

Effective Placement of Surge Arrester during Lightning

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Abstract: Lightning interference occurs mainly on overhead lines and has been a problem since the early days of electricity supply. Over voltages which occur on the lines, travel towards the terminal or substation, and can damage, particularly the expensive equipment such as power transformers. Lightning traveling waves are produced in the system and cause temporary increase in voltage in the transmission line system. The increase in voltage is harmful for the insulator of lines and devices connected to the transmission line. Therefore, it is necessary to analyze such increase in voltage in order to design the surge arrester suitable for the investment, the good performance of the system and the reliability of transmission line. In this work Metal-Oxide Surge Arrester is **used**. The objective of this paper is to protect the power system equipments from lightning and to determine the effective placement of surge arrester. This will be done by comparing the voltage level measured close to the transformer with the suggested basic insulation level (BIL) 650KV used in this work. A powerful electrical tool to simulate the power system model is electromagnetic transient program PSCAD/EMTDC is used in this work. Here we present a proposed model of a three phase 132KV transmission system with over voltage which shows that the lightning surge of 10KA, 8 x 20 μ s can be very dangerous even at low value of current if there is no surge arrester is in operating or used for protection. This over voltage is reduced by using the Metal-Oxide Surge Arrester. The outcome of this paper shows the placement of arrester at 90m, 60m and 30m from the transformer in terms of voltage levels measured at particular points and overall simulation results will demonstrated the importance of having a right location of surge arrester placement as fail to do so will cause a significant damage to the equipment.

Keywords — Lightning, Surge Arrester, Insulation Co-ordination, PSCAD/EMTDC.

I. INTRODUCTION

Lightning is a major cause of overhead line faults. Between 5% to 10% of the lightning-caused faults are thought to result in permanent damage to power system equipment. Lightning has been one of the important problems for insulation design of power systems and it is still the main cause of outages of transmission and distribution lines [4]. Lightning is an unpredictable probabilistic phenomenon, which can be the cause of severe failure in substations such as insulation flashover and damage of substation devices. Consequently the power supply is interrupted and economic losses are considerable. Lightning protection systems for substations are therefore needed to minimize direct lightning strokes to equipment and buses within substation. A complete awareness of the parameters of lightning strokes is essential for the prediction of the severity of the transient voltages generated across power apparatus either by a direct stroke to the power line/apparatus, or by an indirect stroke. However, no two lightning strokes are the same. Because of lightning traveling waves are produced in the system. These traveling waves cause the temporary increase in voltage in the transmission line system. The increase in voltage is harmful for the insulator of lines and devices connected to the transmission line. Therefore, it is necessary to analyze such increase in voltage in order to design the surge arrester (or the insulator) suitable for the investment, the good performance of the system and the reliability of transmission line system.

During the seven years between 1998 and 2004, 81 direct lightning strokes to phase conductors were observed. The number is based on the first stroke for multistroke events and excludes some data for which parameters could not be estimated. All of the lightning strokes were observed in the summer. It is essential for electrical power engineering to reduce the number of outages & services & electric supply.

Therefore it is necessary to protect the power apparatus from over volts in electric system, namely lightning over voltages & switching over voltages. Lightning over voltages is a nature natural phenomenon while switching over voltages originates in the system itself by the connection & disconnection of circuit breakers contacts or due to initiation or interruption of faults. Switching over voltages is highly damped over voltages.

The magnitude over voltage's appearing on transmission lines does not depend on the line design & hence lightning performance tends to improve with increasing insulation level ,i.e. with system voltage on the other hand , switching over voltage's are proportional to operating voltage.

