Evaluation of Lightning Risk for Transmission Lines Considering Both Lightning Current and Lightning Density

Background

Lightning frequency is an important factor in the lightning resistant design of transmission lines. The Lightning Database WG of the Committee of Lightning Protection Design set up at the CRIEPI has compiled the Nationwide Lightning Database (Version 1992 - 2001) based on data provided by the lightning location system of power companies. The resulting lightning frequency map *[1] is used for practical purposes. As this database contains information on the lightning current value, lightning location and frequency, a lightning hazard map using a mesh size of 25 km was prepared to indicate the lightning hazard at individual locations.*[2] However, a large mesh size means inability to properly consider the likely impacts of the local topography and there has been strong anticipation for the preparation of a highly accurate hazard map for its practical use for real power facilities.

Objective

The objective of this research work is the proposal of a practical lightning risk map for actual transmission lines based on the Nationwide Lightning Database (Version 1992 - 2001) while considering both the lightning current and lightning density on the ground.

Principal Results

1. Proposal of a Lightning Risk Evaluation Method

Noting the fact that the marginal transmission capacity decreases with the number of spark-over phases of transmission lines, the lightning risk (hereinafter indicated as "r") originating from a lightning incident involving a transmission line is evaluated by the following equation. Here, the probability of the occurrence of lightning current is the probability of such occurrence actually observed in each mesh.

$$r = k_0 \cdot P(\text{shielding failure}) + \sum_{n=1}^{6} k_n \cdot P(nLG)$$

In this equation, n of P(nLG) means the number of phases which cause an incident of an earth fault with a transmission line. P(1LG) means the probability of the occurrence of lightning current which causes a single phase earth fault incident but not a two phase earth fault. Similarly, P(2LG), P(3LG), P(4LG), P(5LG) and P(6LG) mean the probability of three, four, five and six phase earth fault incidents respectively. Meanwhile, P (shielding failure) means the probability of the occurrence of a shielding failure.

k_0 through k_6 are the coefficients indicating the level of the decrease of the marginal transmission capacity in correspondence with the number of spark-over phases. The larger the number of spark-over phases is, the nearer the value of the coefficient to 1 is. The value of the coefficient lowers with a lower number of spark-over phases. For example, with a 500 kV transmission line, k_0 and k_1 at the time of a single phase earth fault incident are 0.03. The value of k_2 at the time of a two phase earth fault is 0.58. Similarly, the value of k_3, k_4, k_5 and k_6 is 0.70, 0.801, 1 and 1, respectively.*[3]

2. Preparation of a Lightning Risk Map

(1) Assuming the construction of a new transmission line, the lightning situation along two feasible routes was examined. It was found that data which could be used as basic data for lightning protection design could be obtained with a mesh size of approximately 1 km. With a 500 kV transmission line, a single phase earth fault incident generates a high lightning current value of 150 kA. Because the probability of such occurrence is inferred to be around 1%, the current number of observation points can only offer less than 100 observed values per mesh, implying a low level of observation accuracy. The basic mesh size for the lightning risk map was decided to be 6.5 km because this size allows a sufficient number of observation points per mesh to produce reliable data.

(2) With the 500 kV transmission system, a nationwide distribution map of the lightning risk was prepared and each mesh was classified into one of five risk ranks ranging from strong lightning area (SS) to weak lightning area (C) as shown in Table 1. The proportions of strong and weak lightning areas in each region are shown in Table 2. An example of the geographical distribution of the ranked lightning risks is shown in Fig. 1 which indicates that the lightning risk is greater on the Sea of Japan side (Akita Prefecture) where lightning frequently occurs in winter compared to the Pacific Ocean side (Iwate Prefecture) where lightning frequently occurs in summer.

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*1 : Subcommittee for Transmission Lines, Lightning Protection Design Committee, "Guide to Lightning Protection Design for Transmission Lines", CRIEPI Report T72, February, 2003 (in Japanese).

