Effect of Grounding Resistance and Lightning Arrester Non-linear Characteristics in Electrical Distribution System

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Abstract

Lightning Arresters (LAs) are widely used in electrical distribution system for the protection of various electrical equipments of distribution sub-station. For the protection of those sub-station equipments including sub-station transformer, the insulation coordination study is performed which determines the voltage level of electrical equipments in order to ensure their protection against over-voltages. The lightning impulse withstand voltage level or basic impulse insulation level (BIL) of sub-station equipments depends on grounding condition and non-linear characteristics of lightning arrester apart from the magnitude of lightning surge. Hence, it is highly essential to analyze the effects of grounding condition and non-linear characteristics of lightning arrester in order to determine optimized value of BIL of equipments so as to prevent failure and over-investment. In this research work, the lightning over-voltage study is performed for an 11 kV overhead distribution line terminated by a transformer. For the fulfillment of the objective of research work, the sixty cases have been simulated and the lightning impulse withstand voltage levels or BIL of the transformer have been analyzed for all the cases through computer simulations on Alternative Transient Program (ATP). In this context, this research work proposes multiple lightning arresters for the protection of 11 kV sub-station transformers under different grounding conditions. With the introduction of more than one lightning arrester, is has been observed that lightning impulse withstand voltage level or BIL of equipment has reduced a lot.

Keywords

EMTP/ATP – Lightning Arrester – Grounding Resistance
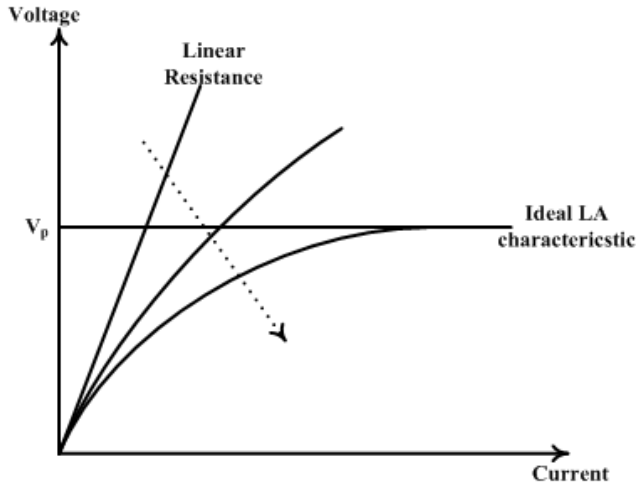
1. Introduction

An electrical power system is a network of electrical components used to supply, transfer and use electrical power. It is composed of generation system, transmission system and distribution system. An electrical power distribution system is the final stage in power delivery system and it carries electrical power from transmission system to the individual consumers. Distribution substations connect the distribution system with the transmission system and they lower the transmission voltage to distribution voltage level with the help of distribution transformers. Normally, there are two distribution voltage levels, viz. primary and secondary.

Since distribution system is one of the vital parts of the power system, it needs protection against various events occurring during the operation of power system.

Over-voltage is one of the events occurring in the power system which needs special attention. Over-voltages occurring in the power system can be broadly classified into temporary over-voltage, switching over-voltage and lightning over-voltage. Out of these over-voltages, lightning causes severe damages in distribution system. Hence, to protect the distribution system against lightning, lightning arrester (LA) is used. Sometimes, LA can also be used to protect power system against switching surges. A typical lightning arrester has a high-voltage terminal and a ground terminal. When a lightning surge travels along the transmission line to the arrester, the surge current in the arrester is diverted to the earth. It means the LA offers low impedance for the flow of surge current due to lightning. But in case of temporary over-voltage or normal voltage, the LA offers very high impedance. Hence we can say that LA is a protective device having variable impedance.
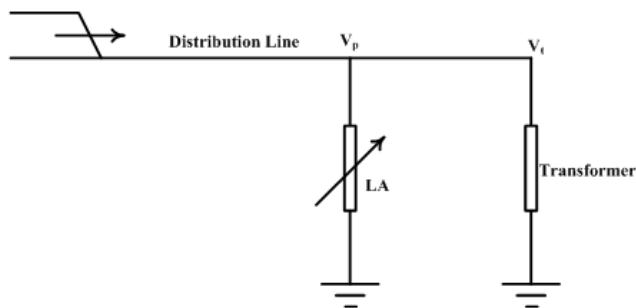
Figure 1: Various Characteristics of LA