Lightning strokes hitting towers, conductors or any object line the neighboring of a transmission line can produce abnormal current/voltage waves along conductors (phase and/or shield wires) as well as along steel towers. Due to these phenomena, over voltages are produced and electric arcs (between two or more conductors as well as between phase conductors and the tower structure) may appear, if insulation breakdown voltage is reached. Back flashover occurs when lightning stroke terminates on the overhead ground wire or tower. A stroke that so terminates forces currents to flow down the tower and

out on the ground wires. Thus voltages are built up across the line insulation. If these voltages equal or exceed the line critical flashover voltage (CFO), flashover occurs [4]. Study on back flashover is very important to

is very important to evaluate lightning performance as majority of lightning strokes terminate on shield wire than phase conductor. The objectives of this study are to protect the power system equipments from lightning and determine the effect of surge arrester placement. This will be done by comparing the voltage level measured close to the transformer with the suggested basic insulation level (BIL) value used by the utility. The ideal approach to study the transient phenomena in a power system is to capture and record the transients using wide bandwidth transducers and recording equipment and then analyse these waveforms. However, capturing transient signals this way representing all possible scenarios is not realistic. An alternative technique is to simulate the power system using a suitable electromagnetic transient program PSCAD/EMTDC. The Power System Computer Aided Design (PSCAD/ EMTDC) programs available in the market today present the power systems components while keeping the complexity of the models to a minimum.

II. MODELLING OF THE SYSTEM

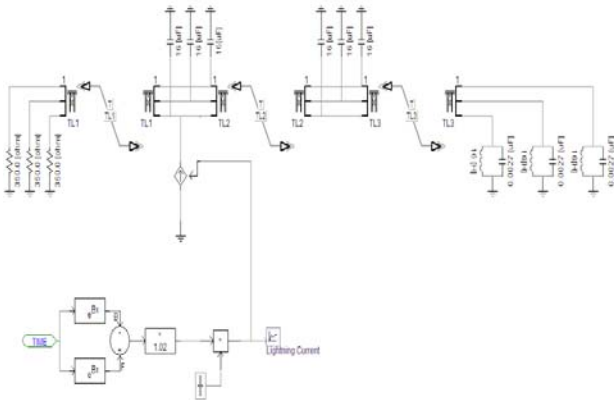


Fig.1. Selected Model

Lightning on phase line of transmission line system might cause insulation breakdown of important devices. Therefore, this occurrence must be avoided as much as possible. The way to reduce the risk is the use of Lightning arresters. The proposed model is a long transmission line includes, transmission lines T_1, T_2, T_3 , transmission line interfaces, lightning surge circuit, line impedance, stray capacitance of the equipments, transformer. Figure 1 shows the modeling arrangements of the system. A 10kA surge with impulse of $8/20\mu s$ is taken. In general lightning is represented by a current source of negative polarity. The transmission of a travelling wave at junction points of equal impedances in a transmission line is of great importance in transmission systems. Sometimes a voltage rise or build – up of voltage can

occur depending on the type of the impedance at transition points. In the above proposed model station 2 was terminated with a transformer, whose solution can be obtained using the Laplace transforms rather than using operational calculus. The transmitted wave reaching the transformer will be either a double exponential or a damped sinusoidal wave and the steepness of the wave front gets reduced. Herein the line terminated with a transformer is taken as an parallel L-C combination [6].

Over voltages could be calculated by lightning current (i) and line surge impedance (Z_s). The circuit is shown in Fig. 1. Therefore over voltage due to lightning (V_0) in Fig. 1 is as follows [1].

$$\text{Over voltage} = \frac{i}{2} Z_0$$

$$V_0 = \frac{10}{2} * 350$$

$$V_0 = 1750 \text{ kV}$$

System with over voltage is simulated using PSCAD/EMTDC software, and circuit with surge arrester is also simulated for finding the best position of the surge arrester by changing the length of transmission line T3 to 100m, 75m, and 45m.

