O.F. Cable에 連結된 154kV GIS의 雷保護

論 文
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Lightning Protection in an 154kV GIS Connected by Oil-Filled Cables

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Abstract

It has been appeared and widely used today SF6 Gas Insulated Substation(Hereafter called GIS) for the power supply to the densely populated area due to the superior insulation withstand ability of SF6 Gas. And to maximize the compact effect of this substation, it is normal practice to connect underground cables.

If it is possible to eliminate the redundant lightning arresters using the physical characterestics of travelling waves in underground cables, economical advantages can be obtained together with easy maintenances.

It is presented in this paper the possiblity of eliminating the transformer protection lightning arresters under some conditions for the 154kV GIS's (BIL: 750kV) which Korea Electric Co. plans to construct using the general purpose digital computer program.

I. INTRODUCTION

Electric utilities supplying energy to densely populated areas are faced with the difficult problems such as;

1) land acquisition with a reasonable cost
2) reduction of noise level
3) requirements in the aesthetic point of view, etc.

SF6 substations with their reduced space requirements, comparative low noise levels and aesthetic qualities, are being employed more widely to solve these problems, together with HPOF (pipe-type) or O.F. cables.

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A number of papers have reported on transient overvaltage and insulation coordination studies of GIS supplied by overhead transmission lines,[2,3] however, little is available in the literature describing considerations for the insulation coordination of a GIS.[1]

It is the purpose of this paper to summarize the basic modelling theories and to present the results of simulations on an 154KV GIS which will be supplied electrically by an O.F. cable circuit. When the GIS is fed by the O.F. cables, the bus of GIS is normally connected directly with cable core through the SF6-gas/oil compartment. Thus the station entrance lightning arresters have to be gas enclosed. Since these will cost significantly more than conventional surge arresters, there is incentive to eliminate them. As the power transformers can be modelled as capacitances with a few thousand pF,[3] if the cables are long enough and the attenuation in the cables is significant, then the designer of GIS can eliminate surge arresters on the transf ormer sides and similar advantages of elimination can be taken place.

Field tests of surge propagation in pipe-type cables and other work on developing models to duplicate these tests[5,6] has demonstrated that pipe-type cables significantly attenuate and reduce the rate-of-rise of incoming surges with fast rise times, such as those resulting from lightning. From the calculation of cable constants, as shown in Fig. 1,2,3, O.F. cables have quite similar patterns with pipe-typt cables. Surge protection for the entire station is then provided by the lightning arresters located at

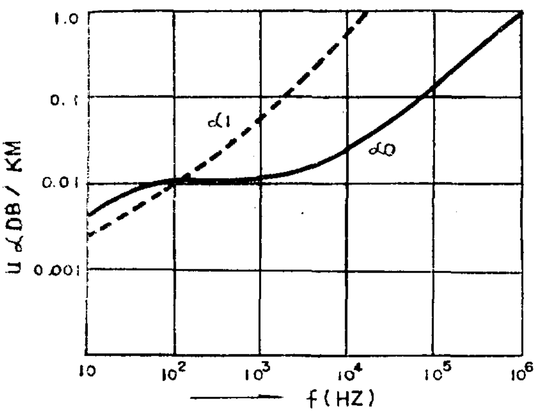

Fig. 1 Modal Attenuation of 154kV O.F. Cable

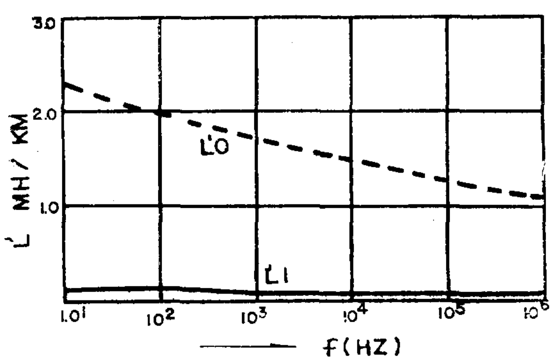

Fig. 2 Modal Inductance of 154kV O.F. Cable

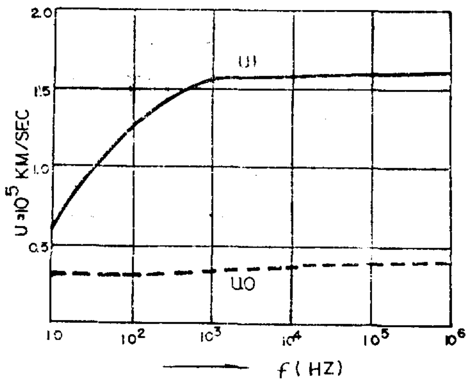

Fig. 3 Modal Propagation velocity of 154kV O.F. Cable

the line-cable potheads and by the cable itself.

