A Study of the Factors Affecting the Lightning Protection Level in 500 kV GIS Substations

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Abstract : This paper presents a study of the factors affecting the insulation level of protection from lightning overvoltages for the selected 500 kV GIS substation using PC EMTP program. The effect of factors such as : tower footing resistance, tower surge impedance and wave velocity on tower and the number and location of surge arrestors have been investigated. The relationship of these factors have been discussed also. The final integrated suggestions have been recommended. The results could be taken as a reference for similar cases.

Introduction

In recent years, the GIS (Gas Insulated Switchgear) has been widely adopted in most EHV systems due to its excellent insulation performance, and its almost free of maintenance and environmentally friendly properties. Meanwhile, the insulation coordination of EHV substation, particularly the EHV GIS Substation also has been expansively considered using the very powerful program EMTP to improve the insulation level of substation and / or power transformer. Therefore, the significant technical advantages and the economical benefits have been achieved.

However, more investigations are still needed because preceding investigations related to the determination of insulation protection level from overvoltages were individually studied and each case normally has its own particular conditions.

A selected 500 kV GIS substation insulation level protected from lightning overvoltages using the EMTP program has been investigated. Meanwhile, the factors which affect the determination of the insulation level have also been studied. These factors are related to the particular case but could be considered in other cases as a reference while designing or analyzing the overvoltage protection of substations.

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In this paper, factors such as : tower footing resistance, tower surge impedance, velocity on tower etc. are studied. Investigation indicated that the footing resistance of a tower that is near the substation seriously affects the lightning overvoltage inside. The higher the tower footing resistance, the higher the lightning surge overvoltage generated by GISs and transformers. On the other hand, the reduction of the tower surge impedance also affects the reduction of the lightning overvoltage. The location and the number of surge arrestors are primarily discussed.

In this investigation, the influencing factors are individually considered to analyze the overvoltage in the GIS substation. Then they are integrated together in the analysis to find the best solution. An appropriate selection of the values of the key factors improved the lightning protection of the 500 kV GIS substation.

Models and Parameters

The study focuses on a model representing the 500 kV GIS substation and using the PC EMIP program. The substation with a loop bus arrangement connects to four power transformers and two transmission lines. A layout diagram of the substation model is shown in Fig. 1. Fig 2 is the diagram of two lines which indicate the towers near the substation. Table 1 intemizes the span distances of the transmission lines.

Results And Analysis

Discussion I : Lightning Overvoltage Value without any protection measure

An first, the basic paramenters are set into the EMTP program and the lightning strikes at the top of the individual tower of Line Y and Z are considered each time. BUS1, BUS2, BUS3 and BUS4 in the GIS; T1, T2, T3 and T4 for relevant transformers and F2 and F3 or Z2 and Z3 for Line Y or Z of the internal substation are the measuring points. The peak value of the

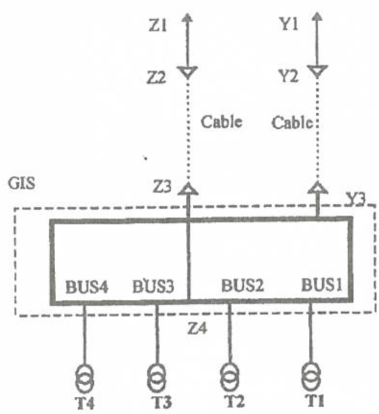

Fig. 1. A layout diagram of the model GIS substation

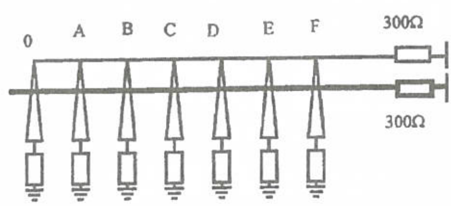

Fig.2. The diagram of transmission line(s)

Table 1. The span distance of transmission lines

The span distance	0A	AB	BC	CD	DE	EF
Line Y (m)	70	150	700	200	550	400
Line Z (m)	90	600	300	900		

surge current is 250 kA, 2/50S. The maximum values of the surge overvoltage entered inside the substation without any overvoltage protection method are shown in Figur 3 and Figure 4.

For Line Y, whichever tower the lightning strikes at , the overvoltage at all measuring points exceeds the 2000 kV. The most severe situation is that when the lightning strikes at the top of Tower B., the overvoltage at each measuring point is higher than that when lightning striked at any other towers and T4 is 3709.48 kV which is the maximum value.

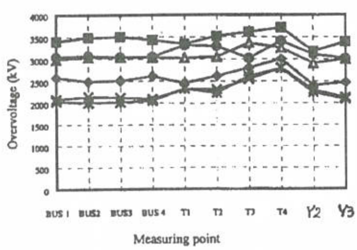

Figure 3: Maximum Overvoltage entered Inside the Substation from Line Y Without Protection

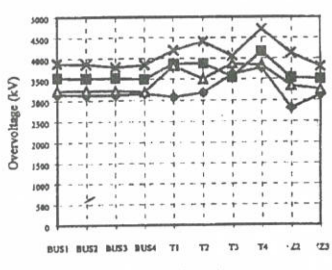

Figure 4. Maximum Overvoltage entered Inside the Substation from Line Z Without Protection

For Line Z, the overvoltage at most measuring points of the GIS and Transformers already exceeds 3000 kV. The most severe case is when lightning strikes at the top of Tower D and the Maximum value is 4702.89 kV at Transformer T4.

Discussion II: The Effect of Tower Footing Resistance on Overvoltages

The effects of the tower footing resistance, tower surge impedance and the surge velocity on tower are considered respectively. The tower footing resistance is changed from 30Ω to 15Ω, 10Ω and 5Ω. The result of the investigation shows that the less tower footing resistance, the better the protection from the surge overvoltage. However, too small tower footing resistance such as 5Ω is difficult to realize in practice. When the value 10Ω is taken to the maximum, overvoltage of every point can reach below 2500 kV without even any arrestors installation. The comparison of changing tower footing resistances at the most severe tower encountering lightning strikes in Line Y and Z are illustrated in Figure 5(a) and (b). From the practical tower structure point of view, the tower footing resistance 15-20Ω is recommended.

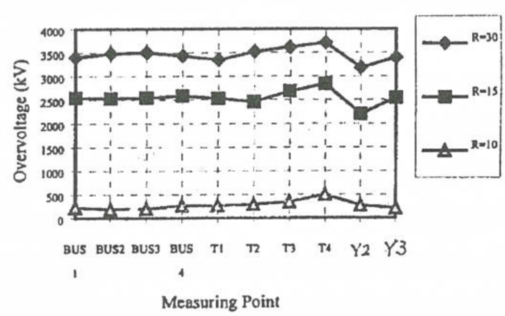

Fig. 5(a) The overvoltage of lightning stroke at tower B of Line Y under different tower footing resistant without protection

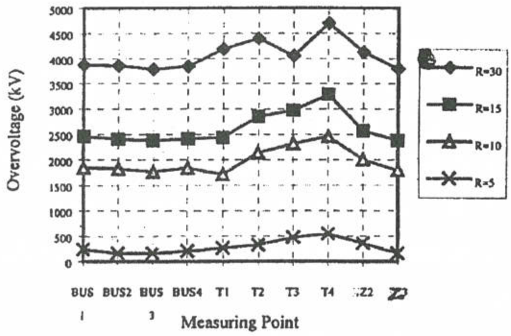

Fig. 5(b) The overvoltage of lightning stroke at tower D of Line Z under different tower footing resistant without protection

Results also show that less tower surge impedance and higher surge velocity on tower are better, however it does not affect the reduction of the overvoltage level much. Therefore, $Z_{tower} = 150\Omega$, $V_{tower} = 2.1\times10^{5}$ km/s are taken as the tower surge impedance and the surge velocity on tower. The maximum values of surge overvoltage entered into the substation are shown in Figure 6 for Line Y and Figure 7 for Line Z when the lightning strikes at the various tower top and all tower footing resistance are 10Ω.

