.

## 3. SIMULATION

### 3.1. Tower footing resistance

TFR comprises of resistance at base and the resistance of soil at the surrounding of tower. For line voltage the tower structure is similar thus the resistance of metal parts can be considered similar. But the footing resistance of all the tower may not be the same. For analysis of small segment of the line the footing resistance can be considered same but for long span for the analysis the uniform footing resistance is not possible [8]. Thus, for long transmission lines the non-uniform footing resistance is considered. Uniform TFR is not possible for the long spans of the transmission line. For the considered length i.e., 60 km for this the varying TFR must have to be considered. The impact of lightning in high TFR region must be studied for obstruct system outages due to lightning.

Nominal value of TFR is 10 Ω so for the analysis TFR of all towers are considered as 10 Ω, then the considered as the higher values. At higher TFR value the surge voltage at transformer rises.

### 3.2. Surge transference

Transformers are naturally vulnerable to voltage surges, particularly when they are placed in aerial circuits, due to their susceptibility to both direct and indirect strikes of lightning. As a result, internal damage such as insulation breakdown along the transformer winding can result from any encountered voltage surge. The surge transference between windings provides an additional impact [9]. It is defined as impact of surge on transformer secondary winding when lightning strikes on the primary side line. This can damage the equipment on the secondary side causing the outage. Transformer having lower voltage rating like distribution transformer prone lightning surges. This transformer is not design to handle larger power like the power transformer thus, the effect of surge transference is important to considered for study. There are many factors affecting the transference, some of them are surge magnitude, surge type, TFR, length of cable at the secondary, frequency of surge. Surges with higher frequency i.e., lightning, quickly transferred through the transformer due to fast rise time of the wave. Longer the length of the cable at secondary more the risk of propagation of surge to the more sensitive equipment. If output of transformer and cable (for secondary side) are uneven the surge will get reflected back to the transformer.

Thus, study of it is essential for surge protection. The impact of surge transference on the position of the arrester is being analyzed. For these different cases have been considered like the case of no arrester, arrester in primary and arrester on both primary and secondary.

### 3.3. Lead length

Length of cable or conductor connecting arrester to the power line connected to the protecting equipment is known as the lead length. Analysis of lead length is important for designing of the arrester in the station.

### 3.4. Modeling of parameters

In the computation of the lightning on the line various components have to be modeled using the EMTP-RV software. In modeling of the transmission line, the frequency dependent model of the line is used and the data for 132 kV and 66 kV are utilized [10,11]. Proper defined data is to be entered by calculating the surge impedance of a line. For cable cp model of line is used and impedance data are entered.
Modeling of arrester is done using the IEEE defined models, frequency dependent model of arrester is used. This contains two mov blocks, defining the properties of blocks like residual voltage rating of the arrester defining the non-linear property of the arrester using the voltage-current characteristics. And the value of another arrester parameter shown in Table 1. Tower model is formed using the impedance model, ground resistance is represented using the resistor for the with some defined value which is the soil resistivity. Velocity of surge is taken as 90% of the speed of the light as recommended in IEEE.

**Table 1:** Arrester parameters calculated

| Arrester parameter calculated | 98kv | 24kv | 48kv | 8kv |
|---|---|---|---|---|
| L1(µH) | 13.5 | 7.5 | 11.25 | 3.71 |
| L0(µH) | 0.18 | 0.1 | 0.15 | 0.05 |
| R1(Ω) | 58.5 | 32.5 | 48.75 | 16.25 |
| R0(Ω) | 90 | 50 | 75 | 25 |
| C1(nF) | 0.111 | 0.2 | 0.133 | 0.4 |

## 4. OBSERVATION AND ANALYSIS

**Table 2:** For the analysis the five different cases are considered

| Case | Description |
|---|---|
| Case1 | Analysis for arrester connected |
| Case2 | Effect of TFR on arrester protection |
| Case3 | Surge transference, without arrester at secondary |
| Case4 | Surge transference, with arrester at secondary |
| Case5 | Effect of lead length of arrester in surge transference. |

Table 2 above shows the analysis the five different cases are considered

**Case-1:**
Case of arrester position from the transformer is observed. Its observation is shown in Table 3 & Table 4.

**Table 3:** Observation for 66 kV

| Arrester location from Transformer | rise in voltage with location of lightning on line (kV) | |
|---|---|---|
| | lightning strike at 0.5 km | lightning strike at 20km |
| 2m | 85.724 | 83.525 |
| 4m | 137.966 | 100.266 |
| 6m | 138.335 | 101.995 |
| 8m | 143.079 | 104.786 |
| 10m | 186.989 | 121.936 |

**Table 4:** Observation for 132 kV

| Arrester location from Transformer | Rise in voltage with location of lightning on line (kV) | |
|---|---|---|
| | lightning strike at 0.5 km | lightning strike at 20km |
| 2m | 185.946 | 179.184 |
| 4m | 257.31 | 267.4 |
| 6m | 282.403 | 270.113 |
| 8m | 282.26 | 274.728 |
| 10m | 324.967 | 279.989 |

**Case-2:**
Effect of TFR with the location of arrester for TFR value of 10Ω and 20Ω for the lightning strike at 0.5km is observed in Table 5 & Table 6. And its analysis is shown in the Figure 1 & Figure 2.

**Table 5:** Observation of TFR for 66kV

| Arrester location from Transformer | rise in voltage with TFR of line (kV) | |
|---|---|---|
| | 10 ohms | 20 ohms |
| 2m | 85.724 | 91.187 |
| 4m | 137.966 | 138.22 |
| 6m | 138.335 | 158.941 |
| 8m | 143.079 | 185.489 |
| 10m | 186.989 | 201.481 |

**Table 6:** Observation of TFR for 132kV

| Arrester location from Transformer | rise in voltage with TFR of line (kV) | |
|---|---|---|
| | 10 ohms | 20 ohms |
| 2m | 185.946 | 186.58 |
| 4m | 257.31 | 262.905 |
| 6m | 282.403 | 282.276 |
| 8m | 282.26 | 290.11 |
| 10m | 324.967 | 333.724 |

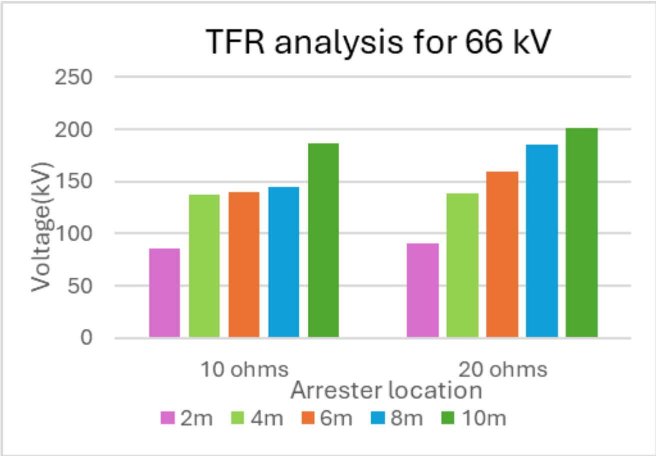


**Figure 1:** Analysis of TFR for 66kV

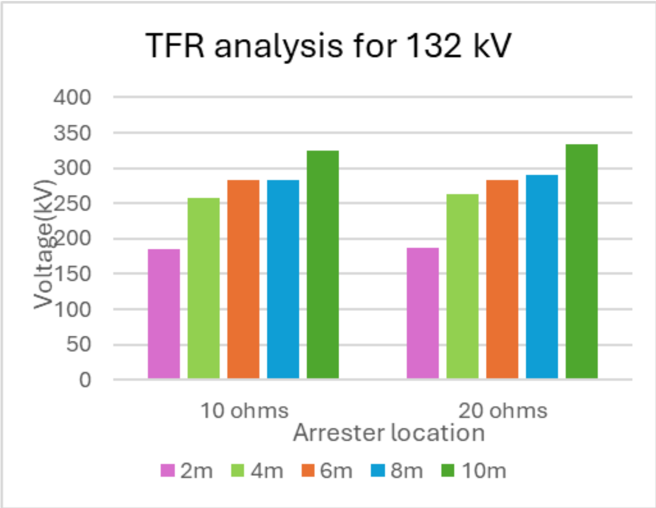


**Figure 2**: Analysis of TFR for 132Kv

**Case-3:**
Observed the effect of surge transference without connecting the arrester at the secondary of the transformer in the station. Rise in voltage at secondary i.e., 11 kV and 33 kV is in Table 7 & Table 8. Analysis shown in Figure 3 & Figure 4.

**Table 7:** Effect of surge transference at 11 kV w/o Arrester

| Arrester location from Transformer | surge transference W/O arrester with location of lightning on line (kV) | |
|---|---|---|
| | lightning strike at 0.5 km | lightning strike at 20km |
| 2m | 17.11 | 14.273 |
| 4m | 23.599 | 16.395 |
| 6m | 25.714 | 23.227 |
| 8m | 26.025 | 23.436 |
| 10m | 28.571 | 24.341 |

**Table 8:** Effect of surge transference at 33 kV w/o Arrester

| Arrester location from Transformer | Surge transference W/O arrester with location of lightning on line (kV) | |
|---|---|---|
| | lightning strike at 0.5 km | lightning strike at 20km |
| 2m | 51.186 | 44.103 |
| 4m | 57.705 | 58.83 |
| 6m | 60.378 | 61.668 |
| 8m | 64.396 | 62.3 |
| 10m | 64.785 | 62.598 |

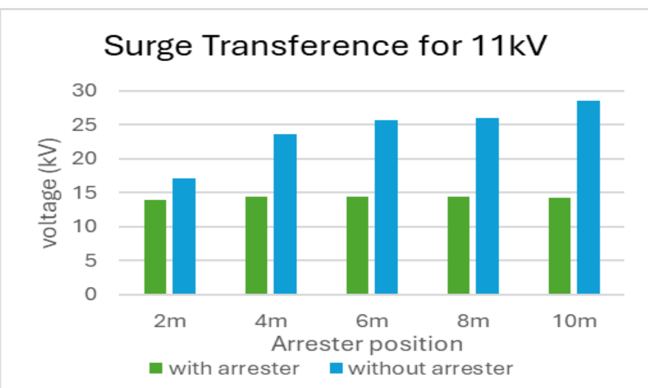


**Figure 3**: Surge transference of 11kV line with and without arrester

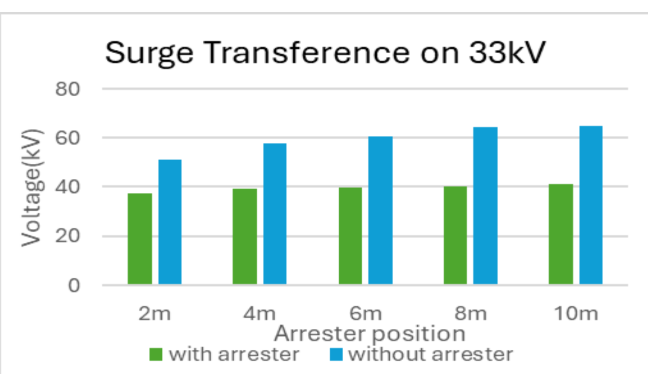


**Figure-4:** Surge transference of 33 kV line with and without arrester

**Case-4:**
Effect of arrester at secondary on surge transference is analyzed in Figure 3 and Figure 4. Observed the same in Table 9 & Table 10.

**Table 9**: Effect of surge transference at 11 kV with Arrester

| Arrester location | Surge transference With arrester with location of lightning on line (kV) | |
|---|---|---|
| | lightning strike at 0.5 km | lightning strike at 20km |
| 2m | 13.977 | 13.669 |
| 4m | 14.436 | 14.112 |
| 6m | 14.448 | 14.021 |
| 8m | 14.341 | 14.236 |
| 10m | 14.31 | 14.273 |

**Table 10**: Effect of surge transference at 33 kV with Arrester

| Arrester location from Transformer | Surge transference with arrester with location of lightning on line (kV) | |
|---|---|---|
| | lightning strike at 0.5 km | lightning strike at 20km |
| 2m | 37.513 | 36.134 |
| 4m | 39.235 | 37.293 |
| 6m | 39.673 | 37.449 |
| 8m | 40.138 | 38.699 |
| 10m | 41.036 | 39.692 |

**Case-5**
Analysis of the lead length of arrester with the different location of the lightning strike in Figure 5 and Figure 6. Observation is recorded in Table 11 and Table 12.

**Table 11:** Observation for lead length of 66kV

| Arrester lead length from connecting wire | Rise in voltage with location of lightning on line (kV) | |
|---|---|---|
| | lightning strike at 500m | lightning strike at 20km |
| 0.5m | 175.301 | 137.991 |
| 1m | 204.828 | 142.815 |
| 1.5m | 244.508 | 144.205 |
| 2m | 255.724 | 154.503 |

**Table 12:** Observation for lead length of 132kV

| Arrester lead length from connecting wire | Rise in voltage with location of lightning on line (kV) | |
|---|---|---|
| | lightning strike at 500m | lightning strike at 20km |
| 0.5m | 220.329 | 216.621 |
| 1m | 236.054 | 227.52 |
| 1.5m | 264.028 | 234.23 |
| 2m | 266.992 | 234.48 |

