Lightning Performance of Medium Voltage Transmission Line Protected by Surge Arresters

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Abstract: Lightning strikes to overhead transmission lines are a usual reason for unscheduled supply interruption in the modern power system. In an effort to maintain failure rates in a low level, providing high power quality and avoiding damages and disturbances, plenty of lightning performance estimation studies have been conducted and several design methodologies have been proposed. The protection of overhead transmission lines is achieved using shield wires and surge arresters. Surge arresters should be insulators at any voltage below the protected voltage and good conductor at ant voltage above. To pass the energy of the lightning strike to ground. In this work an analysis of the lightning performance of 33 kV Aung Pin Lae - Myoma transmission line. The line is protected with only surge arresters and the current simulation of surge arrester is implemented on the sending end and receiving end of the network. By increasing the tower footing resistance, the lightning failure rate become greater. Smaller arresters intervals decerase the failure rate. The results of the current work could be useful for the maintenance and the design of Aung Pin Lae - Myoma 33 kV transmission line.

Keywords: Shield Wire, Surge Arrester, Tower Footing Resistance, Transmission Line.

I. INTRODUCTION

Lightning could causes the travelling waves to different devices connected to both sides of transmission line system which is harmful for insulators of lines and devices connected to transmission line. Thus it is essential to investigate a lightning surge for a reliable operation of a power system, because the lightning surge over voltage is dominant factor for the insulation design of power system and substation. Whenever lightning strikes the top of a transmission tower, a lightning current flows down to the bottom of the tower and causes a tower voltage to raise and results in a back-flashover across an arc horn. This causes transmission line outage and damage of equipment. Because of high frequency range associated with lightning transients phenomena, adequate electrical models are required for which reasons, and simulation studies require detailed modeling of the lightning phenomena and of the network components.

Lightning is the most harmful for destroying the transmission line and setting devices. The uses of surge arresters to decrease or eliminate lightning flashovers or switching surge on transmission and distribution lines are essential in power system overvoltage protection. In the past, a type of surge arrester called protector tube was used. With the advent of the metal oxide arrester with its increased energy capability, and with the development of a nonceramic housing, the use of arresters for protection of lines has received a renewed impetus and popularity. Thus the arresters are now in a very hostile environment, where large current magnitude strokes can impinge on the arresters. The long-term results of these applications are not yet available.

II. LIGHTNING DISCHARGE OF EXTERNAL VOLTAGE SURGE

Overvoltage due to lightning have their cause external to the system. Lightning phenomenon is caused by a peak discharge during which the charge accumulated in the clouds discharges into the neighboring cloud or to the ground. The mechanism of charge formation in the cloud and their discharge, as well as the numerous the factors which help the formation or accumulation of charge in the clouds are complex, and unpredictable. But during thunderstorms, positive and negative charges become separated by heavy air currents with ice crystals in the upper parts and rain in the lower parts of the clouds, and this clouds separation depends on the height of the clouds[1]. Lightning overvoltages are caused either by direct strokes to the phase conductor of as a result of strokes to earth very close to the line which produces induced lightning surges. Overvoltage induced by indirect lightning on overhead lines can cause damage to the power system.
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The scheme transmission lines in power system is presented in Fig.1. Moreover, due to its more frequent occurrence, indirect lightning constitutes a more important cause of micro-interruptions than the direct strike. The majority of lightning strokes takes place from clouds which have positively charge upper regions with the rest negatively-charge except for some localized positive charge in part of the cloud base. The lightning strokes consists basically of two components, a leader stroke and a return stroke then passes. The return stroke, in the course of which the current reaches its peak, may have a current as low as hundreds of amperes, but is more frequently between a few, kiloampers and about 100 kA. The current waveform is generally a unidirectional pulse rising to a peak value in about 3 s and falling to small values in several 10 s.

III. SURGE ARRESTERS

Surge arresters (or lightning arresters or surge dividers) are installed on transmission lines between phase and earth in order to improve the lightning performance and reduce the failure rate. Surge arresters are semiconductors with nonlinear resistance from a few Ω to several MΩ. Several different types of arresters are available (eg. gapped silicon carbide, gapped or non-gapped metal-oxide) and all perform in a similar manner: they function as high impedance at normal operating voltages and become low impedances during surge conditions. Even though a great number of arresters which are gapped arresters with resistors made of silicon-carbide (SiC) are still in use, the arresters installed today are almost all metal-oxide (MO) arresters without gaps, something which means arresters with resistors made of metal-oxide[2].

An ideal lightning arrester should: (i) conduct electric current at a certain voltage above the rated voltage; (ii) hold the voltage with little change for the duration of overvoltage; and (iii) substantially cease conduction at very nearly the same voltage at which conduction started[3]. The main characteristic of a surge arrester are[4]:

- maximum continuous operating voltage (MCOV), which must be greater than the maximum network operating voltage with a safety margin of 5%
- rated voltage, which must be 1.25 × MCOV
- protection level
- capacity to withstand the energy of transient over-voltages.

