A Study on Arrangement of Arresters by a Multiple Flashover Analysis

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Abstract - **A number of transmission line arresters have been installed in Japan as a protection method against lightning, and a reliability for a lightning damage has been improved remarkably. For more economical protection against the lightning, it is necessary to study reliable and economical arrangement of the transmission line arresters. This paper carries out EMTP simulations of multiple flashovers for a tower top lightning against a 77kV vertical double-circuit transmission line. Simulations are carried out with various arrangement of the transmission line arresters and archorns to find a possibility of decreasing the number of the arresters. For each arrangement, the value of a lightning current is increased until the flashover occurs across the archorn, and the lightning current of the first flashover is calculated as a minimum flashover current. A minimum footing resistance causing a flashover is also investigated. Based on the simulation results, it is concluded that installation of the transmission line arresters in upper and middle phases of one circuit could be reliable and economical arrangement of the transmission line arresters.**

Keywords: Line arrester, Lightning surge, Multiple-flashover, EMTP

I. INTRODUCTION

More than half the electrical faults on a transmission line have been caused by lightning, especially on a 77kV line in Japan. In the case of a tower top lightning, an archorn voltage rises by a tower voltage rise, and a flashover occurs across the archorn when the archorn voltage exceeds its insulation strength. To decrease archorn flashovers, transmission line arresters are installed on transmission towers. As the archorn voltage rises by a lightning current, the transmission line arrester discharges before the archorn flashover, and thus, the flashover doesn't occur across the archorn. A follow current due to the lightning is switched off within one cycle to recover the insulation by a non-linearity of ZnO element and a series gap. Thus, a trip of a circuit breaker installed in a substation can be prevented.

From the above explained effect, a number of transmission line arresters have been installed on transmission towers and a reliability for a lightning damage has been improved remarkably. On the other hand, more economical protection against the lightning is required. Thus, it is necessary to study reliable and economical arrangement of the transmission line arresters.

The present paper carries out EMTP simulations of multiple flashovers for a tower top lightning against a 77kV vertical double-circuit transmission line, changing the arrangement of the transmission line arresters to find a possibility of decreasing the number of the transmission line arresters. For each arrangement, a value of a lightning current is increased until the flashover occurs across the archorn, and the lightning current at the first flashover is calculated as a minimum flashover current. Considering a tower footing resistance as a parameter, a minimum footing resistance to cause a flashover is evaluated by similar simulations. Based on the simulation results, the paper investigates the reliable and economical arrangement of the transmission line arresters.

II. SIMULATION CONDITIONS

A. Basic Conditions

EMTP simulations are carried out for a multiple back-flashover analysis by a tower top lightning against a 77kV vertical double-circuit transmission line, of which an equivalent circuit is illustrated in Fig.1. As the transmission line is terminated with a multiphase matching resistance, there is no reflected traveling wave from the far ends of the transmission line, and thus, the transmission line is regarded as an infinite line. The transmission line is represented by ATP-EMTP K.C.Lee model [1]. A lightning stroke hits the top of No.3 tower. Fig.2 shows the configuration of the 77kV transmission tower. Sophisticated flashover models of an archorn and a transmission line arrester with a series gap illustrated in Fig.3 are adopted to carry out multiple flashovers [2]. These flashover models can represent a wide-range V-t characteristic including a wave-tail flashover for sharing an archorn voltage with a nonlinear inductance and a nonlinear resistance. Table 1 shows simulation conditions.

