Simulation of Surge Arrester Effects on 230 kV Transmission Line by ATP Software

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Abstract *- Two common overvoltage surges that can be observed in transmission line as switching surge and lightning surge. These over voltages, which are not possible to prevent, create problems where the insulating level of the equipment is not enough. Selecting a high insulating level will increase the costs and volume of the equipment. For the sake of decreasing insulating levels and their costs, it is necessary to control over voltages and leads them to earth by equipment like arresters. The use of transmission line surge arresters to improve the lightning performance of transmission lines is becoming more common. In this paper, the analysis of surge arresters is executed for 230 kV Pyinmana-Naypyitaw transmission line. Analysis is executed by calculations as well as simulations. For the computer simulation ATP software EEUG05 version is employed. The presented analysis in this paper can be proved valuable to the studies of electric power systems designers intending in a more effective lightning protection, reducing the operational costs and providing continuity of service.*

Keywords *- Surge voltage, Surge Arrester, Insulation level, Discharge voltage, ATP Software, Simulation*

1. INTRODUCTION:

In overhead transmission line system, the most important requirement is insulation, safe clearances to earthed parts and line protection. Transmission lines protection needs for lightning strokes, switching transient and others cases. A reliable operation of the transmission system can be ensured by components with insulation system designed for electrical strength, suitable for the expected stresses. It requires detailed analysis of stresses to which these systems are exposed. The main part of the transmission lines stresses, defining requirements for the power system insulation and crucial. The particularly high over voltages, whose maximal values may be many times higher than the rated voltage, result from lightning discharges and are responsible for the basic hazard of the insulation breakdown.

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 the 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 [5].

Over voltage surge protection for power line and equipment can be devised by using arresters or by a combination of shielding and surge arresters. This paper presents lightning performance and surge arrester analysis of 230 kV transmission line protection system against from lightning effects and lightning protection system.

2. CLASSIFICATION OF LIGHTNING STROKES:

Lightning strokes are defined as a direct stroke if it hits either the tower or the phase conductor or the shield wire. This is illustrated in Figure 1, when the insulator string at a tower flashes over by direct hit either to the shield wire along the span, it is called a back-flash; if the insulator string flashes over by a strike to the phase conductor, it is called shielding failure for a line shielded by shield wires. These lightning strokes terminating directly on phase conductors or equipment terminals develops a very high voltage, which with no surge protection, will flashover the insulation in the majority of cases [6].

Lightning effects can be direct or indirect in Figures 1 and 2. Direct effects are from resistive (ohmic) heating, arcing and burning. Indirect effects are more probable. So, lightning protection in the transmission line is rather difficult.

Stroke one is formed back-flash caused by direct stroke to tower and stroke two is also formed back-flash caused by direct stroke to shield wire. Stroke three is formed insulator flashover by direct stroke to phase conductor (shielding failure). Even today, lightning strokes damage is the most of serious cause of power outages, accounting for about 40% of all cut in the transmission lines.

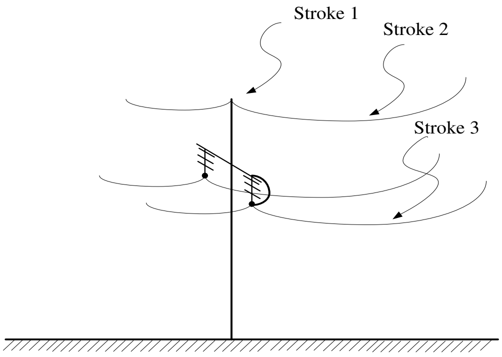


Figure 1. Illustrations of direct stroke [4]

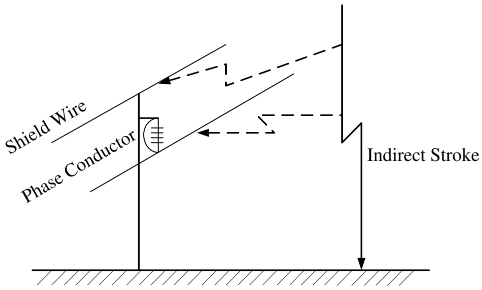


Figure 2. Illustrations of indirect stroke [4]

3. LIGHTNING DISCHARGE OF EXTERNAL VOLTAGE SURGE:

Over voltages 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 neighbouring 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 thunder storms, 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 cloud separation depends on the height of the clouds [7].

Lightning over voltages are caused either by direct strokes to the phase conductor or 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. The scheme of an influence of lightning strokes on overhead transmissions lines in power systems is presented in Figure 3.

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 stroke consists basically of two components, a leader stroke and a return stroke then passes.