A study was performed with the objective of determining the conditions for eliminating station entrance and transformer surge arresters, while maintaining an adequate protective margin for the SF6 bus insulated at 750KV BIL. (15—20 % margin[2]. Results of digital computer simulations of the substation lightning performance are presented.

II. THE SYSTEM

The Korea Electric Company is planning to construct GIS's at WOLKYE, BUKBU #1, BUKBU #2 substations shown in the single-line diagram of Figure 4. It will be energized at 154 KV nominal voltage. For the simplicity, it is assumed that BUKBU #1 and BUKBU #2 substations are supplied by a radial source from WOLKYE substation. Furthermore, all the power transformer banks in the same station is represented by a single resultant transformer bank.

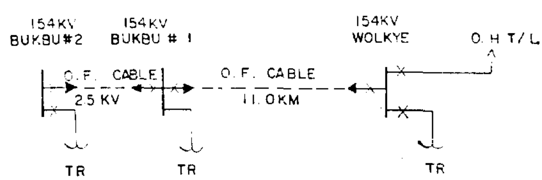

Fig. 4 A single-line diagram in the vicinity of BUKBU #2 substation

Forthe worst case study the effects of bus capacitive potential devices(C.P.D) are neglected.

III. SUMMARY OF MODELLING THEORY

A number of excellent papers(4,7,8,9,11,12) have presented theories on modelling of transmission line transients. From the known transmission line constants, we can derive the partial differential equations describing the behavior of the line as follows:

$$-\frac{\partial e}{\partial x}=[Z']i \text{ where } Z'ij=R'ij+L'ij\frac{\partial}{\partial t} \quad (1a)$$

$$-\frac{\partial i}{\partial x}=[Y']e \text{ where } Y'ij=G'ij+C'ij\frac{\partial}{\partial t} \quad (1b)$$

Where′ means the value per unit length.

If we transform these into frequency domain the above equations can be modified at a particular frequency ω:

$$-\frac{\partial E}{\partial x}=[Z']\ I \text{ where } Z'ij=R'ij+j\omega L'ij \quad (2a)$$

$$-\frac{\partial I}{\partial x}=[Y']E \text{ where } Y'ij=G'ij+j\omega C'ij \quad (2b)$$

The equations 2 can be re-written as follows:

$$\frac{\partial^2 E}{\partial x^2}=[Z']\cdot[Y']E \quad (3a)$$

$$\frac{\partial^2 I}{\partial x^2}=[Y']\cdot[Z']I \quad (3b)$$

The equations 3 will be decoupled through a modal transformation.

$$E=Te\ Em \quad (4a)$$

$$I=Ti\ Im \quad (4b)$$

where subscript m means a modal form and Te, Ti are matrices of eigenvectors for $[Z']\cdot[Y']$ and $[Y']\cdot[Z']$ respectively.

If we express equations 3 as modal forms:

$$\frac{\partial^2 Em}{\partial x^2}=Te^{-1}[Z']\cdot[Y']\ Te\ Em$$
$$=[Zm']\cdot[Ym']Em \quad (5a)$$

$$\frac{\partial^2 Im}{\partial x^2}=Ti^{-1}\ [Y']\cdot[Z']\ TiIm$$
$$=[Ym']\cdot[Zm']Im \quad (5b)$$

We should notice here that the eigenvalues of $[Z']\cdot[Y']$ are the same as those of $[Y']\cdot[Z']$. Equations 5 implies that the result is thus m uncoupled modal equations, and the propagation modes are the same for both voltages and currents. The transformation matrix Te is not unique, however Te and Ti should be always so related that:

$$Te\,Ti^t=D \quad (6)$$

where superscript t means the transpose of a matrix Ti and D is diagonal and may, in particular, be the identity matrix. It can be easily shown that for general untransposed or transposed lines, modal decomposition is always possible. Through the modal decomposition, we are reduced to the analysis of simple scalar differential equations.

