A Case Study on Selection and Application of Lightning Arrester and Designing its Suitable Grounding Grid

[1]Arpan K. Rathod, [2]Chaitanya H. Madhekar

Students
Electrical Engineering,
VJTI, Mumbai, India

Abstract— **Protection of equipment insulation against lightning over voltages and selection of lightning arrester for 220 kV substations that will discharge at lower voltage level than the voltage required to breakdown the electrical equipment insulation is examined. The objectives of this paper is to select appropriate lightning arrester with the lowest rated surge arrester that will provide adequate protection of equipment insulation and equally have a satisfactory service life when connected to a specified line voltage in power system network. The effectiveness and non-effectiveness of earthing system of substation determines arrester properties. Also Standards recognize that particular attention is required for the earthing of surge arresters. A MATLAB program is used in the development of model for the determination of Surge arrester grounding grid parameters like calculation of tolerable limits of current to the body, typical shock situations, tolerable touch and step voltages, maximum fault current, grid resistance, grid current, ground potential rise.**

IndexTerms—**Lightning Arrester, MATLAB program, Ground fault current, Ground Potential Rise (GPR), Mesh Voltage, Soil Resistivity, Step Voltage, Touch Voltage.**

I. INTRODUCTION

Transmission substation delivers bulk power from power stations to the centres and large industrial consumers beyond the economical service range of the regular primary distribution lines. The main components are the transformers, circuit breakers, current and voltage transformers etc. To protect these equipment's from insulation breakdown, as result of over-voltage, over-currents, switching surges and lightning surges, an appropriate protection system must be in place. Lightning [direct stroke and indirect stroke] is one of the major causes of insulation breakdown of equipment in power stations. Lightning could cause 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 rise and results in a back-flashover. 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 modelling 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. With the advent of the metal oxide arrester with its increased energy capability, 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.

Lightning Thunder

An electric discharge between cloud and earth, between clouds or between the charge centers of the same cloud is known as lightning. It involves a huge spark and takes place when clouds are charged to such a high potential i.e. positive or negative with respect to earth or a neighboring cloud that the dielectric strength of neighboring medium [Air] is destroyed. The thunder which accompanies lightning is due to the fact that lightning suddenly heats up the air, thereby causing it to expand and the surrounding air pushes the expanded air back and front causing the wave motion of air.

Lightning Discharge

When a charged cloud moves over the earth, it induces equal and opposite charge on the earth. As the charge gain by the cloud increases, the potential between the cloud and earth increases with corresponding increase in the gradient of air. Break down of the surrounding air starts when the potential gradient is between [5kV/cm – 10kV/cm]. Immediately the air near the cloud breaks down, Pilot Streamer starts from the cloud to the earth. The extent of travel which will be determine by supply of charge from the source in other to maintain a higher gradient at the tip of Leader Stream above the strength of air. Lower gradient will stop the movement and the charge dissipated without forming complete stroke. Maintenance of higher gradient will cause the streamer leader to make contact with the earth .When this leader contacts the ground an extremely bright return streamer propagates upwards from ground to the cloud following the same path of the downward leader at a very rapid rate. Complete breakdown of insulation occurs at this point which leads to a sudden spark called lighting with neutralization of the charge on the cloud.

II. LIGHTNING ARRESTER

Lightning arresters are usually made up of resistor blocks which offers low resistance to high voltage surge and divert the high voltage surge to ground, thereby the insulation of protected installation is not subjected to the full surge voltage. It consists of silicon carbide or zinc oxide elements in series with gap elements. The gap unit consists of air gaps of approximate length. During normal voltages the surge arrester does not conduct. When a surge wave travelling along the line reaches the arrester, the gap breaks down. The resistance offered being low the surge is diverted to the earth. After a few μ seconds the surge vanishes and normal frequency voltage is set up across the arrester. The resistance offered by resistors to this voltage is very high. Therefore, arc current in gap units reduces and voltage across the gap is no more sufficient to maintain the arc. Therefore, the current flowing to the earth is automatically interrupted and normal condition is restored.

Basic Requirements of Lightning Arresters

•It should behave as a perfect insulator for the highest system voltage to ground.
•It should discharge any over voltage into the ground safely.
•It should restore itself as an insulator after discharging the excess voltage.

Selection of Lightning Arresters

The main aim in arrester application is to select the lowest rated lightning arrester that will provide adequate protection of the equipment insulation from burning and be rated in a way that it will have a satisfactory service life when connected to the power system. Lightning arresters are designed by the crest size of the discharge current which the arrester can safely discharge without damage .The lightning arresters are rated as 5, 10 and 20kA. Ratings of 10kA and above are specified for system voltages of 66kV and above. They can safely discharge these current crests. Selection of lighting arrester with approximate rating is preferred because it provides the highest protective margin for the equipment. Higher arrester ratings will increase the ability of the arrester to survive on a specific line but reduce the protective margin between the arrester and the equipment.

