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New Simulation Method of Flashover Rate by Connection of EMTP and MATLAB

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Abstract – Because of the random characteristics of lightning, the Monte Carlo method is applied to estimate the flashover rate due to lightning, however, the simulations using previous methods are difficult to both beginner and expert in power corporations. Therefore, this paper proposes the new and easy method to simulate the flashover rate by connection of electromagnetic transients program (EMTP) and MATLAB. The magnitude of a lightning strike is based on a curve measured in the field, while the classification of direct and indirect lightning depends on the striking distance. In a Korean distribution system, the flashover rate induced by lightning is simulated using proposed method. Simulations of the footing resistance according to the existence of an overhead ground wire (OHGW) are performed and the simulation results are discussed. The simulation results are compared with findings obtained with the IEEE Flash 2.0 program.

Keywords: Distribution system, EMTP, Flashover rate, Lightning, MATLAB

1. Introduction

Flashovers may occur on distribution lines due to both direct lightning strikes and the voltage induced from nearby strikes. Direct lightning strikes often cause insulation flashover in distribution lines. Lightning-induced voltages are currently a major concern in terms of electromagnetic compatibility and power quality due to the widespread use of sensitive devices connected to distribution lines [1-8]. Therefore, the calculation of flashover rate at specific distribution system configuration is very important for lightning protection. In [8], the indirect lightning performance in overhead lines was assessed using computer code called lightning-induced overvoltage code (LIOV). The assessment of flashover rate using this program is difficult to both beginner and expert in power corporations. The IEEE PES Lightning Performance of Overhead Lines Working Group developed the IEEE Flash 2.0 program to estimate the lightning flashover rates in overhead electric power transmission and distribution lines based on IEEE Stds. 1243 and 1410 [9-11]. This program can be applied to specific distribution system configuration.

Therefore, this paper proposes the new method to simulate the flashover rate by connection of electro-magnetic transients program (EMTP) and MATLAB. The main role of EMTP is the calculation of lightning overvoltage and the one of MATLAB is the calculation of flashover rate using results of EMTP. Two programs are carried out simultaneously. This method is applied to calculate the flashover rate according to the various configuration of lightning protection system in Korean distribution system

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2. New Simulation Method of Flashover Rate

Lightning has random characteristics, i.e., the magnitude and location of each lightning strike is different. Therefore, the Monte Carlo method is applied to calculate the flashover rate by lightning. To perform simulations based on the Monte Carlo method, this paper proposes the new simulation method using both EMTP and MATLAB. The concept for the interface between EMTP and MATLAB is shown in Fig. 1. The user must perform the modelling of EMTP and MATLAB, respectively. In EMTP, system configuration, the magnitude of a lightning strike, and the lightning location is modelled. In MATLAB, the m-file coding is required to calculate the flashover rate through the connection of EMTP and MATLAB. After modelling, the simulation is only performed by running in m-file of MATLAB.

2.1 Role of EMTP

EMTP first determines the magnitude of a lightning strike and the lightning location. It then calculates the induced voltage in the phase conductor by direct or indirect

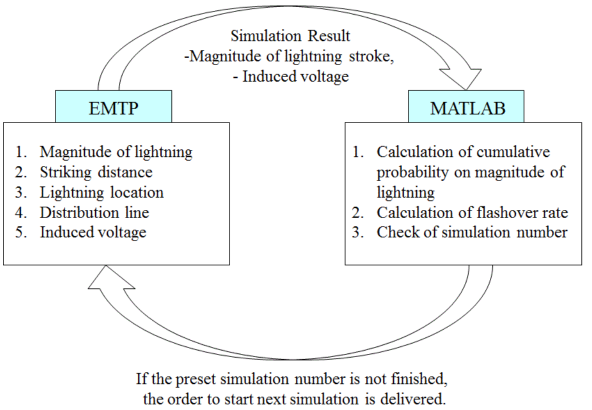

Fig. 1 Interface between the EMTP and MATLAB

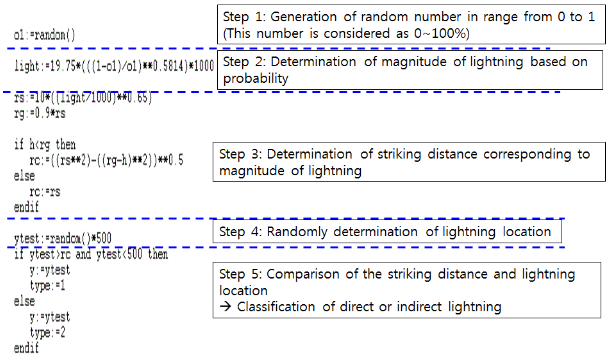

Fig. 2 EMTP/MODELS for determining the magnitude of lightning, lightning location, and striking distance

lightning based on the striking distance. The magnitude of a lightning strike, the lightning location, and the striking distance are evaluated with EMTP/MODELS. Some of the EMTP/MODELS for this procedure are presented in Fig. 2.

