Lightning performance of a HV/MV substation

MAHMUD TRAINBA, LAMBROS EKONOMOU

Department of Electrical and Electronic Engineering
City University London
Northampton Square, London EC1V 0HB
United Kingdom

emails: lambros.ekonomou.1@city.ac.uk, mahmud.trainba.1@city.ac.uk

Abstract: - Lightning overvoltages is the main cause of faults and outages in substations. The appropriate protection of the substation against external overvoltages is critical, in order to ensure the efficient, reliable and safe operation of the system. Shielding wires, mast and surge arresters are the most important parts of a lightning protection system. However, various factors can influence the efficiency of the protection system and the developed overvoltages. In the current work a lightning performance study for a substation is carried out, the grounding resistance and the installation position of the arresters.

Key-Words: - Grounding resistance; Lightning; Substation; Surge arresters.

1. Introduction

External overvoltages can cause several damages to a substation, leading to insulation breakdowns. When the incoming surge exceeds the insulation level of the equipment a breakdown is occurred, resulting to serious damages and interruption of the power supply. Insulators, switching devices, cables and transformers are the main parts of the installation that are intensively stressed by lightning phenomena and their failure creates several serious malfunctions, interruptions and dangers.

The study of the lightning effects and the design of an appropriate protection system against lightning is a crucial issue, since substations are complex installations of high investment cost. Moreover, the safety of the personnel must be considered in priority, in order to avoid accidents.

In case of a lightning hit on the incoming overhead transmission line a shielding failure or a backflashover, i.e., insulation failure of the ceramic of glass insulator, can be occurred, depended on the ground wires position, the peak current of the lightning flash and the grounding resistance. Such an insulation fault results to the development of a travelling wave, which will be directed to the entrance of the substation. The high voltage cables can also be influenced by the incoming surges; when the arisen overvoltages exceed the dielectric strength of the XLPE insulation a fault is occurred. The most vulnerable parts are the joints and the termination positions. Furthermore, a lightning surge can cause breakdown of the transformers’ insulators or the transformers’ dielectrics, resulting to thermal and electromechanical effects (fire, short-circuits, mechanical damages, etc.).

The above indicate the need of appropriate lightning protection system, in order to avoid lightning outages and restrain the repair costs of the equipment. The design of the lightning protection system has to take into consideration the stochastic nature of the external overvoltages phenomena and the various techno-economic factors of a substation. The striking point, the geometrical characteristics of the external lightning protection system, the grounding system and the basic insulation level are factors that influence the severity of the lightning impact. Protection of substations against the catastrophic effects of lightning may be achieved by using higher insulation levels, taking of course into account the economic cost, or by installing overhead ground wires in order to intercept the lightning flashes. Moreover, surge arresters can contribute to the improvement of the lightning performance of the
installation, especially in regions with high soil resistivity.

To this direction, a risk management assessment has to be performed, in order to predict the possible dangers and install the appropriate equipment, in order to restrain the lightning effects, applying sophisticated methods. A four-step procedure is suggested [1]:

- Evaluation of the importance and the value of the under protection installation,
- Investigation of the keraunik level and the exposure of the substation,
- Design of the lightning protection system according to an appropriate method, and
- Evaluation of the effectiveness and the cost of the lightning protection system.

The current paper presents a lightning performance study of a typical 150/20kV substation, calculating the developed overvoltages in various positions of the system. A sensitivity analysis is also performed, considering factors as the grounding resistance and the installation position of the surge arresters.

2. Lightning Protection of Substations

Generally, the annual number of direct lightning strokes in a substation is given by the equation:

\[ D = 10^{-6} \cdot W \cdot L \cdot N \]  \hspace{1cm} (1)

where: W and L are the dimensions of the substation (width and length) and N is the number of flashes to earth per square kilometer per year.

For example, for a substation with W=L=50m and keraunik level T=30, then D=0.0045 strikes/year. Consequently, the substation is directly struck every 222 years.

The design of lightning protection system is performed following appropriate methodologies. The most widely used design methods to protect substation against lightning hits are the [1-3]:

- Fixed angles method,
- Empirical curves method, and
- Electrogeometrical method.

Furthermore, the lightning performance of a substation can be improved by installing surge arresters. Surge arresters are semiconductor devices that protect the equipment of an electrical installation against incoming surges. Several different types of arresters are available and all perform in a similar way; they present high resistance during the normal operation of the network and low resistance during surge conditions. Nowadays, gapped surge arresters with varistors made of silicon carbide have been replaced by gapless metal oxide arresters, due to their advanced characteristics [4]. More analytical, metal oxide arresters present more extreme non-linear voltage-current characteristic compared to the silicon carbide ones, rendering unnecessary the disconnection of the resistors from the line through serial spark gaps [4, 5].

The installation position of the arresters plays important role, due to the fact that overvoltages behave as travelling waves. The voltage level at every instant and at every point on the line results from the sum of the different instantaneous values of each individual voltage wave, considering the refractions and reflections because of the changes of the surge impedance. A connected transformer behaves as an unterminated end, since its winding inductivity for fast voltage waveforms presents much higher impedance compared with the impedance of the line.