III. ARRESTER MODELLING

When specifying a metal-oxide arrester model for a study, the accuracy of the simulation is improved when the arrester characteristic is chosen to be consistent with the frequency or time-to-crest of the voltage and current expected during system perturbations [5]. This concept is key to modelling because metal-oxide arresters are frequency-dependent devices, i.e., the voltage across the arrester is a function of both the rate of rise and the magnitude of the current conducted by the arrester. In order to obtain metal-oxide arrester characteristics for a wide range of wave shapes a number of different current test wave shapes have been used [2].

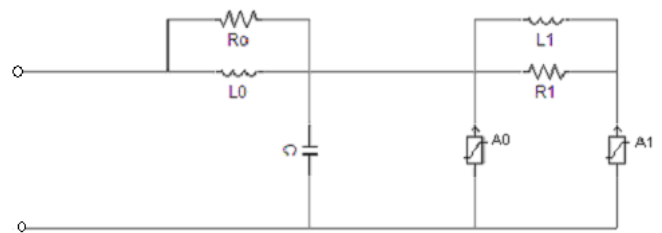


Fig.2. Arrester Model

The inductor L_0 in the model represents the inductance associated with magnetic fields in the immediate vicinity of the arrester.

The resistor R_0 is used to stabilize the numerical integration when the model is implemented on a digital computer program.

Capacitor c represents the terminal-to-terminal capacitance of the arrester.

The inductance L_1 and resistor R_1 of the model comprise the filter between two non-linear resistors. This section details the determination of the metal oxide model parameters for a one column arrester with an overall length of 1.45 meters. The discharge voltage, V_{10} , for this arrester is 248kV for a 10kA, 8 x 20 μ s current wave shape.

A. Arrester Information Required

d - Length of arrester column in meters (use overall dimensions from catalog data)

n - Number of parallel columns of metal-oxide disks

V_{10} - discharge voltage for a 10kA, 8 x 20 μ S current, in kV

B. Lumped Parameter Elements

Using the equations presented here, the initial values for L_0 , R_0 , L_1 , R_1 & C are determined as follows[2]

$$L_1 = \frac{15d}{n} \mu\text{H}$$

Here, d = length of arrester column in meters
= 1.45m

n = number of parallel column of metal oxide disks

$$L_1 = \frac{15d}{n} \mu\text{H} = 21.75 \mu\text{H}$$

$$R_1 = \frac{15d}{n} \text{ ohm} = 94.25 \text{ ohm}$$

$$L_0 = \frac{0.2d}{n} \mu\text{H} = 0.29 \mu\text{H}$$

$$R_0 = \frac{100d}{n} \text{ ohm} = 145 \text{ ohm}$$

$$C = \frac{100n}{d} \text{ pF} = 68.97 \text{ pF}$$

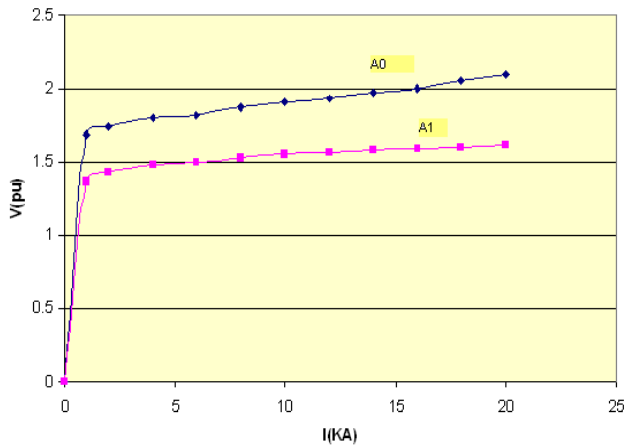


Fig.3. V-I Relationships for Non-Linear Resistor Part of Model

Figure 3 is used to determine the initial characteristics of the nonlinear resistors A_0 , and A_1 . Each of the V-I points for the nonlinear resistors is found by selecting a current point and then reading the relative IR in pu from the plot. This value is then multiplied by $(V_{10}/1.6)$ to determine the model discharge voltage in kV for the associated current. This scaling from pu to actual voltage is done by the application of the following formula to the "Relative IR" pu voltage found for that current as given in Figure 3[2].