*2 : Matsubara, Suda and Motoyama, "Development of Lightning Risk Map Considering Lightning Current and Lightning Density", CRIEPI Report H07009, July, 2008 (in Japanese)

*3 : Takahashi, Inoue and Tanaka, "An Evaluation Method for Power Carrying Capability Enhancement Using Lightning Measures", Journal B of the Institute of Electrical Engineers of Japan (IEEJ), Vol. 115, pp. 1,070 - 1,075, September, 1995 (in Japanese)

Table 1 Ranking of Lightning Risk (with a 500 kV System)

Lightning Risk Value		Rank	Area Ratio*
Strong	≧4.5	SS	≧3%
↑	3.3～4.4	S	3.1～10%
	2.1～3.2	A	10.1%～30%
↓	1～2.0	B	30.1%～60%
Weak	≦0.9	C	≧60.1%

* Area Ratio: ratio in the total number of meshes nationwide

Table 2 Ratio of Meshes Corresponding to Specific Lightning Risk Value (with a 500 kV System)

Region	Ratio of Meshes (%)					Total Number of Meshes
	SS	S	A	B	C	
	≧4.5	3.3～4.5	2.1～3.2	1～2.0	≦0.9	
Hokkaido	0.08	0.03	0.05	0.81	99.0	7995
Tohoku	4.2	5.3	10.6	20.3	59.7	6751
Kanto	1.4	3.6	7.9	22.2	64.9	3121
Chubu	9.3	8.8	15.3	26.3	40.2	1729
Hokuriku	2.7	4.7	15.4	33.0	44.1	657
Kansai	0.5	1.2	5.1	15.2	77.9	1791
Chugoku	0.1	0.5	2.7	11.1	85.7	2928
Shikoku	2.7	31.9	16.7	20.9	27.7	1553
Kyushu	0.00	0.09	0.5	6.5	92.9	1105
Total						27630

* These ratios include the number of meshes falling on the ocean area.

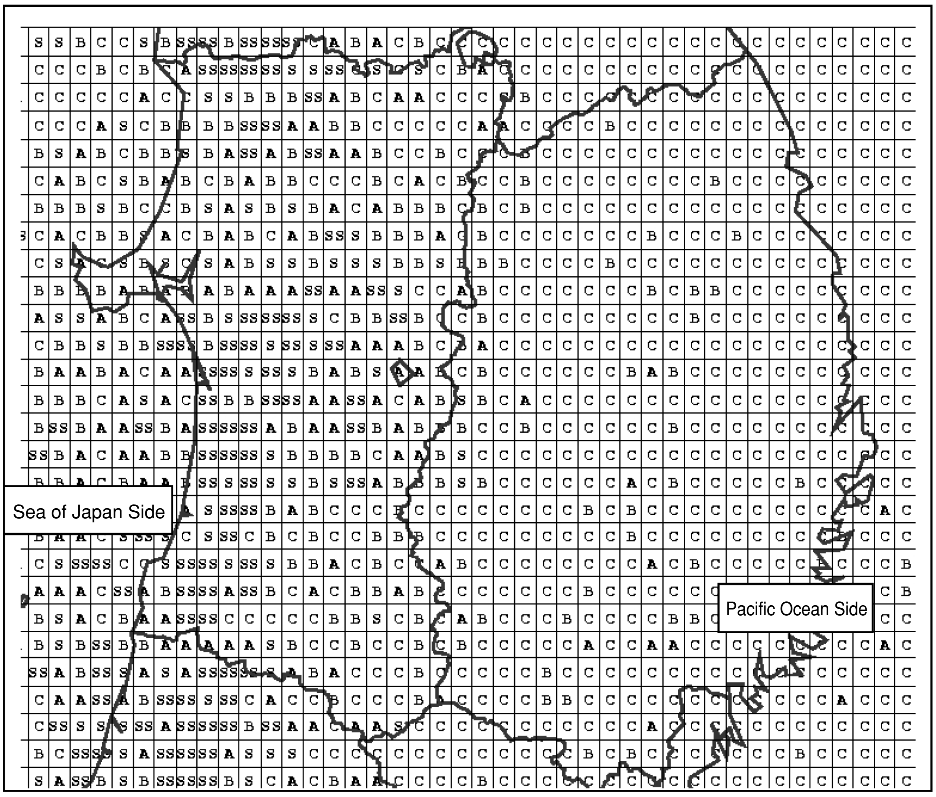

Fig.1 Example of Lightning Risk Map
(Example of the presentation of the lightning risk ranks using a 6.5 km mesh size)