Fig. 1 depicts an overvoltage running towards a transformer, assuming a propagation velocity equal to the speed of the light. The arrester presents an ideal behavior, limiting the desired residual voltage. Note that, a voltage wave is totally reflected when reaching an unterminated end of a line. The voltage level at every instant and at every point on the line results from the sum of the different instantaneous values of each individual voltage wave. Thus, at the terminated end this value will be doubled. A connected transformer appears similar to an unterminated end since its winding inductivity for rapid functions exhibits high impedance compared with the surge impedance of the line [4].

Fig. 1 Power transformer protected by a surge arrester
3. System configuration

Fig. 2 shows the topology of the examined system, presenting the basic parts of the substation. A single transmission line (Fig. 3, Al, 636MCM) is connected with a high voltage cable (XLPE), which transfers the electrical energy to the power transformer (150/20kV). Note, that an overhead transmission line of 15km is considered; the span between the towers is 200m and the tower footing resistance is 10Ω. The lengths AB and BD are 100m and 300m, respectively. The transformer is protected by metal oxide surge arresters (Table 1).

![Overhead transmission line](Image)

Fig. 2 System configuration

![Overhead transmission line](Image)

Fig. 3 Overhead transmission line

<table>
<thead>
<tr>
<th>Maximum Continuous Operating Voltage</th>
<th>86kV</th>
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<tr>
<td>Rated voltage</td>
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<tr>
<td>5kA</td>
<td>242kV</td>
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<tr>
<td>10kA</td>
<td>254kV</td>
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<tr>
<td>20kA</td>
<td>280kV</td>
</tr>
<tr>
<td>40kA</td>
<td>313kV</td>
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A lightning stroke hits either a phase conductor (30kA, 8/20μs) or an overhead ground wire (200kA, 8/20μs) at position A, considering that the majority of the substations failures occur due to shielding failures or backflashover on the lines. The developed voltage surge travels through the conductor and the cable to the substation’s transformer. The developed overvoltages at the terminals of the transformer are estimated by using appropriate simulation tool. A sensitivity analysis is performed, considering the installation position of the arresters and the grounding resistance of the arrester.

The transmission line and the cable are represented by the distributed parameter models, based on the Bergeron’s traveling wave method. The towers are modelled according to equation [6]:

\[ Z_r = 60 \ln \left( \cot \left( \frac{1}{2} \tan^{-1} \left( \frac{r}{h} \right) \right) \right) \]  

where: \( r \) in m is the tower base radius and \( h \) in m is the tower height.

When the developed overvoltage across the insulators of the line exceeds their dielectric strength, then a flashover is occurred. The flashover strength \( V_{FO} \) is determined by the voltage-time characteristic of the insulator strings [7, 8]. \( V_{FO} \) is given as [8]:

\[ V_{FO} = (400 + 710 / t^{0.75}) \cdot D \]  

where: \( D \) in m is the insulator string length, and \( t \) in μs is the elapsed time after lightning stroke.

For the representation of surge arresters the IEEE model is used [9-11]. As far as the grounding resistance concerns, it is represented as a lumped resistance according to [12]. The lightning current is given by a double exponential equation:

\[ i(t) = I \cdot (e^{-\alpha t} - e^{-\beta t}) \]  

where: \( \alpha, \beta \) are constants, dependent on the lightning current waveshape.

4. Results

Figs 4-7 depict the developed overvoltage at the entrance of the transformer in function with the grounding resistance and the installation position of the arrester in case of lightning flash on phase or ground wire. The obtained results clearly indicate the dependence of the estimated surges on the above factors. In details, high grounding resistance values may result to the exceedance of the basic insulation
level of the installation, leading to breakdowns and faults, since only a part of the injected lightning impulse is diverted to the ground through the arrester. The installation position is also a critical factor that strongly influences the lightning performance of the substation. Note, that the protection distance of the arrester depends on the lightning current characteristics, the residual voltage of the arrester and the insulation withstand capability of the installation to be protected. Furthermore, the grounding resistance of the towers is an important factor, in order to avoid transient phenomena due to backflashover.

Thus, it is concluded that the efficient operation of the arresters requires the satisfaction of critical parameters, i.e., the achievement of low grounding resistance values and the installation of the arresters near to the equipment under protection. Otherwise, the lightning protection measures (shielding wires, masts, arresters) will not limit the incoming surges under the permitted insulation level.

5. Conclusion

The adequate lightning protection of the substations is of great importance, in order to avoid the development of overvoltages that exceed the basic insulation level of the installation and may result to faults and interruption of the normal operation of the system. In the current work a lightning performance
study for a typical 150/20kV substation is carried out and the voltage surges at the entrance of the transformer are computed, taking into consideration the role of the grounding resistance and the installation position of the arresters. Two different cases were examined, i.e., the lightning hit on the phase conductor or the lightning hit on the ground wire. The results highlight how the above factors influence the range of the expected overvoltages. Future work includes the performance of a sensitivity analysis of other parameters (e.g., length of cable, hit position, etc.) and the computation of the lightning failure rate.

References:


