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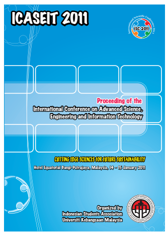

Cost and Benefit Analysis of Line Arresters for a 69kV Transmission System in Taiwan

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***Abstract*— This paper presents a systematical evaluation experience on the performance and economic studies of line arresters for a 69 kV transmission system in Taiwan. The transient over-voltage phenomenon in high voltage transmission lines under lightning by using the Electro-Magnetic Transients Program (EMTP) package is well modeled and analyzed. The modeling for the simulated system including lightning, transmission line, transmission tower and line arrester are all considered to have more practical results. The cost and benefit evaluation for line arresters installation is then conducted to provide a reasonable suggestion for lightning protection. The performance of line arresters is evaluated by considering different installation schemes and lightning currents. Finally, a Taiwan's experience is illustrated from both of the cost and benefit points of view.**

***Keywords*— Lightning, Line Arrester, Transmission Line, EMTP, 69kV Transmission Systems.**

I. Introduction

According to the yearly data measured by Lightning Location System (LLS) of Taiwan Power Company (TaiPower) [1], [2], there are over fifty thousand times of lightning in Taiwan every year. Most of lightning strokes during the seasons of summer and autumn. The areas of Nantou, Chiayi, Tainan, Kaohsiung, Pingtung and Taipei counties are the most prone to lightning. When the over-head ground wires or transmission lines of transmission towers are stricken by lightning, the lightning current will be directed to the ground system through the towers. Therefore, an extremely high transient voltage will exist between the insulators that equipped in the transmission tower for hanging the power lines. If the transient voltage is higher than the flashover voltage of insulators, arc will occur along the insulators that make the power lines directly ground electrically. Even though the lightning is over, the arcing from flashover still exists due to the low insulation ability of ionized air. The circuit breaks which connect with the transmission line will be tripped to extinguish the flashover. Then an instantaneous power failure will come up and may result inconvenience for Power Company.

Generally, there are three types of flashover according to their causes: tower back flashover, between-line back flashover and shield failure. No matter which type it is, power reliability will be influenced by either the damage of electric equipment or the operation of protection facilities. The most serious phenomenon is the so-called Back-Flashover that is caused by the penetration of insulators. As for extremely concentrated transmission grids, the possibility of breakdown of transmission system resulting from lightning is relatively high in these areas. Thus, in order to promote the reliability of power system for TaiPower, the constant strengthening on lightning protection methods is necessary. It is a very important topic to work out an effective method of measurement and against lightning.

How to prevent the affection of lightning flashover is always a major topic for power systems industry all over the world. Various types of methodologies or equipments [3] have being developed to improve the reliability of power system under lightning attack such as: smaller shielding angle, increasing over-head ground wires, reducing tower footing resistance, and taking unbalance insulation design for double circuits of transmission tower. Recently, line arresters are proved effective on the lightning protection of transmission lines. In [4], a type of line arrester with series air gap is developed which is directly connected with the insulators at both ends. It was first installed on a selected 77kV transmission line in an area of heavy lightning. It has produced great results as seen from long term observation. At present, Japan, China, Mexico, and Hong Kong have already provided a fairly adequate protection of important transmission lines with line arresters. However, totally equipped with line arresters for a long transmission line is very expensive. Also, the effectiveness cannot be correctly evaluated as they are just in operation for a relatively short period. Furthermore, working environment and power system structure of other countries and areas are different from TaiPower's. Thus, it is necessary to evaluate and study in detail the effectiveness and economy of this equipment. Therefore, this paper focus on the evaluation of how to effectively decrease the occurrence of lightning accidents by selected equipped of line arresters. The transmission line from Nantou to Ershui located in middle Taiwan is selected as the demonstration line in this paper due to the highest statistics of average in annual lightning density.

II. Models for Analysis

The EMTP package is the most widely used Electro-magnetic Transients Program and the accuracy had been verified for most researchers. Therefore, this paper uses the EMTP as the simulation tool to evaluate the performance and economy factors of line arresters. It is very important to model the transmission line system properly for an accuracy simulation results. Therefore, the components including lightning, transmission line, tower and line arrester are well modeled as below.