The Figure 1 shows the various characteristics of an LA. Out of the non-ideal characteristics of LA, as we move along the arrow, we obtain better characteristics similar to the ideal one.
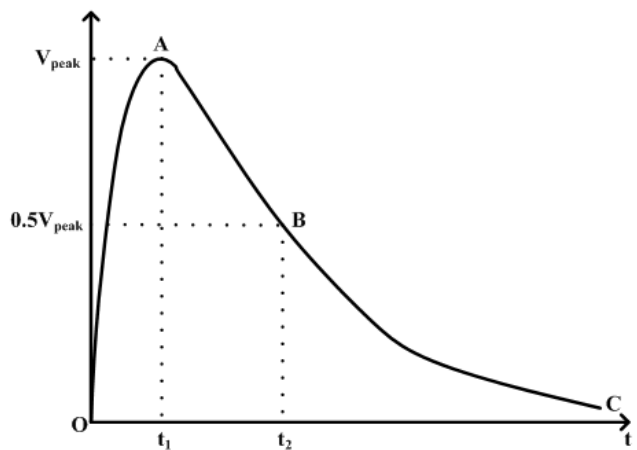

Figure 2: Transformer protected by LA

From the ideal characteristic of LA, we can see that the voltage across it remains constant irrespective of the discharge current. When lightning surge strikes an LA, it offers very low resistance to the flow of high surge current maintaining constant voltage across it. But when the grounding resistance of LA is high, during the flow of high surge current, very high voltage will be developed across LA. This over-voltage may exceed the BIL of the protected equipment and it may damage the equipment. Hence, some measures are to be adopted to solve this problem.

2. System Components Model

In order to achieve the objective of this research work which is to analyze the effect of grounding resistance and lightning arrester non-linear characteristics in electrical distribution system, the lightning impulse wave shape has been generated, overhead distribution line and arrester models have been developed and analyses have been performed on the Electromagnetic Transient Program (EMTP)/Alternative Transient Program (ATP) which is one of the most widely-used Power System Transient simulation program. The following sections present lightning impulse wave shape, overhead distribution line model and lightning arrester model in detail.

2.1 Lightning Impulse Wave Shape

An impulse voltage is unidirectional voltage surge which rises to a maximum value within a very short period of time and falls slowly to zero value. The wave diagram of such impulse is shown below.
The standard wave shape of an impulse is shown in Figure 3.

Figure 3: Standard wave shape of an impulse

The maximum value is termed as Peak Value of impulse with which any impulse wave is specified. In the wave diagram shown in Figure 3, OA part is front impulse and ABC is called tail of the wave. An impulse voltage is characterized by its peak value and its front time and tail time. The wave front time of an impulse is the time taken by the wave to attain its maximum value starting

from zero value. The wave tail time is the time taken by the wave between starting point O and the point on wave tail where the voltage is 50% of the peak value. The standard impulse wave used in the research work is $3500kV;1.2/50\mu s$
where, 3500 kV is the peak value of impulse
$1.2\mu s$ is wave front time
$50\mu s$ is wave tail time

2.2 Overhead Distribution Line Model

An overhead distribution line is characterized by four parameters: series resistance R due to conductor resistivity, shunt conductance G due to leakage current between phases and ground, series inductance L due to magnetic field surrounding the conductors, and shunt capacitance C due to the electric field between conductors. In case of overhead lines, the effect of shunt conductance is small and usually neglected. Apart from this, overhead line can also be modeled in terms of surge impedance and velocity of wave propagation. The calculation of related surge impedance and wave velocity is as below [1]:

$$Z_{surge} = \sqrt{\frac{L}{C}}$$

&

$$v = \frac{1}{\sqrt{LC}}$$

where L is the line geometrical inductance (H/km)
and C is the line geometrical capacitance (F/km).
In this research work, 11 kV overhead distribution line with 'DOG' conductor has been taken and has been modeled in terms of R, L & C parameters having values as follows:
$R = 0.28\Omega/km, L = 1mH/km, C = 10nF/km$

2.3 Lightning Arrester Model

Lightning arresters are also known as surge arresters or surge diverters. Surge arresters used for protection of exterior electrical distribution lines will be either of the Metal Oxide Surge Arrester (MOSA) with resistors made of Zinc Oxide (ZnO) blocks, or gapped with resistors made of Silicon-Carbide (SiC) [2]. Expulsion type units are no longer used. Since the goal of installing lightning arrester is to provide protection at