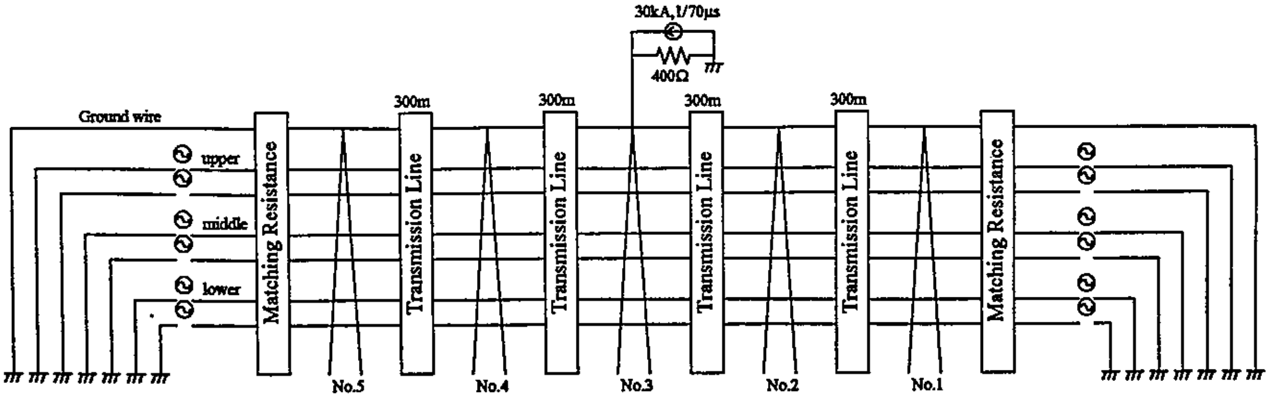


Fig.1 Equivalent circuit for 77kV transmission line

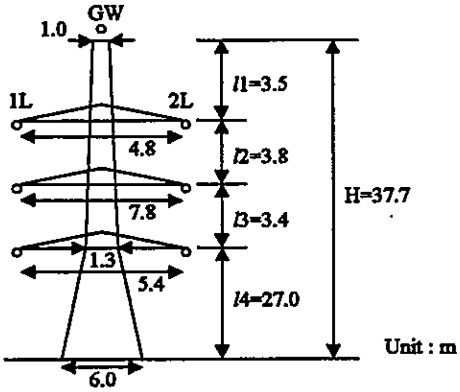
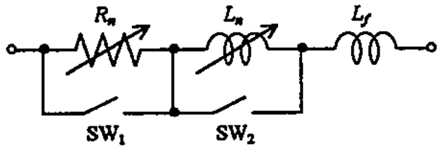
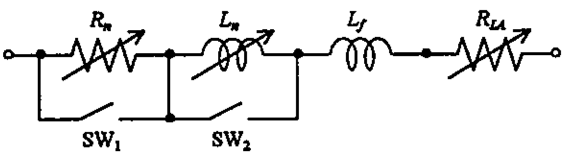


Fig.2 77kV transmission tower configuration



(a) Archorn model



(b) Transmission line arrester model

Fig.3 Flashover model combined with nonlinear elements

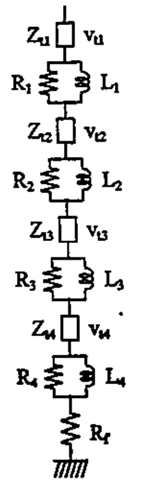
Table 1 Conditions for simulation

Item	Value
lightning current	30kA
tower footing resistance	10Ω
AC source voltage	62.9kVcrest
gap length of transmission line arrester	350mm
gap length of archorn	650mm

B. *Tower Models*

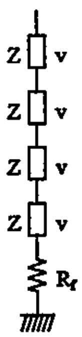
A tower model is a significant factor in a back-flashover analysis for the tower top lightning because the back-flashover occurs across the archorn by a tower voltage rise. In EMTP simulations, a multistory tower model and a distributed line model have been recommended by the Japanese Guideline of Insulation Design/Co-ordination against Lightning [3],[4]. The multistory tower model [3],[5] illustrated in Fig.4 consists of distributed parameter lines with parallel R//L circuits, and is used as a detailed tower model in Japan lately. This model was developed based on measured results of archorn voltages on a 500kV vertical twin-circuit line. Its accuracy, however, has not been sufficiently confirmed in comparison with measured results on a transmission line other than the 500kV line. The distributed line model [4] illustrated in Fig.5 consists only of distributed parameter lines with a loss, and has been widely used as a simple tower model. Since this model is simple, it is necessary to confirm its applicability against the back-flashover analysis. Thus, the simulation results by two tower models are compared with field test results to confirm the applicability to the 77kV transmission line.

