CALCULATION OF LIGHTNING OVERVOLTAGE FAILURE RATES FOR A GAS INSULATED SUBSTATION

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ABSTRACT

Lightning overvoltages can cause damage to the equipment in a substation, leading to poor utilisation of assets. In order to prevent this damage from occurring, an acceptable level of lightning protection should be installed.

Designing this level of protection requires that the acceptable rate of failure for the substation due to lightning overvoltagest be defined.

An acceptable failure rate is normally calculated based on experience and historic records of failure due to lightning overvoltages. However there is no method freely available to enable designers to calculate acceptable substation failure rates when this historical data is unavailable.

The International Standard IEC-60071-2 "Insulation Coordination" Third Edition 1996 states the following; "For apparatus, acceptable failure rates Ra due to overvoltages are in the range of 0.001/year up to 0.004/year depending on the repair times."

This paper deals with an approach to calculate a failure rate for a substation based on a function of; lightning strike magnitude, lightning strike location, surge arrester location and substation topology. The substation, with 110kV unshielded overhead line connected to the substation via underground cable, is modelled using Alternative Transient Program Draw (ATP Draw).

ATP Draw is graphical user interface for Electromagnetic Transient Program (EMTP), which is a software program used to simulate electrical transient phenomena.

INTRODUCTION

The aim of insulation coordination is to define the optimum network design at minimum cost. Sufficient insulation of the network, along with adequate protective equipment is required to help ensure the best performance of assets. Typically the overvoltages seen at a substation as a result of switching or lightning are the most important factors to consider when carrying out an insulation coordination study. An important element in limiting the overvoltage at a substation is the employment of overvoltage protection equipment i.e. surge arresters and adequate earthing.

Designing this level of protection requires a definition of the acceptable rate of failure for the substation due to lightning overvoltage. This paper details how to calculate a failure rate for a given substation topology using ATP Draw software. The acceptable rate of failure can then be defined based on this calculation.

HIGH FREQUENCY SUBSTATION MODELLING

In order to model a substation in ATP Draw and to sufficiently analyse resultant overvoltages resulting from a lightning strike, several pieces of equipment must be modelled; busbar, surge arresters, overhead lines, underground cables, towers and transformers. The source of lightning is another important component that must be modelled. The overhead lines were modelled as unshielded and connected to the substation via underground cable, which is common in Ireland.

Standby feeding arrangements for events such as maintenance or outages must be considered. Different substation topologies such as multiple transformers or multiple feeders connecting to the substation must also be considered. The ATP Draw model is shown in Figure 1.

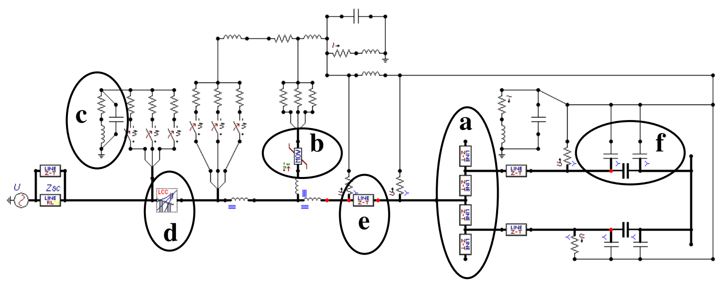

Figure 1 – Simplified ATP Draw Illustration

ATP Draw Modelling Components

Busbar (a) – The busbar was modelled as a surge impedance [1].

Surge Arresters (SA) (b) – The surge arrester was modelled using the MOV component in ATP Draw.

Tower Footing Impedance (TFI) (c) – The tower footing impedance was modelled as an RLC circuit as shown in section 7.6.11.1 of [2].

Overhead Lines (OHL) (d) – The OHL was modelled using a JMarti model in ATP Draw.

Underground Cables (e) – The underground cables were modelled as surge impedance [2].

Transformers (f) – The transformers were represented as capacitances to ground [1].

Lightning Source (g) – The lightning source was modelled as a Heidler Source in ATP Draw [3].

SIMULATIONS

A lightning strike is simulated at a point on the OHL connected to the substation. The energy from the strike will result in an overvoltage on the OHL, which if large enough will flash across the three phases. Part of the energy from the strike will dissipate through the TFI of the angle masts and SA at the cable interface. The strike will also lead to an overvoltage on the substation equipment. If the overvoltage is large enough it will exceed the basic insulation level (BIL) rating of the substation equipment affected.

The voltage level at pieces of substation equipment deemed to be vulnerable, such as the busbar or transformer, should be calculated. In the cases where the BIL is exceeded, the lightning strike magnitude and overvoltage at the piece of equipment is recorded.

Lightning strikes of different magnitudes are simulated at varying distances from the substation. The furthest distance away from the substation considered should be a point at which the resultant overvoltage from any magnitude of lightning strike will not exceed the BIL of the substation equipment. This distance can be estimated as shown in [4].

This will allow the results to show a definitive distance from the substation at which lightning can cause dangerous overvoltages, beyond which a strike should not cause the BIL of the substation equipment to be exceeded.

Table 1, shows the magnitude and distance from the substation at which lightning strikes were simulated.

Distance of strike from CSE (km)	0.1	0.2	0.5	0.1	1	5	10	15	20
Magnitude of Lightning Strike (kA)	1	1	1	1	1	1	1	1	1
	3	3	3	3	3	3	3	3	3
	5	5	5	5	5	5	5	5	5
	10	10	10	10	10	10	10	10	10
	20	20	20	20	20	20	20	20	20
	80	80	80	80	80	80	80	80	80
	200	200	200	200	200	200	200	200	200

Table 1 – Magnitude and Distance of Strikes

When a lightning strike is simulated, the voltage at a piece of equipment can be plotted, as shown in the example in Figure 2.

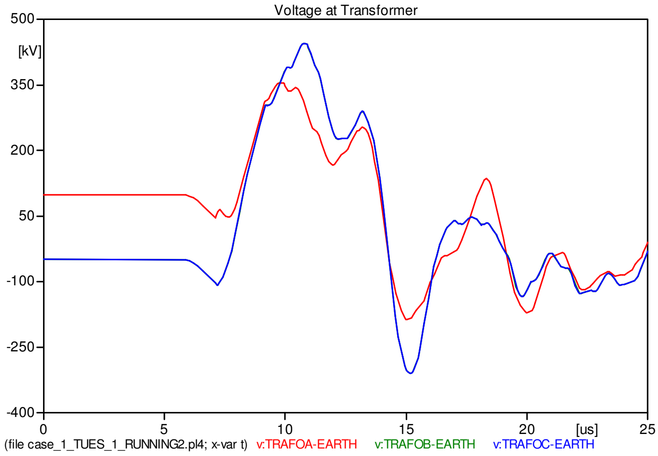

Figure 2 – Plot of Voltage at Monitored Equipment

The highest voltage level for each separate simulation can be recorded and displayed as shown in Figure 3. If any of the voltage levels exceeds the BIL for a piece of substation equipment the distance and magnitude of the strike should be noted for use in the failure rate calculation.

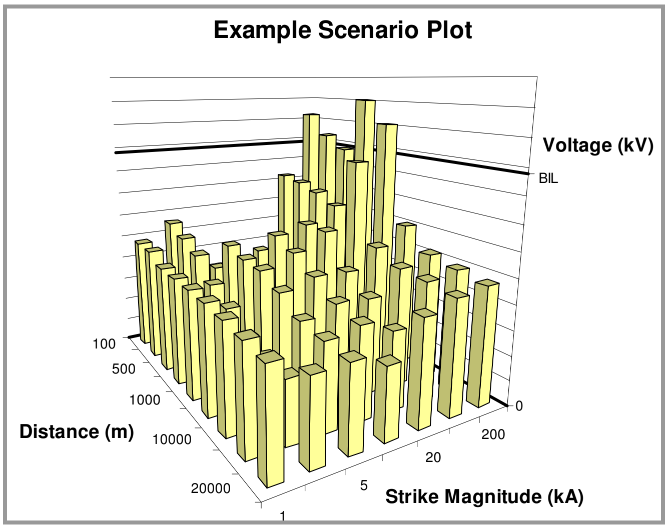

Figure 3 – Plot of Overvoltages

Figure 3 shows an example for a particular substation topology and surge arrester deployment. In this case lightning strikes that are above 80kA result in the BIL being exceeded when the strike is 1km or closer to the cable line interface. It can also be seen that strikes of 200kA result in the BIL being exceed at 1km or closer to the cable line interface.

FAILURE RATE CALCULATION

The failure rate was calculated considering the probability of a lightning strike on the OHL connected to a substation and the probability that this strike is of sufficient magnitude to cause the BIL of substation equipment to be exceeded.

The lightning flash collection rate is the number of lightning flashes per 100km per year for a given region. This data must be provided for the study.