high voltages, it should conduct no or little current at normal operation voltage and conduct current at over-voltages in order to prevent a fault due to high voltages, as defined in [3]. Hence, the lightning arrester model should have a non-linear voltage versus current characteristics. Previously, this non-linear characteristic used to be provided by Silicon-Carbide material with series connected spark gaps. Spark gaps cause high impedance and no current conduction. After the spark over of the spark gaps, silicon carbide material provides current flow. However, nowadays, metal oxide (MO) material that inherently provides non-linear characteristic is used in lightning arresters. In this type, the number of discs determines the voltage rating and the diameter and parallel columns of the discs define the energy rating of the MO lightning arrester. For the purpose of simulation and analysis, the lightning arrester has been classified into three classes throughout the research work. The characteristic of Class I arrester is the best and that of Class III the worst. The Figure 4 depicts the characteristics of all three classes of lightning arrester used in the research work.
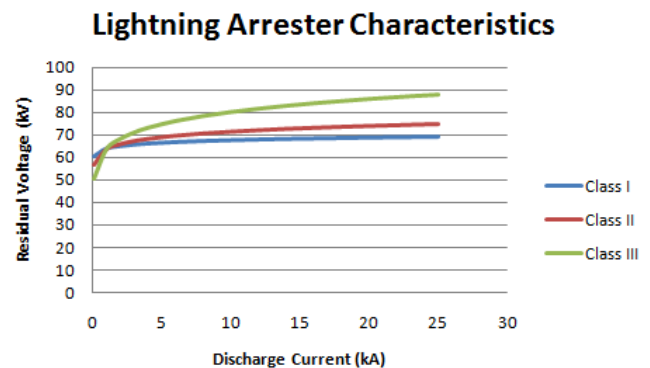

Figure 4: Characteristic of various classes of Lightning Arrester
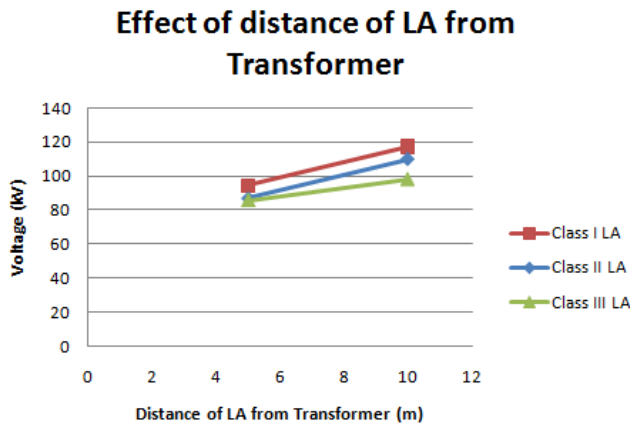
3. Simulation & Results

After digital electromagnetic transients programs became available in the late 1960's and early 1970's for mainframe computers, and later for personal computers, it is possible to make transient analysis on computer. The analyses in this thesis study are performed on the Alternative Transient Program (ATP). The cases are determined in order to analyze the possible situations and observe the worst case scenarios. In this scope, the sixty different cases have been determined.

Using these cases, the effects of distance of arrester from transformer, the effects of non-linear characteristics of various classes of lightning arrester, the effects of grounding resistance and the effects of various classes of multiple lightning arresters have been analyzed and evaluated separately. For these sixty cases, defined variable parameters are as follows:

- Lightning Arrester location
- Amplitude and wave shape of impulse wave
- Length of distribution line
- Lightning Stroke Location

3.1 Effect of distance of Lightning Arrester from the Transformer

The effect of distance of Lightning Arrester from the Transformer has been illustrated in Figure 5. As shown in Figure 5, the maximum voltage across transformer goes on increasing as its distance from lightning arrester is increased for each class of arrester. Hence, the lightning impulse withstand level or BIL rating of transformer should be increased if its distance from the arrester is increased for proper insulation coordination.
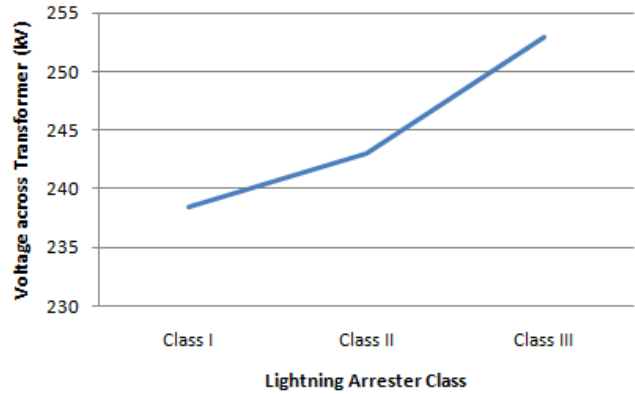

Figure 5: Effect of distance of various classes of lightning arrester from transformer