A. Lightning Model

As lightning in nature has great number of wave-changing patterns, some types of forms should be designed to apply to solve the power system problems. References [5]-[7] show lightning current waves are classified into two main types: double exponential model [5] and Heidler model [7]. The latter one is adopted by more researches, and this paper also uses this model as the lightning current source I_g, represented as below.

$$i(t) = I_0 \cdot \frac{(t/\tau_1)^n}{[(t/\tau_1)^n + 1]} \cdot e^{-t/\tau_2} \qquad (1)$$

where

I_0 : current peak value

τ_1 : current rise time

τ_2 : current fall time

Fig. 1 is the lightning model used in this paper. Fig. 1(a) represents the lightning model scheme. Mainly, the natural lightning is simulated by a current source in parallel connection with the 400Ω lightning path resistance. Fig. 1(b) represents the lightning model for EMTP simulation where R_t is the lightning path resistance.

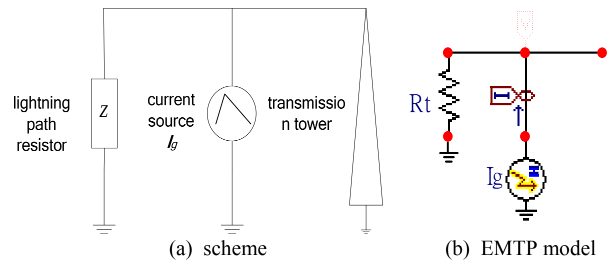


Fig. 1 Lightning model

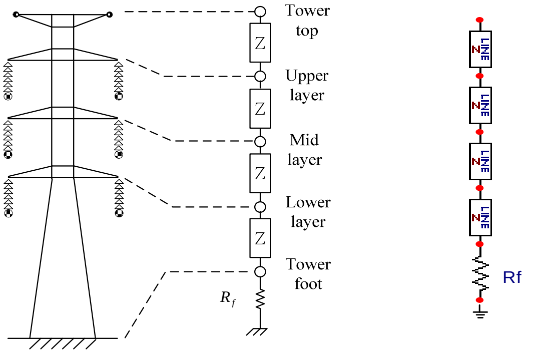
B. Transmission Line Model

The EMTP package provides two different transmission line models [8]: (1) Constant parameter model and (2) Frequency dependent model. The constant parameter model is suitable for the study of parameter, power frequency, low-frequency phenomenon or various exactly fixed parameters cases. The frequency dependent model is usually employed when the frequency dependability is taken into consideration such as switch surge study and other transient response over 1kHz system. It can be further categorized into (a) Mayer-Dommel structure and (b) J-Marti structure. The differences are clearly indentified through comparative studies between various models of transmission line provided in the EMTP Application Guide [8]. According to the suggestion from [8] and references [9], [10] that analysis and study on the lightning current surge, J-Marti model is the most recom-mended one. Therefore, this paper takes J-Marti model as the transmission line model.

According to the data provided by TaiPower, the radius of power line conductor (954MCM) for the selected trans-mission line is 1.48 cm and the direct current resistance is 0.0594 Ω/km. The radius of over-head ground wire is 0.5 cm and the direct current resistance is 0.54Ω/km.

C. Tower Model

Tower model is vital to the correctness of simulation of lightning current surge. According to the relevant references [11]-[14], mathematical models of tower can be classified into three types: (1) Multistory Tower Model, (2) Multistory Tower Model without parallel RL circuits, and (3) Simple Distributed Line Model. By using 69kV Nantou-Ershui transmission system and following the recommendation of [12]-[14], this paper takes Simple Distributed Line Model. Fig. 2 is the Simple Distributed Line Model used in this paper. Fig. 2(a) represents the tower model schematic. The components of an EMTP model in Fig. 2(b) shows that each layer of the tower is equivalent to a surge resistance Z, R_f is the footing resistance.



(a) scheme (b) EMTP model

Fig. 2 Tower model

D. Line Arrester Model

Line arresters are installed between transmission lines and the towers. In the normal operation, line arrester is at open and high resistance status. When the voltage of line arrester is over the flashover value, it will be quickly conducted and formed a short resistance path for the inrush current to prevent system failure. While the voltage is below certain limit, the line arrester will switch back to normal open status.

Line arresters can be divided into Gapless and Gapped Type according to different design. In TaiPower's policy, the gap type line arrester is often used for transmission line due to the "gap" which can prevent short circuit under the case of failure for arrester. Therefore, since there is an air gap in gapped type line arrester, the EMTP built-in arrester model can not be applied on this paper. The modified model for gapped type line arrester is shown in Fig. 3. A SWITCHVC.SUP sub-program must be added in programming to simulate instant arc at both ends when series-wound voltage surpasses flashover voltage or discharge current is lower than a certain value to switch back to normal. The voltage/current ratio of conducted line arrester is using the data taken from the standing transmission line arrester criterion. Thus, the V-I characteristic curve in Fig. 4 are inputted into the MOV.SUP sub-program. Finally, the equivalent model of line arrester is shown as Fig. 3 will be worked out by integrating SWITCHVC.SUP sub-program and MOV.SUP sub-program.

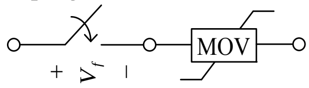


Fig. 3 Equivalent model of gapped type line arrester

Discharge current (kA)	5	10	20	40
Discharge voltage (kV)	165	175	190	215

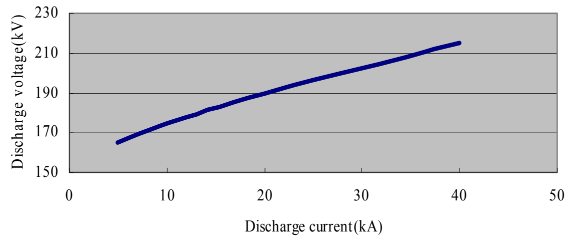


Fig. 4 V-I characteristic curve of line arrester

III. Transient Analysis

The Nantou to Ershui transmission line of TaiPower system is considered as the simulation example in this paper. This transmission line covers 2.738km with 46 towers from Nantou to Ershui in order from No.1 to No.46. The transmission conductor used for the system is 954MCM (45/7) aluminum cable with bronze wire. Two 3/8" G.S.W over-head ground wires are setup along with the third over-head ground wire that installed between the conductors in the lower layer to enhance the lightning protection capability. The three-phase short circuit capacities of the transformers in Nantou and Ershui are 30.947kA and 10.818kA respectively. Table I is the basic data of Nantou-Ershui transmission system including nominal voltage, tower numbers, and transmission line specifications. Fig. 5 demonstrates the entire equivalent circuit of the transmission line for EMTP simulation.

TABLE I
Basic Data of Nantou-Ershui Transmission System

Line name	Nantou-Ershui			Nominal voltage (kV)	69
Line distance (m)	2738	Tower number	#1 to #46 (46 in total)	Transmission conductor specifications.	954MCM (45/7) ACSR
Insulator flashover voltage (kV)	495	Beginning discharge voltage (kV)	320	Over-head ground wire specification	3/8" G.S.W.
Line arrester type	Gapped Type Line Arrester				