Field tests were performed on the 77kV transmission line in an area of a high IKL for four months from June to September, summer in Japan [6]. When the lightning struck the tower top and a back-flashover occurred across the archorn, an instantaneous AC voltage just before the back-flashover was measured from sensors installed in a substation. EMTP simulations are carried out under the basic condition shown in Fig.1 and Table 1. A lightning current is taken to be –50kA since almost all the summer lightning currents have a negative polarity.



$Z_{t1} = Z_{t2} = Z_{t3} = 220$ [Ω]
$Z_{t4} = 150$ [Ω]
$v_{t1} = v_{t2} = v_{t3} = v_{t4} = v = 300$ [m/μs]
$\gamma = 0.8944$
$\tau = 2H / v$ [μs]
$r_1 = -2 \times Z_{t1} \times \ln\gamma / (l1+l2+l3)$ [Ω/m]
$r_2 = -2 \times Z_{t4} \times \ln\gamma / l4$ [Ω/m]
$R_1 = r_1 \times l1 = 16.058$ [Ω]
$R_2 = r_1 \times l2 = 17.434$ [Ω]
$R_3 = r_1 \times l3 = 15.599$ [Ω]
$R_4 = r_2 \times l4 = 33.472$ [Ω]
$L_1 = R_1 \times \tau = 4.036$ [μH]
$L_2 = R_2 \times \tau = 4.382$ [μH]
$L_3 = R_3 \times \tau = 3.921$ [μH]
$L_4 = R_4 \times \tau = 8.413$ [μH]
$Rf = 10$ [Ω]

Fig.4 Multistory tower model



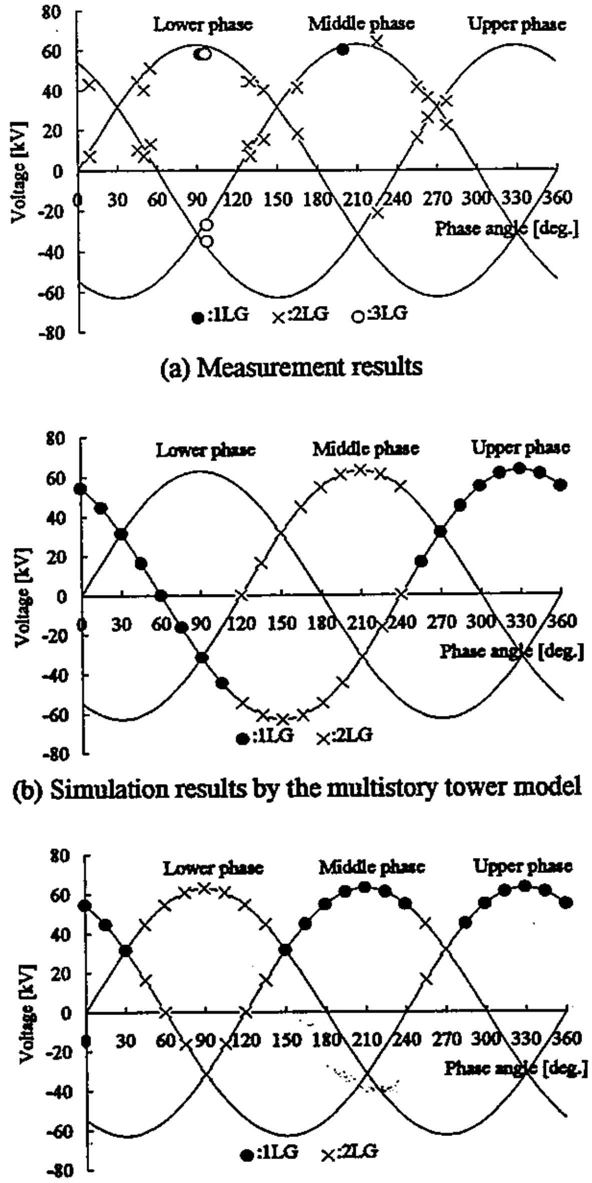
$Z = 100$ [Ω]
$v = 210$ [m/μs]
$\gamma = 0.9$ (at 50m)
$R_f = 10$ [Ω]