The solution of equations 5 has the following general solution form:

$$E=Ae^{-\gamma x}+Be^{\gamma x}=E'+E'' \quad (7a)$$

$$I=\frac{1}{Zc}[Ae^{-\gamma x}-Be^{\gamma x}]=I'+I'' \quad (7b)$$

where E', I' are incident voltage and current waves respectively, E'', I'' are reflected voltage and current waves respectively

$$\gamma=\sqrt{(R+j\omega L)(G+j\omega C)}$$

$$Zc=\sqrt{\frac{R+j\omega L}{G+j\omega C}}$$

A,B can be determined from the initial and boundary conditions. R,L, G and C are frequency dependent thus γ and Zc are also functions of ω. Notice that all the subscripts and/or superscripts have been dropped for simplicity.

Eq. 7 can be modified as follows:

$$E+ZcI=2E' \quad (8a)$$

$$E-ZcI=2E'' \quad (8b)$$

Thus, known E' permits establishing a unique E VS I relationship, as indicated by (8a). This relationship can be used along with other equations from the shunting network for E and I to solve for both E and I. And from this solution we can calculate E'' from (8b). The value of E'' at point "m" in the line(say for $x=0$) will also permit the calculation of E' for point "k" (say for $x=d$):

$$Ek'=Em''e^{\gamma d} \quad (9a)$$

$$Em'=Ek''e^{\gamma d} \quad (9b)$$

As we previously noted γ and Zc are function of ω in general thus E' and E'' can be considered as frequency dependent. Equations (8) and (9) can be converted to the time domain as follows:

$$ek+zc*ik=2ek' \quad (10a)$$

$$em+zc*im=2em' \quad (10b)$$

$$ek' = em'' * s \quad (11a)$$

$$em' = ek'' * s \quad (11b)$$

$$ek'' = ek - ek' \quad (12a)$$

$$em'' = em - em' \quad (12b)$$

$$zc(t) = F^{-1}\{Zc(w)\} \quad (13a)$$

$$s(t) = F^{-1}\{e^{\gamma d}\} \quad (13b)$$

where x*y denotes convolution:

$$x*y = \int_{-\infty}^{\infty} x(\tau)y(t-\tau)d\tau = \int_{-\infty}^{\infty} y(\tau)x(t-\tau)d\tau$$

F^{-1} denotes inverse Fourier transformation.

From the above discussions we can summarize one of the possible simple solutlon algorithms as follows:

1) Determine e' from (11).

2) Convert modal equations (10) to phase equations. Convolution must use a numerical approximation where both present and prior values of ik and ek appear.

3) Solve these equations along with any other system equations for the present phase value of e and i.

4) Convert to modal values.

5) From (12) determine e''.

6) Increase time, go to step 1.

IV. SIMULATION

The system is simulated by Electromagnetic Transient Program (EMTP). 1.5/50μ sec., triangular lightning surge current source is applied at the entrance of GIS, WOLKYE substation for 100 micro seconds. The magnitude of lightning current is assumed 20kA since the nominaldischarge current of 10kA lightning arresters are being used for 154kV system protection in Korea Electric Co. Due to the past history limit of compter the cable length is adjusted to 5.5Km, however, it is not expected the big difference in voltage magnitude because the voltage wave is attenuated by 2.3% during travelling of 13.5Km at 1,000 Hz. On the other hand, it is attenuated by 1.0% for 5.5Km travelling at the same frequency.

The lightning arresters are installed near the overhead T/L cable junction at WOLKYE substation and the voltage-current characteristics of the lightning arresters are the same as shown in reference (10) and they are connected in tandem with linear resistance of 0.5 ohms to ground. Each power transformer is represented to be a pure capacitance of 1,600 PF[3]

Before deciding the possibility of eliminating the arresters for power transformer, one should consider the following aspects;

1) Breakdown possibility between GIS conductor and enclosure.

This can be checked easily with the voltage between GIS conductor and enclosure. If this voltage does not exced the BIL of GIS (considering safety margin), breakdown does not occur since the conductor is shielded by the metal enclosure. (GIS is single phase enclosure type.) Figure 5 shows the result of GIS conductor to ground voltages and Figure 6 shows the initial voltage build-up at the sending end for 20kA lightning current.

2) Line-to-Line voltage at transformer terminal

The power transformer terminals are not shielded by grounded metal, therefore, voltage between phases should be considered in case the lightning invades not all the phases at the same time. This voltage depends on the modal propagation volocity, the eigenvalues of the system and the length of T/L. However it may not exceed line to ground voltage by 1.3 times.

3) GIS enclosure voltage to ground

It is common practice to ground the various points of the enclosure through earth grids. However, it is almost impossible to eliminate the earth resista nce completely. Consequently a certain amount of voltage is induced between enclosure and earth. Figure 7 shows the induced voltage at GIS enclosure under the lightning current of 20kA. It is assumed that earth equivalent resistance is 0.1Ω.