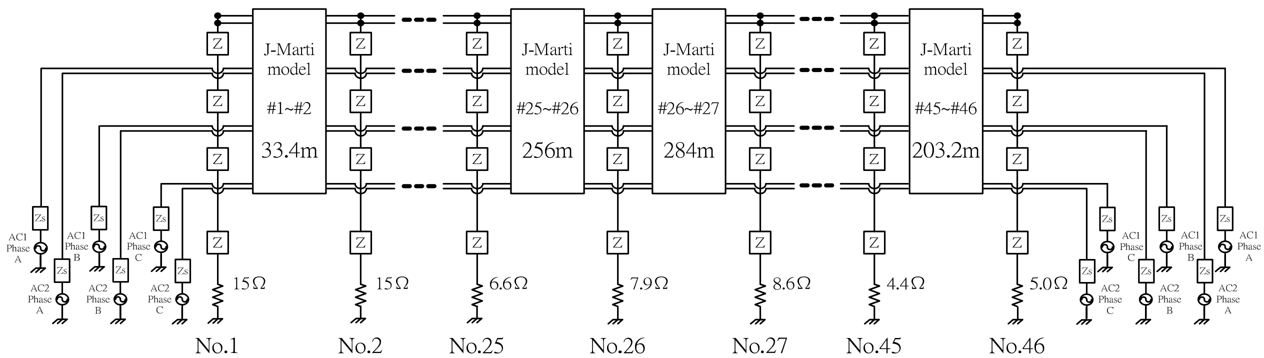


Fig. 5 Equivalent circuit for the selected transmission system

A. None Line Arrester Installed

In the following study, different lightning peak currents will be adopted to simulate the degrees of lightning affection and then to observe the change of voltages across the insulators in order to understand the impact of various lightning currents. The voltage across the insulators will reach flashover value when the peak of lightning current arrives at 33kA according to the simulation results. Therefore, situations of peak current below 33kA are not considered.

In table II, the lightning peak currents are taken as 33kA, 40kA, 50kA, 60kA and 100kA respectively. These currents are closed from LLC of TaiPower based on the accumulative lightning strikes percentages of 60%, 75%, 85%, 90% and 98% respectively. It is obvious from the simulation results that the voltage across insulators of the lowest layer is the highest and the voltages will increase in proportion to the lightning current peaks.

TABLE II
THE VOLTAGE ACROSS INSULATOR OF #26 TOWER IN EACH LAYER UNDER DIFFERENT LIGHTNING CURRENTS WITH NO LINE ARRESTER INSTALLED

Peak / Position	33kA		40kA		50kA		60kA		100kA	
	left	right	left	right	left	right	left	right	left	right
Upper layer	451.5	451.5	547.3	547.3	684.1	684.1	821	821	1368.3	1368.3
Mid layer	497.7	497.7	603.2	603.2	754.1	754.1	904.9	904.9	1508.1	1508.1
Lower layer	501.8	501.8	608.3	608.3	760.3	760.3	912.4	912.4	1520.6	1520.6

B. Cost/Benefit Evaluation for Different Installing of Line Arresters

The main purpose of this research is to choose the effective installed positions and also reduce the amount of line arresters as far as possible to diminish the capital cost under the safe conditions. Analysis on various feasible installation schemes of line arresters are conducted and shown in table III. To decide that the best installed numbers and positions, observing the change of voltages across the insulators and transient characteristics when lightning stroke on the over-head ground wires of No. 26 tower is performed and the results are shown in table III. The "Pass" in table III represents the insulator is not flashover and "Fail" means flashover happened.

According to the simulation results, several conclusions for line arrester installed suggestion can be made below:

(1) If the lighting peak currents exceed 100kA, the only way to reduce the transient over-voltage is to install line arresters in the whole system. However, the probability of 100kA lightning is very small so that it might not necessary to do so.

(2) If the lightening peak currents are below 60kA, we can suggest installing line arresters on upper and middle layer, upper and lower layer ,or middle and lower layer. They are all effective to protect lightening over-voltage accidents.

(3) If the lightening peak currents are below 50kA, we can suggest installing line arresters on middle layer, or lower layer and they are effective to protect lightening over-voltage accidents. However, only upper layer equipped with line arrester seems not to be a good suggestion.

(4) In the double circuit transmission line, only installed line arresters on one side is not economy compared with only middle layer, or lower layer cases. Since they have the same protection ability.

TABLE III
COMPARISON ON INSTALLATION SCHEME OF LINE ARRESTER

Line arrester installation scheme	The number of line arrester	Lightning current peaks (kA)				
		33	40	50	60	100
no installation	0	Fail	Fail	Fail	Fail	Fail
double circuit, each layer	276	Pass	Pass	Pass	Pass	Pass
double circuit, only upper and mid layer	184	Pass	Pass	Pass	Pass	Fail
double circuit, only upper and lower layer	184	Pass	Pass	Pass	Pass	Fail
double circuit, only mid and lower layer	184	Pass	Pass	Pass	Pass	Fail
double circuit, only upper layer	92	Pass	Pass	Fail	Fail	Fail
double circuit, only mid layer	92	Pass	Pass	Pass	Fail	Fail
double circuit, only lower layer	92	Pass	Pass	Pass	Fail	Fail
only single circuit, each layer	138	Pass	Pass	Pass	Fail	Fail

IV. CONCLUSION

An evaluation of the performance and economy for the installation of line arresters on transmission line system by using EMTP is proposed. The simulation is based on the well developed mathematically equivalent models that including lighting, tower, transmission line and arrester. According to the results of simulation:

(1) The voltage across insulators will reach flashover and cause breakdown and accidents from lightning when over 33kA lightning current strikes a tower in Nantou to Ershui transmission line of TaiPower.