The lightning energy $E$ (in Joule) absorbed by an arrester is computed by the relation:

$$E = \int_{i_{o}}^{t} u(t) \cdot i(t) dt$$

(1)

where:

- $u(t)$ is the residual voltage of the arrester in kV and,
- $i(t)$ is the value of the discharge current through the arrester in kA.

When the absorbed energy by the arresters exceeds their maximum acceptable level of energy, then they will fail (damage). Assuming that surge arresters are the last protection measure of a transmission line, an arrester failure is considered as a line fault. The arresters' failure rate is given as

$$FR = N_{g} L \int_{T_{1}}^{T_{2}} \int_{I_{A}(T_{1})}^{I_{A}(T_{2})} f(I_{p}) \cdot h_{A}(I_{p})dI_{p}dl_{p}g(T_{1})dT_{1} +$$

$$\int_{T_{1}}^{T_{2}} \int_{I_{B}(T_{1})}^{I_{B}(T_{2})} f(I_{p}) \cdot h_{B}(I_{p})dI_{p}dl_{p}g(T_{1})dT_{1}$$

(2)

where:

- $I_{A}(T_{1})$ -is the minimum stroke peak current in kA required to damage the arrester, when lightning hits on a phase conductor, depending on each time- to- half value,
- $I_{B}(T_{1})$ -is the minimum stroke peak current in kA required to damage the arrester, when lightning hits on the overhead ground wire, depending on each time- to- half value,
- $f(I_{p})$ -is the probability density function of the lightning current peak value,
- $g(T_{1})$ -is the probability density function of the time-to-half value of the lightning current,
- $FR$ -is the arrester total failure rate,
- $N_{g}$ -is the ground flash density in flashes per km² per year and,
- $L$ -is the line length in km.

A. Types of Lightning Arresters

- Expulsion type
- Nonlinear resistor type with gaps (currently silicon-carbide gap type)
- Gapless metal-oxide type
- Rod Gap type
IV. TRANSMISSION LINE SURGE ARRESTERS

The Metal Oxide resistor column, together with the accompanying supporting construction, comprises the actual active part of the arrester. The column consists of individual Metal Oxide resistors stack on top of each other. Their diameter decisively determines the energy absorption and the current carrying capability. It is within a range of about 30 mm when used for distribution system, and up to 100 mm or more for high-voltage and extra-high voltage system. Metal-Oxide resistors vary in height between 20 mm and 45 mm.

A. Operating Principle

The currents passing through the arrester within the range of possibly applied power-frequency voltage are so small that the arrester almost behaves like an insulator. If, however, surge currents in kiloampere range are injected into the arrester, such as in the case when lightning or switching over-voltages occur, then the resulting voltage across its terminals will remain low enough to protect the insulation of the associated device from the effects of overvoltage. At the same time, the leakage current flows through the arresters. This consists of a large capacitive and a considerably smaller, resistive component.

B. Functions

- operation of the system i.e., to hold off the system voltage,
- To limit the transient voltage to a safe level with the minimum delay and fitter, and
- To bring the system back to its normal operation mode as soon as the transient voltage is suppressed, i.e., to interrupt the power-follow current and to reseal itself.

The normal operation or operational mode includes the system under faulted condition. Under several faults, such as the single line-to-ground faults, the voltage to ground across the unfaulted phases will rise above the normal voltage level. The arrester must not go into conduction during this fault condition. It should also be able to interrupt the power-follow current and reseal itself under system fault conditions when the power-frequency voltage across it rises.

C. Components

- Saddle Clamp
- Flex Joint
- Shunt
- Arrester Body
- Disconnector
- Ground Lead

Fig. 3. Typical suspension lightning arrester [5].

V. ARRESTER SELECTION

The objective of arrester application is to select the lowest rated surge arrester which will provide adequate overall protection of the equipment insulation and have a satisfactory service life when connected to the power system. A higher rated arrester increases the ability of the arrester to survive on the power system. Both arrester survival and equipment protection must be considered in arrester selection. The proper selection involves decisions in three areas:

- Selecting the arrester voltage rating. This decision is based in whether or not the system is grounded and the method of system grounding.
- Selecting the class of arrester. In order of protection, capability and cost as follow:
  - Station class
  - Intermediate class
  - Distribution class

The station class arrester has the best protection capability and is the most expensive.
- Determine where the arrester should be physically located.
V. CLASSIFICATION OF TRANSMISSION LINE SURGE ARRESTER

Fig. 4. Dimension of Transmission Line Arresters [6].

Fig. 5. Transmission Line Arrester discharge class -2 installation in tower: Case (a) across the insulator.