For A_0 , the

$$\text{Discharge KV} = [\text{Relative IR in pu for } A_0(i)] * [V_{10}/1.6]$$

For the above arrester, the associated V-I voltage for a 10kA current for the nonlinear resistor, A_0 , is determined by reading the "Relative IR" for a 10kA current from Figure.3 Examination of the plot shows that the "Relative IR" for a 10 kA current is 1.9pu. Therefore the discharge kV for A_0 associated with 10kA is [2]

$$\text{Discharge KV} = 1.9 * \frac{248}{1.6}$$

$$\text{Discharge KV} = 294.5$$

Similarly, For A_1 , the

$$\text{Discharge KV} = [\text{Relative IR in pu for } A_1(i)] * [V_{10}/1.6]$$

$$\text{Discharge KV} = 1.55 * (248/1.6)$$

$$\text{Discharge KV} = 240.25$$

TABLE 1
V-I CHARACTERISTICS FOR A_0

Is(KA)	V(pu)	V ₀ (KV)
1	1.68	256.31
2	1.74	268.16
4	1.80	277.42
6	1.82	280.49
8	1.87	288.21
10	1.90	292.82
12	1.93	297.43
14	1.97	303.62
16	2.00	308.23
18	2.05	315.95
20	2.10	323.65

TABLE 2
V-I CHARACTERISTICS FOR A_1

Is(KA)	V(pu)	V ₁ (KV)
1	1.68	207.0
2	1.74	220.0
4	1.80	228.1
6	1.82	231.18
8	1.87	235.81
10	1.90	238.89
12	1.93	240.43
14	1.97	243.51
16	2.00	245.05
18	2.05	246.60
20	2.10	248.14

V_0, V_1 are the discharge voltages of A_0 and A_1 Non-Linear resistors respectively. Discharge voltage is nothing, but the voltage that appears across the terminals of an arrester during passage of discharge current.

IV. SIMULATION RESULTS

The selected model is connected with transmission lines, lightning surge circuit and transformer. Digital simulation is done by using PSCAD/EMTDC software and the results were presented here. System with over voltage is shown in Figure 4. The output over voltage of the system is shown in Figure 5. The Over Voltage is 1784KV. To reduce the over voltage and to protect the system equipments Metal-Oxide Surge Arrester is used. The system with surge arrester and waveforms for arc current and waveform of discharge voltage are shown in Figures 6, 7, 8 respectively. The discharge voltage of the arrester is 303KV.