(2) To avoid accidents and damage from lightning, this paper evaluates the amount and positions of line arresters for transmission towers. It provides valuable references for power companies on economic evaluation of line arresters installation under different lightning protection requests.

The lightning distribution, transmission line data, tower type and characteristics of line arrester will directly influence various transient statuses of a transmission tower. Therefore, it is very important to get a correct data of transmission line systems to proceed an effective and reliable analysis. The proposed evaluation procedure could be an important reference before installing line arresters of transmission line systems.

REFERENCES

[1] Du-ming Tsai, The Final Report on the Establishment of the Lightening Detection Statistics in Taiwan in 2003, The Comprehensive Research Institute of Taiwan Power Corp., 2003.

[2] The Comprehensive Research Institute of Taiwan Power Corp., "The Statistics of Lightning Frequency in the Entire Taiwan," 20 Nov. 2009. <http://www.taipower.com.tw/>

[3] IEEE Guide for Improving the Lightning Performance of Transmission Lines, IEEE Std 1243-1997, Jun. 1997.

[4] Shuji Furukawa, Osamu Usuda, Takashi Isozaki, and Takashi Irie, "Development and Application of Lightning Arresters for Transmission Lines," IEEE Transactions on Power Delivery, Vol.4, No.4, pp. 2121-2129, 1989.

[5] Chen Yazhou, Liu Shanghe, Wu Xiaorong and Zhang Feizhou, "A New Kind of Lightning Channel-Base Current Function," 3rd International Symposium on Electromagnetic Compatibility, pp. 304-307, May 2002.

[6] C E R Bruce and R H Golde, "The lightning discharge," IEE, London, pp. 487-520, 1941.

[7] F.Heidler, "Traveling Current Source Model for LEMP Calculation," Proc.6th Int. Zurich Symp. Tech. Exhib. Electromagn. Compat, Zurich, pp. 157-162, 1985.

[8] Electromagnetic Transients Program (EMTP) Application Guide, Electric Research Institute, 1986.

[9] J. R. Marti, L. Marti and H. W. Dommel, "Transmission Line Models for Steady State and Transients Analysis," Athens Power Tech, 1993. APT 93. Proceedings. Joint International Power Conference, Vol.2, pp. 744-750, Sep. 1993.

[10] J. R. Marti, "Accurate Modeling of Frequency Dependent Transmission Lines in Electromagnetic Transient Simulations," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No. 1, Jan. 1982.

[11] M. Ishii, T. Kawamura, T. Kouno, E. Ohsaki, K. Shiokawa, K. Murotani and T. Higuchi, "Multistory Transmission Tower Model for Lightning Surge Analysis," IEEE Transactions on Power Delivery, Vol.6, pp. 1327-1335, Jul. 1991.

[12] Takamitsu Ito, Toshiaki Ueda, Hideto Watanabe, Toshihisa Funabashi and Akihiro Ametani, "Lightning Flashovers on 77-kV Systems: Observed Voltage Bias Effects and Analysis," IEEE Transactions on Power Delivery, Vol.18, No.2, pp. 545-550, Apr. 2003.

[13] T. Hara and O. Yamamoto, "Modelling of A Transmission Tower for Lightning Surge Analysis," IEE Proc-Gener. Transmission Distribution, Vol.143, No.3, pp. 283-289, May 1996.

[14] Hideki Motoyama and Hiroji Matsubara, "Analytical and Experimental Study on Surge Response of Transmission Tower," IEEE Transactions on Power Delivery, Vol.15, No.2, pp. 812-819, Apr. 2000.