3.2 Effect of Non-linear characteristics of various classes of lightning arrester

The effect of non-linear characteristics of various classes of lightning arrester has been illustrated in Figure 6. The Figure 6 clearly indicates that the maximum voltage across the transformer increases as we move towards the worst class arrester from the best class arrester for

a particular value of grounding resistance. Hence, the higher value of BIL is required for the transformer as we move towards worse class arrester.
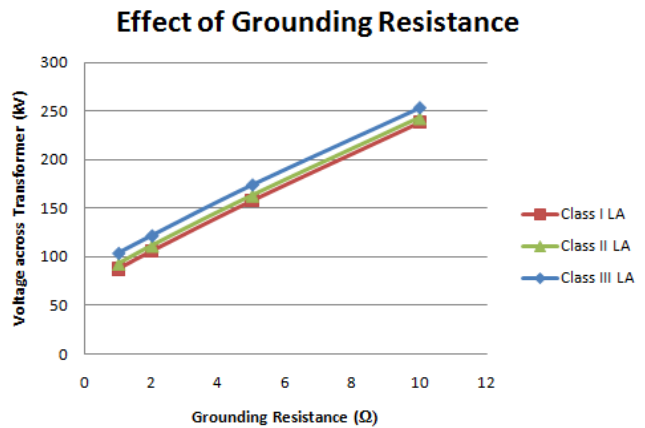

Figure 6: Effect of various classes of LA on the maximum voltage across transformer for the grounding resistance of 10 Ω

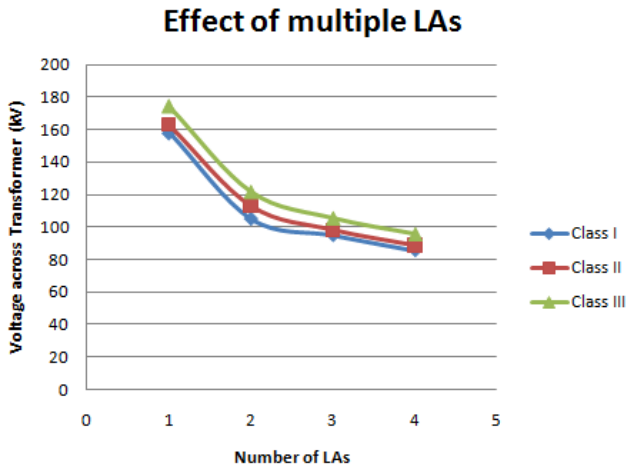## 3.3 Effect of Grounding Resistance

The effect of grounding resistance for various classes of arrester has been demonstrated in Figure 7. It can be clearly observed from the figure that as the grounding resistance becomes higher, the BIL rating of transformer should also be increased. Hence, there should be compromise between the cost of insulation of protected equipment and the cost incurred in reducing the grounding resistance.

Figure 7: Effect of grounding resistance on maximum voltage across transformer for various classes of LA

3.4 Effect of various classes of multiple lightning arresters

The effect of various classes of multiple lightning arresters for a particular value of grounding resistor (here, 5Ω) has been demonstrated in Figure 8. The figure clearly demonstrates that as the number of lightning arrester increases for any class of arrester, the BIL rating of the transformer can be reduced for a particular value of grounding resistance.

Figure 8: Effect of various classes of multiple lightning arresters on maximum voltage across transformer for grounding resistance of 5 Ω

Moreover, from Figure 8, it can be clearly observed that the slope of the curve goes on decreasing as we increase the number of arrester i.e., the curve is more steep as we move from one arrester to two arresters but change becomes less significant as we move towards three and four arresters. Hence, it indicates that no significant reduction in maximum voltage across transformer is observed as we go for more than two lightning arresters.

4. Conclusion

In this research work, the effects of grounding resistance and lightning arrester non-linear characteristics in electrical distribution system have been simulated and analyzed by using ATP. For the fulfillment of the objective of the research, sixty different cases have been simulated and analyzed which mainly investigated the effects of distance of transformer from arrester, the effects of grounding resistance and the effects of non-linear characteristics of various classes of multiple lightning arresters on the BIL rating of transformer.

From the results obtained from simulation study varying the distance of transformer from arrester, it has been concluded that as the distance of transformer from arrester is increased, the BIL of transformer should also be increased. From the results obtained from cases simulated under varying conditions of grounding resistance, it has been concluded that higher value of grounding resistance leads to the increment in BIL of transformer. From the cases simulated by varying the non-linear characteristics of lightning arrester ranging from the best characteristic to the worst characteristic, it has been concluded that the lightning arresters having worst non-linear characteristics require the increment in BIL of transformer for a particular value of grounding condition. Finally, the results obtained from simulation by varying the number of lightning arresters lead to the conclusion that as the number of lightning arrester is increased, the BIL of transformer can be reduced. The reduction in BIL of transformer is more dominant in the system having high grounding resistance. The results show that there is significant reduction in BIL of transformer when the number of arrester is increased from one to two, but when the number of arrester is further increased to three and four, there is less significant reduction in BIL of transformer. Hence, the optimized number of lightning arresters is two for the protection of transformer in the simulated scenarios.

References

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