When the lighning current is 20kA, the maximuminduced voltage is 1.3kV. Let's assume that resistance of human body is approximately 3,000 ohms then 43 mA can flow through human body, if an operator touches the enclosure at the time of lightning. This current may cause the operator to death therefore special cares should be taken to prevent this accident.

From the result of simulation it is known that the weakest part is transformer terminals in the view point of insulation under the lightning in GIS. The maximum line-to-line voltage is expected up to 688 kV(crest) at 20kA lightning. The actual voltage can be much lower than this value considering corona and branching effects, thus, we can eliminate lightning arresters at transformer terminal for the lightning current up to 20kA.

CONCLUSION

1) Nodal voltage magnitudes under lightning surges are determined by the current magnitude, termination conditions, attenuation coefficient, surge impedance of transmission lines, and R,L,C lumped elements, etc.

2) The cable attenuates the high frequency components of surge, thus, surges propagating into the substation have much lower rate-of-rise than those entering the cable.

3) Special cares should be taken to prevent accident due to the induced voltage between GIS enclosure and earth during lightning.

4) Transformer protecting lightning arresters can be eliminated together with substation entrance lightning arresters in an 154 kV GIS served by O.F. cables if the lightning surge current is 20kA or less.

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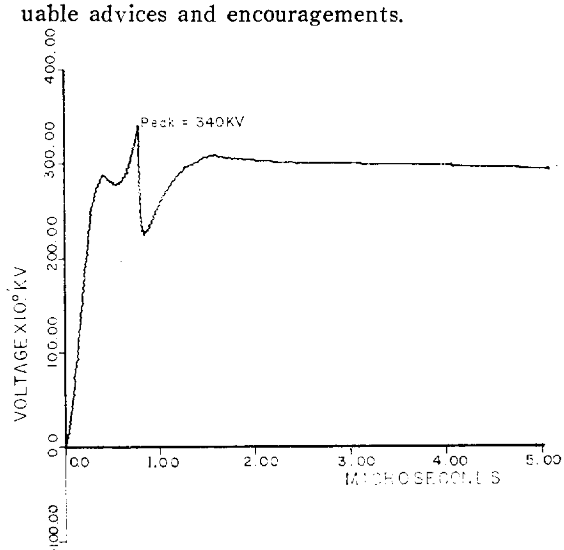

Fig. 6 Initial Conductor Voltage Build-up (at Sending End) under 20kA lightning current L.A. fired at 0.75μ sec.

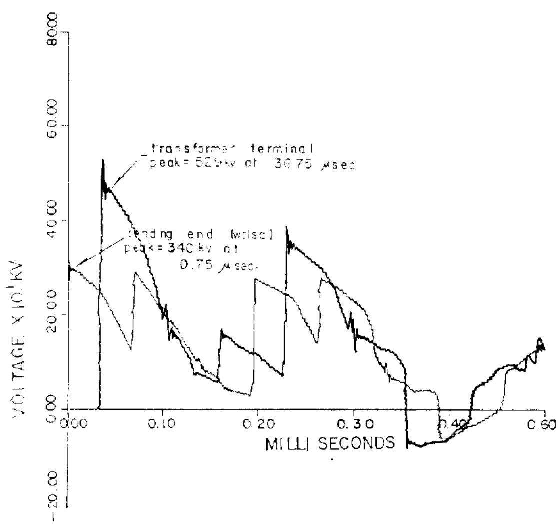

Fig. 5 Conductor Voltage Build-up under 20kA lightning current L.A. fired at 0.75μ sec.

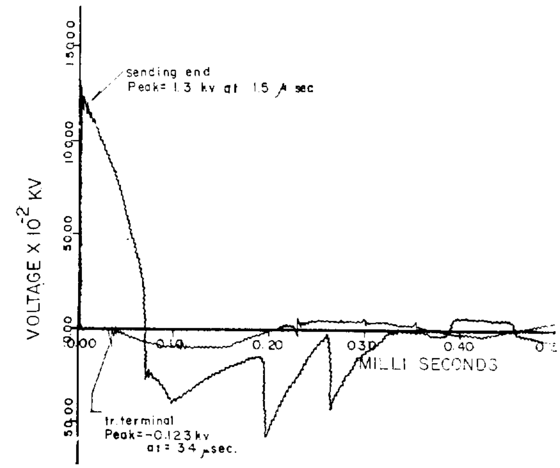

Fig. 7 GIS Enclosure to Ground Voltage under I=20kA

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