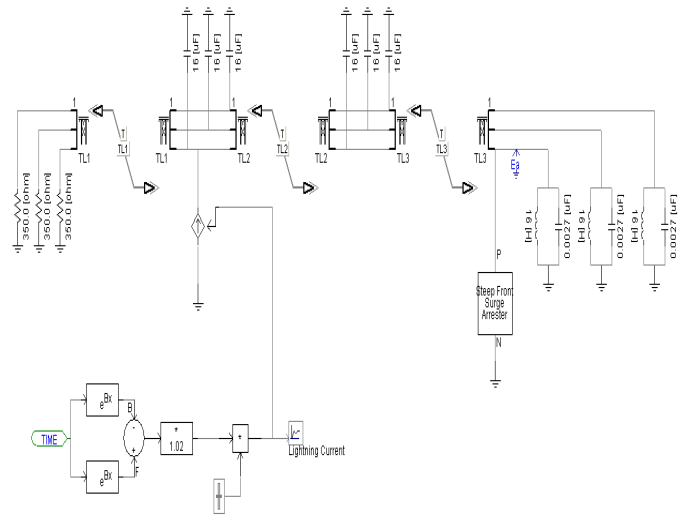


Fig.6. System with Surge Arrester

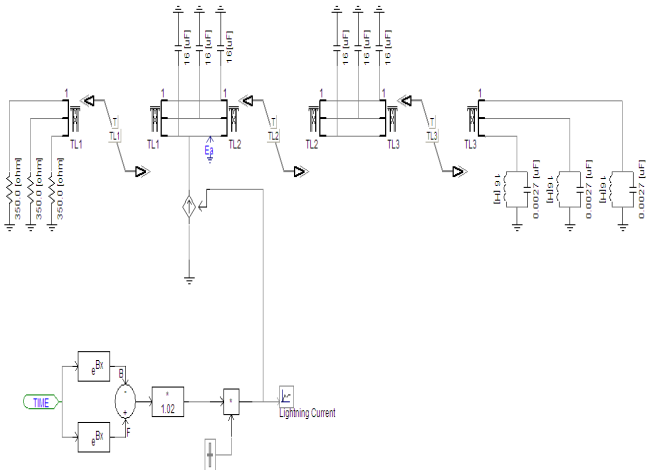


Fig.4. System with Over Voltage

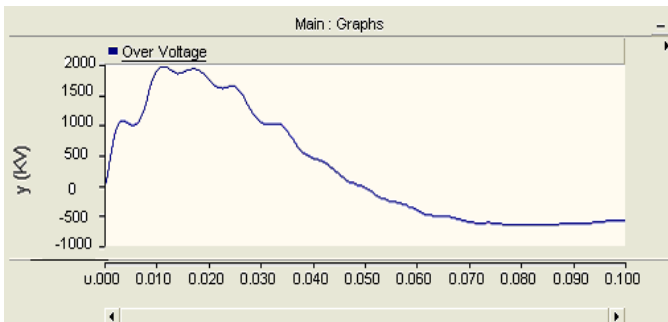


Fig.5. Waveform of Over voltage

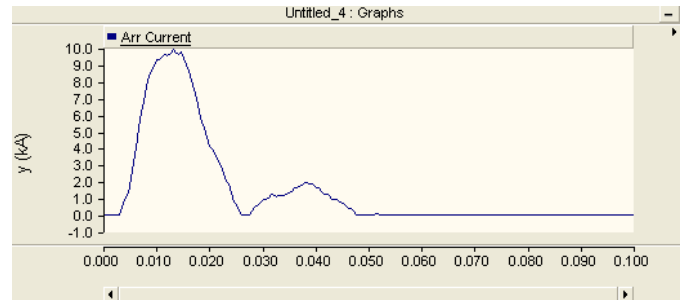


Fig.7. Waveform of Arc Current

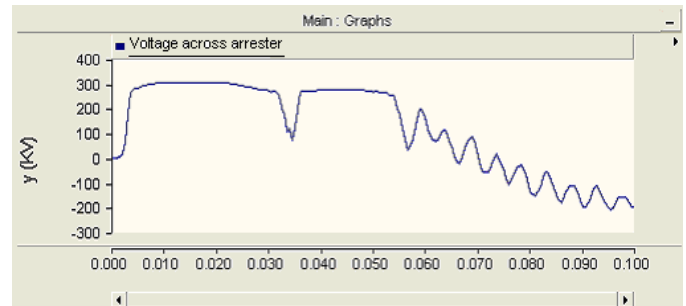


Fig.8. Output Voltage Waveform when Arrester is set

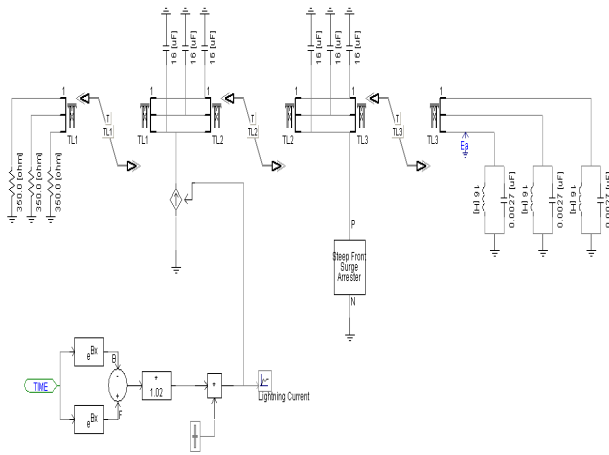


Fig.9. System with placement of Surge Arrester

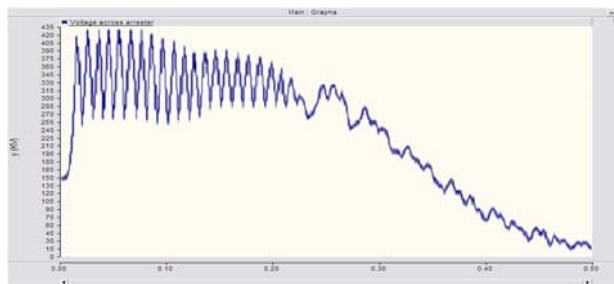


Fig.10. Placing the Surge Arrester 100m away from the Transformer

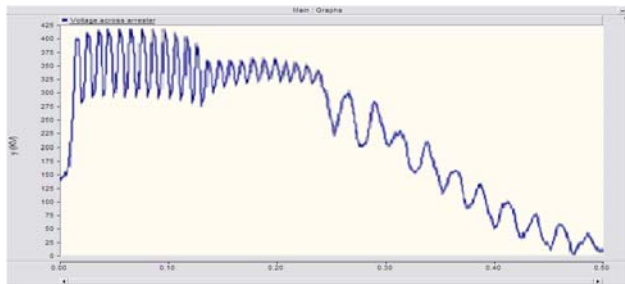


Fig.11. Placing the Surge Arrester 75m away from the Transformer

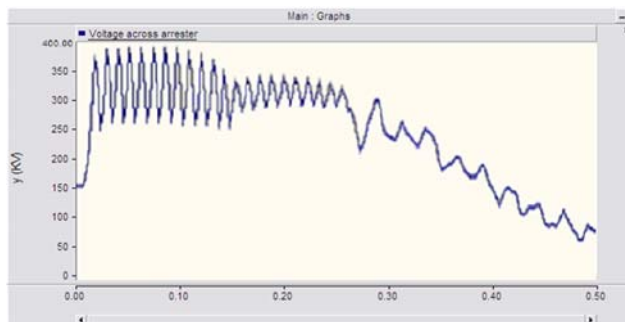


Fig.12. Placing the Surge Arrester 45m away from the Transformer

By moving the surge arrester the arc current and voltages before transformer is shown in Table 3.

TABLE 3
SIMULATION RESULTS

Surge Arrester is set at	Arc current (kA)	Discharge Voltage (kV)
45m away from the transformer	9.91	398.75
75m away from the transformer	10	417.30
100m away from the transformer	10	432.93

Table3 shows the results for different arrester positions. Surge Arrester is placed 45m, 75m and 100m away from the transformer. The output voltages 398.75, 417.30KV and 432.93KV respectively.

V. CONCLUSIONS

A detailed proposed model was successfully presented. As system over voltage is very high, it shows that the lightning surge can be very dangerous even at low value of current if there is no surge arrester is in operating or used for protection. This over voltage is reduced by using the Metal-Oxide Surge Arrester. In the proposed model the distance between arrester and transformer was set at 100m, 75m and 45m. The output voltages 398.75, 417.30KV and 432.93KV respectively. According to the simulation results, at such distances the surge arrester did not work best because these distances were too far from the equipment to be protected, making the traveling waves resound due to the increase in traveling range. Hence overall results have demonstrated the importance of having a right location of surge arrester placement. The best way to prevent surge is to set the best distance, that is to say, to set the surge arrester as close as possible to the equipment to be protected, as fail to do so will cause a significant damage to the equipment.

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