For the designing of lightning arrester there are parameters which constitute together to build sustainable and efficient lightning arrester. They are

- Maximum continuous operating voltage
- Rated Voltage
- Earthing Co-efficient
- Lightning Impulse Protective Level
- Protective Ratio
- Impulse Withstand Ratio
- Rated Discharge Current
- Residual Voltage at Rated Discharge Current

Maximum Continuous Operating Voltage (MCOV)

MCOV is the maximum continuous operating voltage to which the unit may be subjected continuously and remain thermally stable after being subjected to standard impulse currents. It is the maximum voltage at which the arrester can be permanently energized i.e., MCOV greater than or equal to $K_t.V_{lng}$. Where V_{lng} is the line to ground fault voltage and K_t is the voltage tolerance factor, which considers allowances for variations due to voltage regulations. It may be typically taken as 1.05.Equation1is:

$$MCOV = [1.05 \times V_{lng}] + [5\% \text{ overvoltage factor} \times V_{lng}] \quad (1)$$

Rated Voltage (V_a)

Rated voltage in KV is the maximum permissible rms value of power frequency voltage. This is selected by taking care of temporary overvoltages (TOV). Equation2is:

$$1.1 \times [\text{Selecting } 80\% \text{ arrester } (0.8) \times V_m] \quad (2)$$

Earthing Co-efficient (EC)

The selection of an arrester with a specified voltage rating is governed by the value of 'Earthing co-efficient (EC)' or the 'Earth-fault factor (EFF)'. These is defined as the ratio of rms value of the healthy phase voltage to line to line voltage at arrester location and earth fault factor is $\sqrt{3}$.EC. Equation3is:

$$EC = \text{RMS Value of healthy phase voltage at arrester location} / \text{Line- to-line voltage at arrester location} \quad (3)$$

Equation4is:

$$\text{Earth-fault factor, } EFF = \sqrt{3} \times EC \quad (4)$$

Lightning Impulse Protective Level (V_p)

The important characteristic of an arrester is the protective level offered by it to the connected equipment. The lower the protective level offered by the arrester, it is evident that lower can be the insulation level of the equipment it protects. This will bring down the cost of major equipment such as transformers.Equation5is:

$$V_p = 3.6 \times V_a \quad (5)$$

Protective Ratio (N_p)
The most important property of a surge arrester is the 'protective ratio' which is Equation6:

$$N_p = \text{Peak impulse insulation level of the protected equipment / Rated arrester power frequency voltage, RMS value} \quad (6)$$

Impulse Withstand Ratio (C_i)
It is the ratio of station equipment impulse withstand level (BIL) to maximum system voltage. Equation7is:

$$C_i = \text{BIL / Maximum system voltage } (V_m) \quad (7)$$

Rated Discharge Current (I_a)
Rated discharge current in KA is the maximum current that passes through the lightning arrester. The lightning ar-resters are designated for 8, 10, 20 KA. Equation8is:

$$I_a = (2V_w - V_p) / Z \quad (8)$$

Residual Voltage at Rated Discharge Current (V_r)
Maximum discharge voltage and discharge factor for the arrester is defined as the maximum value of voltage which appears across the arrester terminals at the time of discharging. Residual voltage at rated discharge current in kvp is the voltage which appears across the lightning arrester at the passage of lightning discharge current. It is taken from table GE company i.e. for 10 kA discharge voltage is 450 kV.

Installation of Lightning Arrester

The best location for installation of lightning arrester is as close as possible to the equipment it is protecting, preferably at the terminals where the service is connected to the equipment. An approximate rule of thumb for the location of lighting arrester is shown in equation 9:

$$\text{Maximum distance in feet} = \text{(Nominal system voltage in kV) / 2} \quad (9)$$

In practice, however, there may be a length of the line between the two extending to 20 to 40 meters. This results in a slightly higher voltage across the equipment due to repeated reflections.

Steps taken when selecting lightning Arrester

- Calculation of the maximum line to ground voltage during a system fault.
- Calculation of the maximum continuous operating voltage.
- Calculation of the maximum line to ground dynamic overvoltage to which the arrester maybe subjected to for any condition of system operation.
- Determination of co-efficient of Earthing.
- Make a tentative selection of the Lightning Impulse protective level of the arrester.
- Determine the maximum arrester discharge voltage for the impulse current and type of arrester selected.
- Establish the full wave impulse voltage withstand level of the equipment (BIL) to be protected.
- Make certain that the Lightning Impulse protective level of the arrester is below the full wave impulse withstand level of the equipment insulation to be protected by an adequate margin.
- Establish the separation limit between the arrester and the equipment to be protected.

III. DESIGN PROCEDURE TO SELECT AN ARRESTER

For 220 kV System :

Input:
Nominal line voltage (V_n) = 220 kV
Maximum line voltage (V_m)= 245 kV
Basic insulation level (BIL) = 1050 kV

Output:
V_{lng} = 141.4 kV.
Maximum distance in (m) = 33.5 m.

MCOV = 156 kV.
Rated Voltage (V_a) = 216 kV.
EC = 0.8.
EFF =1.4
LIPL (V_p) = 778 kV.
Suppose an impulse voltage crest V_w = 1500 kV is travelling on 220 kV line which has BIL of 1050 kV and LIPL (V_p) of 778 kV with a surge impedance (Z) = 300 ohms then :
Current flowing in the line is given as:
$I_w = V_w /Z = 1500 /300 = 5$ kA.
And the current through the arrester is given as:
$I_a = (2V_w – V_p) / Z = (2 \times 1500 – 778) / 300 = 7.4$ kA.
Thus Rated Discharge Current selected is 10 kA.
Residual voltage at Rated Discharge Current is 450 kV as taken from table of GE Company.
Protective Ratio (N_p) =1.34.
Impulse Withstand Ratio (C_i) = 4.28.

As $N_p < C_i$, Thus safe design is obtained and Arrester can be selected.

IV. LIGHTNING ARRESTER GROUNDING

Earthing means a connection to the general mass of earth. Earthing is so widespread in an electric system that practically every point in the system from the generating system to the consumers equipment earth connections are made. Surge arresters should always be provided with a reliable low resistance ground connection. Arrester should be connected as close as possible to the terminals of the apparatus to be protected and have a short and direct path to the grounding system as practical. The main objective is to reduce the voltage stress due to lightning surges by providing a path through which these excesses are discharge safely into the ground. Therefore Substation grounding is a critical part of the overall electric power system. It is designed to not only provide a path to dissipate electric currents into the earth without exceeding the operating limits of the equipment, but also provide a safe environment for any people that are in the vicinity. Design of a proper grounding system will be discussed as well as performing of calculations necessary to ensure a safe design.

Common Lightning Protection Earths

- Single earth rod, which is not generally acceptable other than in areas with a constantly high water table.
- Combination of rods and conductors are most commonly used.

Ground Grid Mesh Electrodes

The use of conductors buried under the surface of the earth is the ground-grid mesh. Grid meshes are often used to complement rods or can be used separately when deep driven rods are impractical due to soil and terrain considerations. Grid meshes are often used for the earthing in substations to create an equipotential platform and also to handle the high fault currents returning to the transformer neutrals. They are particularly useful when multiple injection points are required, at a substation for example. In this case a number of items will be connected to the grid at various locations, the mesh provides a good earth irrespective of the injection point of the fault current. Earthing resistance of buried grid meshes can be considerably lower than those implemented using vertical earth spikes. Increasing the area of the grid coverage can also significantly reduce earth resistance.

V. DESIGN PROCEDURE FOR GROUNDING GRID

Input:
Assuming Low resistivity soil
Area of the plot = 67.5 x 45 m2
Maximum earth fault current = 40KA
Duration of fault = 0.5 sec
Soil resistivity = 50 Ω m.
Surface layer soil resistivity = 2500 Ω m.
Thickness of crushed rock = 0.102 m
length of ground rod = 10 m
Depth of grid from surface = 0.5 m
Grid reference depth = 1 m
Current division factor = 0.6
Decrement factor = 1

Output:
The safe design is obtained with inclusion of 40 ground rods.
Diameter of Grid conductor d = 0.0224 m
Reflection factor K = -0.9608
Reduction factor of surface layer of crushed rock Cs = 0.7000

Tolerable step voltage E_{step70} = 2.5534e+03 V
Tolerable touch voltage $E_{touch70}$ = 804.8643 V
Grid resistance R_g = 0.4369 Ω
Maximum grid current I_g = 16.9706 KA
Ground potential rise GPR = 7.4153e+03 V
Calculated mesh voltage E_m = 675.8692 V
Calculated step voltage E_s = 615.6045 V

VI. CONCLUSION

This paper has focus on the design and selection of lightning arrester and its suitable grounding grid for 220 kV line substation. Surge Arrester Selection Shall Be Made With Complete Clarity Of System Parameters. Residual Voltages, Energy Class Shall Be Chose In Coordination With System BIL and Applications Respectively. The results for the specifications obtained are of safe values. The paper uses both hand calculation as well as MATLAB program. It was also found that with increase in size of grid, lower is the value obtained of grid resistance. But larger the area, more land it occupies and in high resistivity soil wherein if hard rocks like granite are present it is difficult to lay grounding grid in that case vertically driven rods or rods in parallel can be a choice. The uniform soil resistivity is assumed in the designed calculations. But in actual practice the resistivity of soil is not uniform. Analysis of grounding systems with finite volumes of different resistivity's can be done as a future work. Study of these types of soils has significant advantages because these soil models represent many practical situations where a relatively small heterogeneity may have a major influence on the earth potentials at points within or near the heterogeneity. Encasement of the earth grid in bentonite is recommended for reduction of the soil resistivity and resistance although it would be costly due to the size of the grid.

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