Fig.5 Distributed line model

Fig.6 shows measured and simulated results of instantaneous AC voltages and phase angles at the back-flashover. For the measured results illustrated in Fig.6(a), it is observed that most back-flashovers concentrate in the positive voltage region and the back-flashovers occur uniformly on each phase. Fig.6(b) by the multistory tower model shows that the back-flashovers occur on the upper phase in every phase angle and no flashover occurs on the lower phase at all. In fig.6(c) by the distributed line model, most back-flashovers concentrate in the positive voltage region and the back-flashovers occur uniformly on each phase. This tendency agrees well with the measured one.

The reason for the upper phase flashover by the multistory tower model is as follows. Since the multistory tower model was developed based on measured results of the 500kV transmission line of which the tower has about twice the height of the 77kV transmission tower, the tower voltage of the upper phase was higher according to the high geometrical position. Therefore the flashover on the upper phase occurs independently from the AC source voltage on each phase.

Because the distributed line model is suited for the multiple back-flashover analysis against the 77kV transmission line based on above observations, this model is adopted for following simulations.



(a) Measurement results

(b) Simulation results by the multistory tower model

(c) Simulation results by the distributed line model

Fig.6 Phase voltages and phase angles at back flashovers

III. SIMULATION RESULTS

A. Minimum Flashover Current

As a basic arrangement of transmission line arresters and archorns, the transmission line arresters are installed in every phase of #1 circuit, and the archorns are installed in every phase of #2 circuit as illustrated in Fig.7. Simulations are carried out with various arrangement of the arresters and the archorns to find a possibility of decreasing the number of the transmission line arresters of #1 circuit. Also, in the phase removed the transmission line arrester, the archorn is installed instead. For each arrangement, the value of the lightning current is increased until a flashover occurs across the archorn, and the lightning current of the first flashover is calculated as a minimum flashover current.

Table 2 and Fig.8 show minimum flashover currents at each arrangement. The results are summarised as follows.

(1) A comparison of the U-M-L case with the case of nothing shows that the single-circuit-trip current 44kA in the U-M-L case is greater by 8kA than the current 36kA in the case of nothing. It can be said that a flashover in #2 circuit installing only archorn becomes hard to occur by installing the transmission line arresters in #1 circuit.

(2) A comparison of three cases of two phase arrangement (i.e. U-M case, U-L case and M-L case) indicates that the current in the U-M case is the largest among three cases in single-circuit-trip, and the current is similar to that in the U-M-L case. In double-circuit-trip, the current in the U-M case is the highest among three cases too. Therefore, it can be said that the U-M case is the most reliable arrangement among the three cases.

(3) For one phase arrangement (i.e. U case, M case and L case), currents in single-circuit-trip and double-circuit-trip are nearly equal to the three cases. However those currents are smaller than that in the U-M case. Thus, the U-M case is more reliable than one phase arrangement.

B. Minimum Footing Resistance

A tower footing resistance is one of the most important factor for the occurrence of an archorn flashover. As the tower footing resistance increases, a negative reflected traveling wave from the tower footing becomes smaller and the tower voltage becomes higher. Therefore, if the value of the tower footing resistance is large, the archorn flashover easily occurs. Thus, the tower footing resistance should be as small as possible. However, from the viewpoint of more economical protection against the lightning, it is desirable that the tower footing resistance can be made greater. Because the archorn flashover is hard to occur when the transmission line arrester is installed, it is necessary to study the effect of the tower footing resistance on the first flashover for each arrangement.

The lightning current is taken to be 30kA. For each arrangement, the value of the tower footing resistance is increased until a flashover occurs across the archorn, and the tower footing resistance of the first flashover is calculated as a minimum footing resistance.