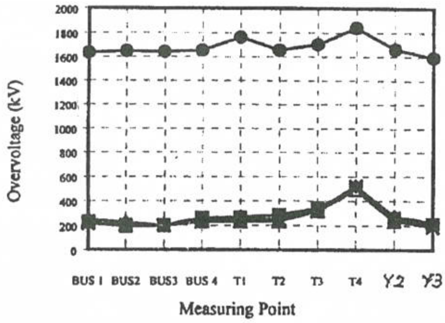

Fig. 6 Maximum overvoltage entered inside the substation from Line Y without protection when the tower footing resistance is 10 Ω

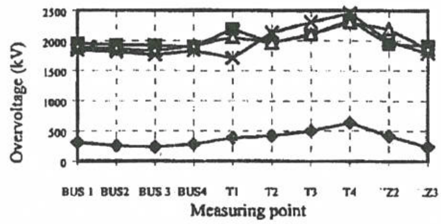

Fig. 7 Maximum overvoltage entered inside the substation from Line Z without protection when the tower footing resistance is 10 Ω

From analysing Figures 6 and 7, it can be observed that the effect of low tower footing resistance is also depended on the distance form the stroked tower to the substation. In Figure 6, the effects are considerable for all towers except tower F in Line Y. However, in Line Z (Figure 7) only reducing the resistance of tower A has a considerable effect, probably due to the fact that other towers are far from the substation.

Discussion III: The Effect of Location and Number of Arrestors in Protecting from Overvoltage

In the 500 kV GIS substation ,the sophisticated arrangement of surge arrestors is necessary due to the high cost of the GIS and the transformers. As well known, the arrestor location has a great significance to protection from overvoltages. Normally, arrestors are installed as close to the power transformer as possible. For the selected case which has two lined and four transformers, the investigation results show that when arrestors are installed at Y1, Y2, Z2, Z3 and T4, T3 (all tower footing resistances are at 10Ω), the values of the surge overvoltages in all measuring points are reduced to lower than 1290 kV, i.e. less than the BILW of equipment.

However, the lowest value could be reached when arrestors are located on T1, T2, T3, T4, and Y2, Z2. At this location the tower footing resistance could rise to 20 Ω, except on the tower A of Line Z. Its footing resistance still has to be reduced to 15Ω, then all points inside the substation will encounter overvoltage Value less than the BILW value. Fig. 8 shows the result.

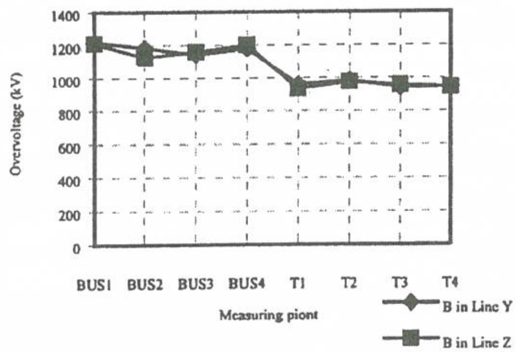

Fig. 8 Maximum Overvoltage inside the substation from lightning strike at Tower B of both Line Y & Z

Discussion IV: The Effect of Opening-Loop Operations in Protecting from Overvoltage

There are normally four operation measures in substation. Results show that when the tower footing resistance R = 20 (Tower A of Line Z is 15), and six arrestors are installed as mentioned above, all four operation schemes are satisfied for the protection from lightning surge overvoltage.

Conclusion

The selected 500 kV GIS substation has been studied using the EMTP PC program to analyse the insulation level when the lightning overvoltage enters the substation. The major investigation results as:

1. Theorectically the lower the resistance, the better insulation level is. But very low tower footing resistance is hard to acheive in practice. Therefore, a reasonable tower footing resistance of 15-20Ω is recommended.
2. The distance form stroked tower to substation plays a great role in reducing the overvoltage value due to decreasing the tower footing resistance. In longer distances, the effect is lowered.
3. Reducing surge impedance of tower and increasing the surge wave velocity have low impact on improving the overvoltage protection.
4. Location with the least number of arrestors in GIS structure and substation layout. Six arrestors is necessary for the selected type layout if the location is rational under any operation states. The scenario for four arrestors located close to the transformers and two located in the cable terminals with all tower footing resistance being at 20Ω, except the tower A of Line Z with 15 Ω, probably is the optimal one for the particular case.

The above conclusions may used as a reference in the GIS substation design.

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