TABLE I: LINE DISCHARGE CLASS AND TRANSMISSION LINE VOLTAGE RATING

<table>
<thead>
<tr>
<th>Class</th>
<th>Voltage Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLA 1</td>
<td>15-45 kV</td>
</tr>
<tr>
<td>TLA 2</td>
<td>48-96 kV</td>
</tr>
<tr>
<td>TLA 3</td>
<td>108-144 kV</td>
</tr>
<tr>
<td>TLA 4</td>
<td>150-192 kV</td>
</tr>
</tbody>
</table>

VI. TYPICAL TRANSMISSION LINE SURGE ARRESTER INSTALLATION

A. Grounding System
The grounding system must address low impedance as well as low resistance. The factors which influence the grounding system are:
- Earthing Electrodes
- Tower Footing Resistance
- Resistivity of Soil
- Using Electrodes in Parallel

Fig. 6. Transmission Line Arrester discharge class -2 installation in tower: Case (b) beside the insulator.

Fig. 7. Transmission Line Arrester discharge class -2 installation in tower: Case (c) parallel to the insulator.

VII. TRANSMISSION LINE ARRESTER SELECTION

System highest voltage ≈ 1.1× system voltage

The minimum continuous operating voltage,

$$U_{c,\text{min}} = 1.05 \times \frac{U_s}{\sqrt{3}}$$

The minimum rated voltage,

$$U_{r,\text{min}} = 1.25 \times 1.05 \times \frac{U_s}{\sqrt{3}}$$

The actual continuous operating voltage,

$$U_c = U_r / 1.25$$

Power frequency withstand voltage, 1min, = 0.88/ $\sqrt{2}$ × switching impulse protective level
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Power frequency withstand voltage, $U_{\text{min}} = 0.88/\sqrt{2} \times$ switching impulse protective level

Creepage distance = $16 \text{mm} \times \frac{U_s}{kV}$

(8)

(9)

The protective level = $\frac{\text{basic insulation level}}{\text{lightning impulse protective level}}$

(10)

Earth fault factor, $k = 4$

Maximum duration of temporary voltage = 10 s

TABLE II: Specification of Lightning Arrester for 132kV and 230kV Transmission Line

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System voltage</td>
<td>33 kV</td>
</tr>
<tr>
<td>Highest voltage</td>
<td>36.3 kV</td>
</tr>
<tr>
<td>Max. short circuit current</td>
<td>20 kA</td>
</tr>
<tr>
<td>Discharge current</td>
<td>10 kA</td>
</tr>
<tr>
<td>Basic insulation level</td>
<td>170 kV</td>
</tr>
<tr>
<td>Resistor diameter</td>
<td>45 mm</td>
</tr>
<tr>
<td>Protective level</td>
<td>2.01</td>
</tr>
<tr>
<td>Height of resistor column</td>
<td>180 mm</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage</td>
<td>109.98 kV</td>
</tr>
<tr>
<td>Power frequency withstand voltage</td>
<td>40.322 kV</td>
</tr>
<tr>
<td>Creepage distance</td>
<td>580.8 mm</td>
</tr>
</tbody>
</table>

VIII. PROPOSED MODEL OF 33 KV TRANSMISSION LINE

Fig. 8 shows a 33 kV transmission system with two transmission line arrester placed at the sending end and the receiving end of the line. Over the system a lightning surge of 20 kA was induced and the resulting simulation was carried out by using MATLAB software.

Fig. 8. Proposed Model.

Fig. 9. Voltage and Current waveform at MOV 1.

Fig. 10. Voltage and Current waveform at MOV 2.

Fig. 11. Voltage and Current waveform at load side (8 MW).
A 33 kV transmission system feeds a load (8 MW) through a 16.093 km transmission line as shown in Fig.11. A transformer rating 3(5MVA) is connected at the sending end of the network. The results of the simulation show that the temporary increase in current at MOV 1 and MOV 2 which is done by the lightning when 20 kA lightning current is applied as shown in Figs.9 and 10. On the other hand, the temporary increase in voltage in each arrester. After 0.03 sec the arresters serve as the steady state condition. The load voltage is increased and the load current decreased during the time, where the lightning occurs.

IX. CONCLUSION

For the analysis of surge arrester in transmission line, MATLAB software is employed for the simulation of the selected transmission line as well as the lightning surge and MOV arrester. For the Aung Pin Lae-Myoma transmission line, the discharge voltage and current rating of arresters are selected as 30 kV and 10 kA. The simulation is carried out near the receiving end of the transmission line. This paper will help and give the electrical knowledge of the overvoltage protection system by surge arrester in transmission lines which coach to the technicians, the professional engineers, the students who facing the overvoltage condition and protection coordination of transmission lines.

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XI. REFERENCES