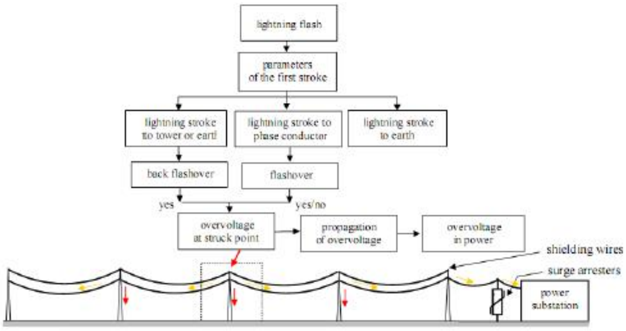


Figure 3. Lightning over voltages scheme on transmission line [5]

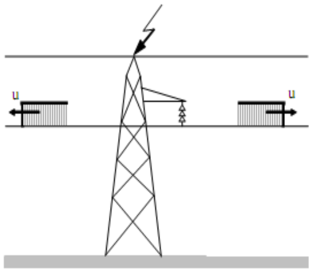


Figure 4. Voltage wave formed as a sequence of lightning stroke [7]

The return stroke, in the course of which the current reaches its peak, may have a current as low as hundreds of ampers, 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 μs and falling to small values in several 10 μs.

4. SELECTION OF LIGHTNING ARRESTER:

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 and application of lightning arresters in a system involve decisions in three areas:

1) Selecting the arrester voltage rating. This decision is based on whether or not the system is grounded and the method of system grounding.
2) Selecting the class of arrester. There are three classes of arresters. 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.
3) Determine where the arrester should be physically located.

5. CASE STUDY SYSTEM:

The case study transmission system is executed at Pyinmanar Primary Substation. It is one of the largest substations in Myanmar; supply the electricity to Naypyitaw from this substation. It is comprised with two transformers having 100 MVA and 60 MVA. This substation consists of 230 kV transmission feeders as well as 33 kV distribution feeders. The single line diagram showing 230 kV transmission feeders of Pyinmanar primary substation is described in Figure 5.

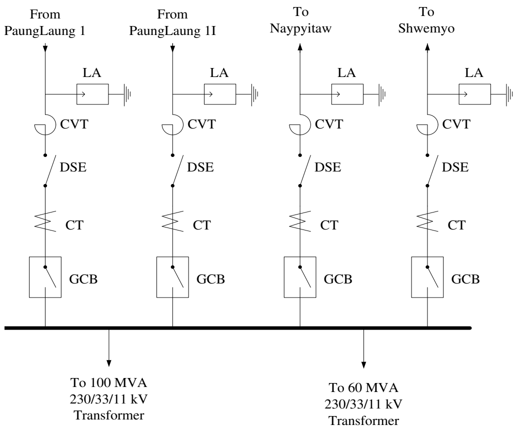


Figure 5. Single line diagram of pyinmanar primary substation [1]

TABLE I
PARAMETERS OF 230 KV PYINMANAR PRIMARY SUBSTATION [1]

Item	Feeder Name	Length	Conductor Size	Number of Towers	Number of Circuit
1	Pyinmanar -Paung Laung I	8.3 km	300/20 mm^2	38	Double
2	Pyinmanar -Paung Laung II	8.0 km	397.5 MCM	34	Double
3	Pyinmanar -Shwemyo	22.36 km	265/33 mm^2	117	Double
4	Pyinmanar - Naypyidaw	12.76 km	605 MCM	62	Double

A). Transmission Line Under Study

The analysis of surge arrester is executed for Pyinmanar-Naypyitaw 230 kV transmission line. For the analysis, the study is start from the selection of surge arrester for this transmission line.

B). Selection of Surge Arrester

The selection is carried out in two major steps:

- matching the electrical characteristics of the arresters to the system's electrical demands
- matching the mechanical characteristics of the arresters to the system's mechanical and environmental requirements [7].

The final selection is reflected in the arrester type designation. The commonly used terms for selection of surge arrester are shown in Table II.