Table 3 and Fig.9 show the minimum footing resistance at each arrangement. The results are summarised as follows.

(1) Compared the U-M-L case with the case of nothing, the single-circuit-trip resistance 31Ω in the U-M-L case is greater by 13Ω than the resistance 18Ω in the case of nothing. It is said that the tower footing resistance can be made greater by installing the transmission line arresters on three phases of one circuit.

(2) A comparison of one phase and two phase arrangement cases shows that no suitable case is obtained. However the tower footing resistance can be made greater by installing the transmission line arresters only on one phase.

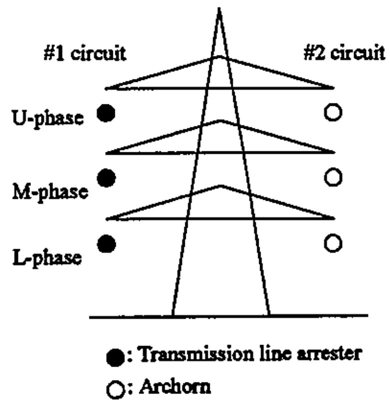


Fig.7 Basic arrangement of arresters and archorns

Table 2 Minimum flashover currents

Arrangement of arresters	Single circuit trip [kA]	Double circuit trip [kA]
U-M-L	44	-
Nothing	36	36
U-M	43	56
U-L	40	49
M-L	38	39
U	39	40
M	38	39
L	36	37

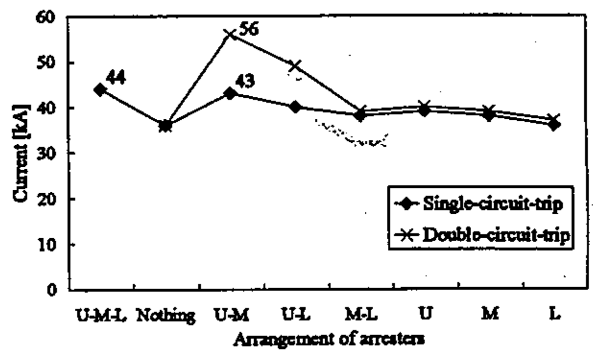


Fig.8 Minimum flashover currents at each arrangement

Table 3 Minimum footing resistance causing flashover

Arrangement of arresters	Single circuit trip [Ω]	Double circuit trip [Ω]
U-M-L	31	-
Nothing	18	18
U-M	25	37
U-L	26	36
M-L	28	39
U	21	24
M	23	30
L	22	24

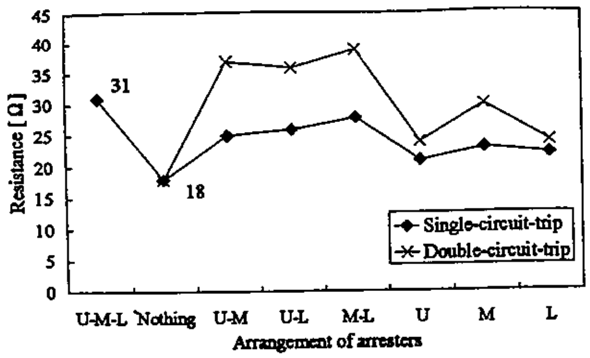


Fig.9 Minimum footing resistance causing flashover at each arrangement

IV. CONCLUSIONS

This paper investigates the reliable and economical arrangement of the transmission line arresters, based on the minimum flashover current and the minimum footing resistance evaluated by EMTP simulations of multiple flashovers on a 77kV vertical double-circuit transmission line. The reliability of upper and middle phase arrangement is nearly equal to three phase arrangement against single circuit trip, and upper and middle phase arrangement is more economical than three phase arrangement. Thus, upper and middle phase arrangement could be the most reliable and economical arrangement. Also, it can be said that the value of the tower footing resistance can be made greater by installing the transmission line arresters only on one phase.

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