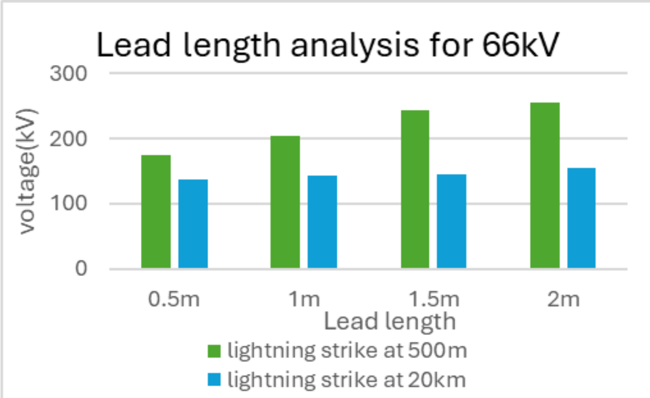


**Figure 5:** Analysis of lead length of arrester for 66kV line

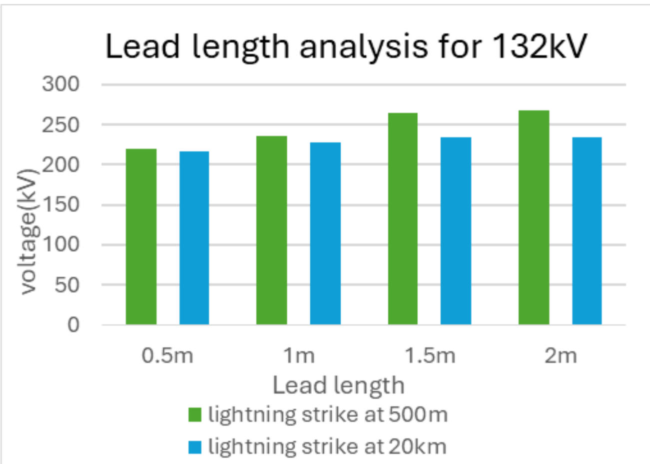


**Figure 6:** Analysis of lead length of arrester for 132kV line

It is observed that the least value of voltage rise is seen when MOSA placed near to the transformer i.e., 2m from the transformer this is for the both location of the lightning strike. It is noted for both the lines of 66kV and 132kV which is considered. In the analysis of the surge transference without MOSA the least surge is transferred to secondary of transformer form primary side, when MOSA connected on primary side at 2m distance from transformer. Impact of surge transference is reduced when arrester is placed at secondary. Arrester placement of secondary, it is important to note that with increase in distance the protection level of arrester decreases. In the analysis of lead length, the surge voltage increases on the transformer with increase in the lead length. As it is seen the voltage rise is least i.e., 175.30kV at 0.5m of lead length and 255.72kV for 2m of the lead length for 66 kV system when lightning strikes at 0.5 km distance. Similarly for 132 kV line least voltage rise when lead length is 0.5m which is 220.329 kV, and 266.992 kV when arrester lead length is 2m. It is observed that the overvoltage through transformer increases i.e., 85.724 kV at 10Ω and 91.187 kV at 20Ω for 66 kV line voltage. It is noted the impact of arrester position with TFR is seen. In the same way for the 132 kV line the 185.94 kV at 10Ω and 186.88 kV at 20Ω. For the TFR analysis it shows as the with increase in the footing resistance, grounding of surge through the tower is reduced thus the surge on the transformer is increased.

## 5. CONCLUSION

This study proves the effective operation of MOSA for 44 kV & 132 kV system voltage. Various configuration considered in this study like different values of TFR, Location of MOSA, different lead length. Also, surge transfer from transformer primary to secondary winding with and without MOSA has been carried out. Results shows that, both the lines are least vulnerable to the lightning at 20 km but for lightning at 500 m the surge current grounding has reduced which increase the surge over voltage. For 66kV and 132kV line the placement of MOSA must have to near to the station transformer at 2m, this increases the stability of the line against the lightning. TFR should be less as possible i.e., 10 Ω or less. For the distant lightning and high TFR the overvoltage at station transformer increases, but the insulator on tower is vulnerable to flashover. Lead length have to be about 0.5 m from MOPSA terminal to line terminal. MOSA is important for surge protection it reduces the effect of the surge transference. Further the stability of line can be attained in the high TFR region by using appropriate grounding method.

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