The lightning flash collection rate for a given poleset or tower per 100km/year, N_L, is given by

$$N_L = N_g \cdot \frac{28H^{0.6} + b}{10}$$

where

N_g is the ground flash density (flashes/km^2 /year).

H is the pole / tower height in meters
b is the structure width in meters

The probability of a lightning flash N_M, for a given line length is given by

$$N_M = \frac{N_L}{100} \cdot l$$

Where l is the length of line in km. [5].

N_M is calculated for each of the distances at which a lightning strike is simulated.

For example, if

$$N_g = 0.1$$
$$H = 10m$$
$$b = 5m$$

The different values for N_M would be as shown in Figure 4;

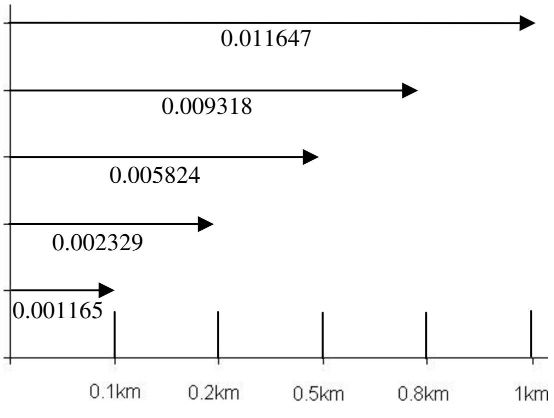

Figure 4 – Probability of Strike per distance from Cable Interface

The lightning strike data provided for Region A was plotted as shown in Figure 5. The probability of a lightning strike of a given magnitude or higher occurring was calculated by using this figure.

For example, in Figure 5 if we have a lightning strike, the probability that the magnitude of the strike will be 20kA or higher is approximately 9%. This probability is represented by S.

S is calculated for strike magnitudes at which the BIL of substation equipment is exceeded.

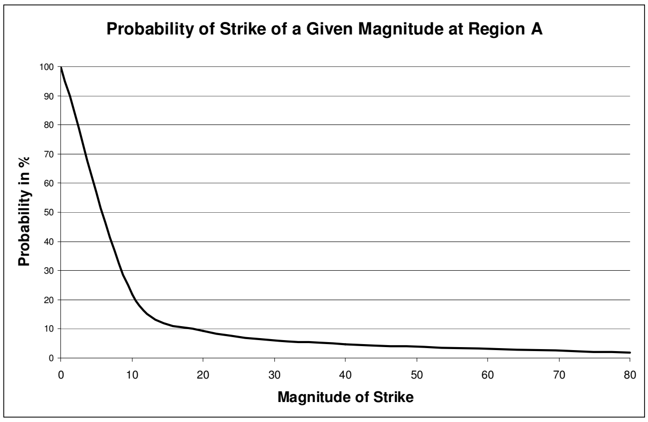

Figure 5 – Lightning Strike Magnitude Distribution

N_S is the probability of a lightning strike overvoltage which exceeds the BIL of substation equipment occurring over a given length of line.

$$N_S = N_M \cdot S$$

A value for N_S is calculated at each distance from the substation where a simulated lightning strike overvoltage exceeds the BIL of substation equipment.

The summation of the different values for N_S will give an overall rate of failure for that particular substation.

$$N_{Stotal} = N_{S100km} + N_{S200km} + N_{nkm} \cdots$$

Example:

If the results from Figure 3 and the values for N_M as shown in Figure 4 are used, the two lightning strike magnitudes that exceed the BIL are 80kA and 200kA, at a distance from the cable interface of 1km for both strikes. Since a strike of 80kA is sufficient to exceed the BIL at 1km and the 200kA strike does not exceed the BIL at a distance further than 1km, N_S should only be calculated for 80kA.

S for an 80kA strike, using Figure 5 = 1.9% or 0.019

N_M for 1km = 0.011647

$$\therefore N_S = 0.011647 * 0.019 = 0.000221293 / year$$

If we compare this to the IEC acceptable failure rate of 0.001/year we can see that in this example the given level of lightning overvoltage protection is sufficient.

Figure 3 show the results from 63 simulations, used to calculate a failure rate, for one topology type. In order to calculate a failure rate for stations with different topologies and feeding arrangements, many more simulations would be required.

CONCLUSIONS

This method for failure rate calculation is useful for examining the effectiveness of overvoltage protection on substations where there are no prior records of failures due to lightning overvoltages.

It is also an efficient way of examining overvoltage protection for new substation designs of different feeding arrangements and topologies.

ACKNOWLEDGMENTS

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