TABLE II
TERMINOLOGY FOR ARRESTER SELECTION

U_m	Maximum system voltage	k	Earth fault factor
U_c	Continuous operating voltage	U_{ps}	Switching impulse protective level
U_r	Rated voltage	U_{pl}	Lightning impulse protective level
TOV	Temporary overvoltage	U_{ws}	Switching impulse withstand level
T	TOV strength factor	U_{wl}	Lightning impulse withstand level

For the selection of surge arrester, its rated voltage is formerly obtained.

$$\text{Rated Voltage} = \frac{\sqrt{2}}{\sqrt{3}} \times V_l = \frac{\sqrt{2}}{\sqrt{3}} \times 230 = 187.8\,\text{kV}$$

Thus 180 kV rated voltage arrester is selected for lightning overvoltage protection. Then the discharge voltage of LA is obtained by,

Discharge Voltage = Discharge factor × Rated voltage of LA

Taking discharge factor of 1.6,

Discharge Voltage = 1.6 × 180 kV = 288 kV

To obtain minimum impulse insulation level of arrester, tolerance factor and margin factor will be taken as 10 % and 25 % respectively. Then the minimum impulse insulation level (L_S) is calculated as-

$$L_S = \frac{\text{marginfactor} \times \text{tolerancefactor} \times \text{dischargefactor} \times \sqrt{2} \times E_{rated}}{0.8}$$

$$= \frac{1.25 \times 1.1 \times 1.6 \times \sqrt{6} \times 288\text{kV}}{0.8}$$

=1120 kV

The lightning arresters are designated as 8, 10, 20 kA ratings for discharge current. For the maximum protection from lightning strokes, 20 kA discharge current is recommended for the protection.

6. APPLICATION OF SURGE ARRESTER IN PYINMANA-NAYPYITAW TRANSMISSION LINE:

For the analysis of surge arrester in transmission line, the detail study is carried out at Pyinmana-Naypyitaw transmission line. The application of surge arrester for Pyinmana-Naypyitaw transmission line is analyzed by ATP software. The simulation model for the selected transmission line is shown in Figure 6.

In the model, a source is attached at Pyinmana bus and a load is attached at Naypyitaw bus since the power flow is occurred from Pyinmana to Naypyitaw. The surge arresters are attached at the incoming of each bus as shown in Figure 6. There are 62 towers along the transmission line and tower names are counted from Pyinmana to Naypyitaw as shown in Figure 6.

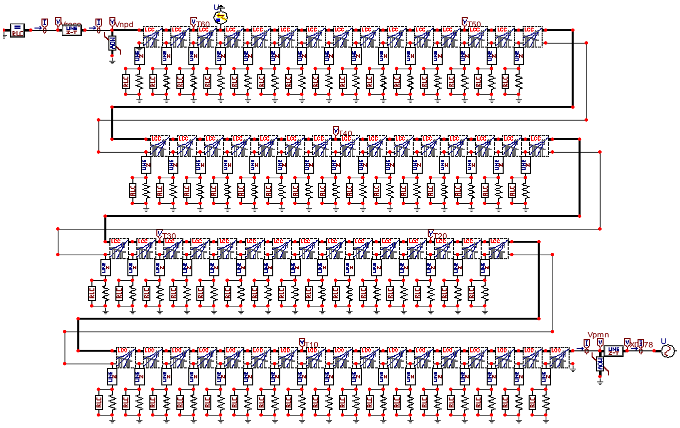


Figure 6. ATP model for analysis of surge arrester on pyinmana-naypyidaw transmission line [1], [3]

For the surge arrester application, the lightning surges are applied at three different locations as the beginning, middle and end of the line. The Heidler type surge is selected for lightning strike. The surge amplitude is set as 10 MW and the rising and falling times are given as 0.5 µs and 20 µs respectively. Figure 7 shows the selected lightning surge for analysis.

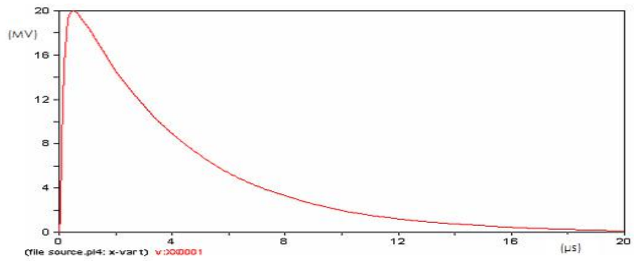


Figure 7. Waveform of fast front voltage surge using Heidler model,
20 MV with 0.5µs fast front time [2]

The lightning source was simulated by using Heidler model with 20 kA magnitude and 0.5 µs front time. The current surge is a single stroke with positive polarity. The current source can be represented by the following equation and the wave shape of the fast front current surge by using Heidler model is shown in Figure 7.

$$I = \frac{Amp \times (t/Tf)^{n}}{1+(t/Tf)^{n} \int t/Ta}$$

Where:

Amp = Multiplicative number in (A) or (V) of the function, does not represent peak value of surge.

Tf = the front duration in (sec), which is interval between t=0 to time of the function peak.

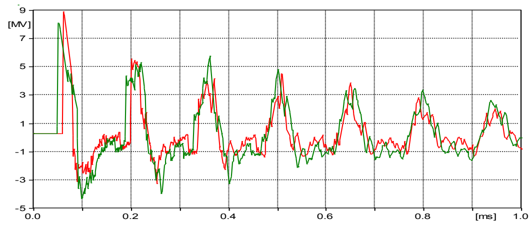
Ta = the stroke duration in (sec), which is interval between t = 0 and the point on the tail where the function amplitude has fallen to 37% of its peak value.

n = factor influencing the rate rise of the function

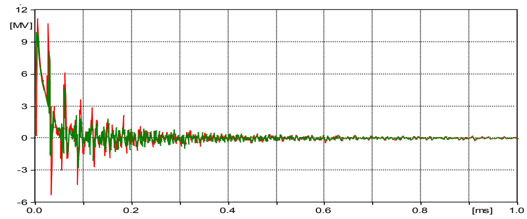
A 20MV DC type source was used as the lightning input step voltage.

7. LIGHTNING SURGE AT THE RECEIVING END OF LINE:

In this case, the surge is applied at 58th tower (T58). The effect of lightning surge on each substation is studied.



(a)

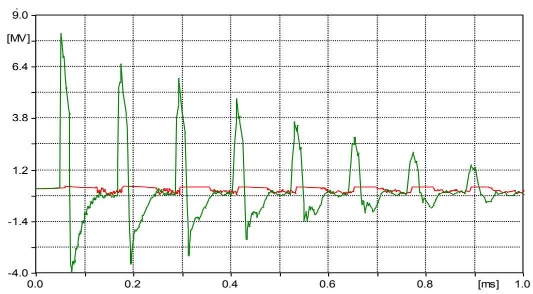


(b)

Figure 8. Voltages at each substation without arresters: (a) Pyinmana substation and (b) Naypyitaw substation

The voltage of Pyinmana substation is shown in comparison with tower number 10 (T10) and that of Naypyitaw substation is shown in comparison with tower number 60 (T60). In the waveform displays, only phase ‘a’ magnitudes are described.

In Figure 8, the lightning surge voltage reach tower 10 at 47 µs and Pyinmana substation at 57 µs. At Pyinmana substation, the surge voltage amplitude is 9 MV and surge current is about 25 kA which can cause large destruction at the substation equipments. Similarly, the lightning surge voltage reach tower 60 at 2 µs and Naypyitaw substation at 4 µs. At Naypyidaw substation, the surge voltage amplitude is 11 MV and surge current is about 16 kA.



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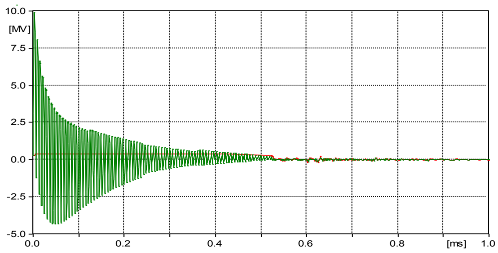


(b)

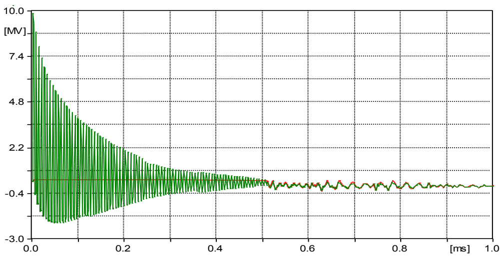
Figure 9. Voltages at each substation with designed arresters:
(a) Pyinmana substation and (b) Naypyitaw substation

In Figure 9, the lightning surge voltage reach tower 10 at 48.5 μs and Pyinmana substation at 58.5 μs. At Pyinmana substation, the surge voltage is 369 kV and the surge current is about 1000 A. At Naypyitaw substation, the surge voltage is 389 kV and the surge current is about 500 A. These values are not much higher than the rated values at peak load condition; the substation equipment can withstand the suppressed surge voltage and currents. Thus the surge protection by designed arrester is acceptable.

8. LIGHTNING SURGE AT THE SENDING END OF LINE:

In this case, the surge is applied at 3rd tower (T3). The effect of lightning surge on each substation is studied. In Figure 10, the voltage at the Pyinmana substation terminal and at tower number 1 (T1) are described. The effectiveness of designed arrester can be observed in this Figure. With the designed arrester, the Pyinmana substation terminal is maintained at less than 300 kV while the lightning surge is applied. The voltage of Naypyitaw substation is shown in comparison with tower number 60 (T60). By such comparison, the effect of the surge arrester is more evident with comparison. In the waveform displays, only phase ‘a’ magnitudes are described.

In Figure 10, the lightning surge voltage reach tower T1 at 2.0 μs and Pyinmana substation at 2.89 μs. At tower T1, the surge voltage amplitude is 9.85 MV and at Pyinmana substation, the surge voltage is 379 kV. Similarly, the surge current at Tower T1 is about 154 kA and that at Pyinmana substation terminal is about 4.1 kA.



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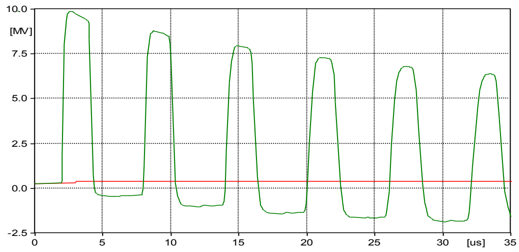


(b)

Figure 10. Lightning overvoltage at Pyinmana substation and Tower T1: (a) 1 ms duration and (b) 35 μs duration

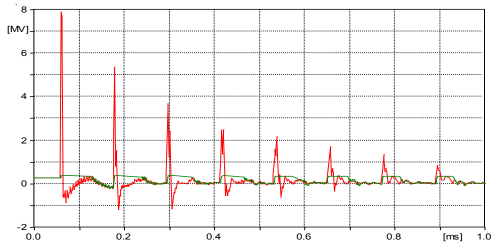
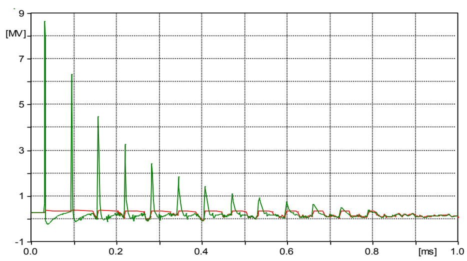


Figure 11. Lightning overvoltage at Naypyitaw substation and
Tower T60

In Figure 11, the lightning surge voltage reach tower 60 at 56.5 μs and Naypyitaw substation at 58.5 μs. At tower T60, the surge voltage is 7.8 MV and the surge current is about 1.4 kA. At Naypyitaw substation, the surge voltage is 376 kV and the surge current is about 720 A.

9. LIGHTNING SURGE AT THE MIDDLE OF LINE:

In this case, the surge is applied at 32st tower (T32). In Figure 12(a), the voltage at the Pyinmana substation terminal and at tower number 1 (T1) are described. With the designed arrester, the Pyinmana substation terminal is maintained at less than 376 kV while the lightning surge is applied. The voltage of Naypyitaw substation is shown in comparison with tower number 60 (T60).



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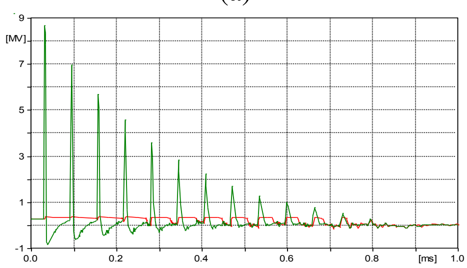

(b)

Figure 12. Lightning overvoltage: (a) At Tower T1 and Pyinmana substation and (b) At Tower T60 and Naypyitaw substation

In Figure 12(a), the lightning surge voltage reach tower T1 at 30.0 μs and Pyinmana substation at 30.5 μs. At tower T1, the surge voltage amplitude is 8.65 MV and at Pyinmana substation, the surge voltage is 376 kV. Similarly, the surge current at Tower T1 is about 47 kA and that at Pyinmana substation terminal is about 2.1 kA.

In Figure 12(b), the lightning surge voltage reach tower 60 at 28.5 μs and Naypyitaw substation at 30.5 μs. At tower T60, the surge voltage is 8.7 MV and the surge current is about 1.05 kA. At Naypyitaw substation, the surge voltage is 376 kV and the surge current is about 590 A.

10. CONCLUSION:

For the Pyinmana-Naypyitaw transmission line, the discharge voltage and current rating of arresters are selected as 288 kV and 20 kA. The simulations using ATP software are carried out with three different lightning strike positions as at the sending end, receiving end and at the middle of the line. The results of the analysis show that the temporary increase in voltage value will be rise to about 9.0 MV at the line which is done by lightning when the surge arrester is not set in the system. On the other hand, the temporary increase in voltage value will be about 379 kV at the line. This paper will give the electrical knowledge of the overvoltage protection system by surge arrester in high voltage transmission lines.

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