2.1.1 Magnitude of lightning strikes

In Fig. 2, step 1 and 2 is based on cumulative probability function for lightning strikes as measured by the KEPCO Lightning Detection & Information Network (KLDNet) of the Korea Electrical Power Research Institute from 2005 to 2010. The cumulative probability distribution versus the lightning strike magnitude is shown in Fig. 3 [12]. The cumulative probability from the KEPRI data is estimated between the Anderson-Erikson and Popolansky methods. The magnitude of a lightning strike in Fig. 3 can be written as

$$P = \frac{1}{1+\left(\dfrac{I_{light}}{19.75}\right)^{1.72}} \qquad (1)$$

where P is the cumulative probability function and I_{light} is the magnitude of a lightning strike [12].

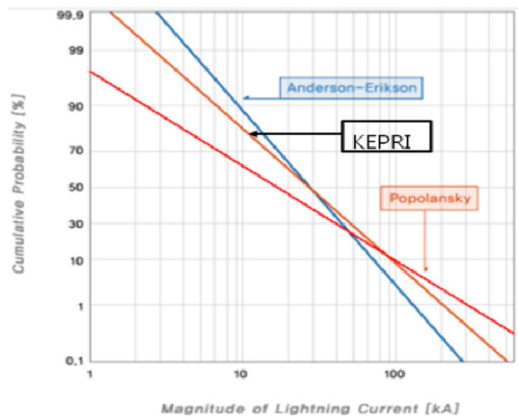

Fig. 3 Cumulative probability distribution versus the lightning strike magnitude

Table 1. Comparison between the simulation results and the field measurements

Magnitude of lightning (kA)	Field Measurements (%)	Simulation Results (%)
4.4	97.4	97.4
10	78.4	79.4
20	33.4	34.8
30	13.6	13.6
50	3.5	3.6
100	0.6	0.8

To validate the accuracy of the modeling, agreement between the simulation results and the field measurements of the cumulative probability of the magnitude of lightning is verified. A comparison of the results when the simulation number is 1000 is shown in Table 1; very good agreement is observed.

2.1.2 Classification of direct and indirect lightning

Step 3, 4, and 5 is based on IEEE std. 1410 [9]. The location of a lightning strike, i.e., the distance from the distribution line, is randomly determined in 1 km^2 of the distribution line for each lightning event. To distinguish between direct lightning and indirect lightning, the striking distance y_{min} is determined by IEEE std. 1410 [9]. If the lightning location is less than y_{min}, the direct lightning is considered. If the lightning location is larger than y_{min}, the indirect lightning is considered.

2.1.3 Modeling of Direct and Indirect Lightning

The waveform of direct lightning is modeled by EMTP/MODELS based on a Heidler-type analytical formulation [13]. The magnitude of a lightning strike is determined by (10). The modeled waveform is 2/70 μs and it is connected to an overhead ground wire or phase conductor by a type 60 TACS source in EMTP [14-16]. In the case of direct lightning, a pole surge impedance of 200 Ω is added [5].

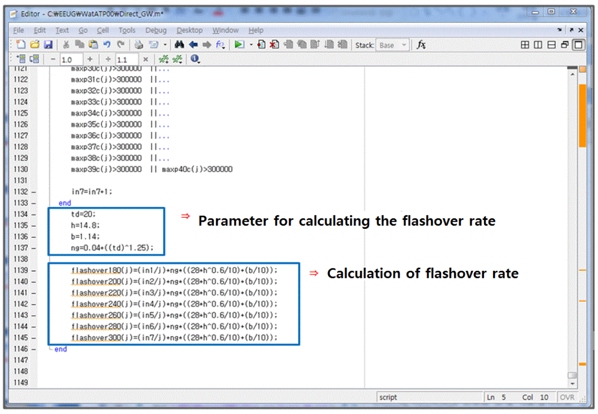

Fig. 4 Part of MATLAB m-file

Many researchers have studied the overvoltage due to indirect lightning [4-5, 17-20]. In this paper, the lightning-induced voltage on an overhead line is calculated via a method proposed by H. K. Hoidalen [17]. This method was implemented in EMTP/MODELS.

2.2 Role of MATLAB

After running one EMTP simulation, the magnitude and induced voltage are inputted into MATLAB. Pl42mat.exe file is necessary in this process. MATLAB calculates both the flashover rate and the cumulative probability of the magnitude of lightning. The flashover rate is calculated by equations in [9]. It then checks the simulation number. If the present simulation number is not the preset simulation number, the signal for the next simulation is delivered to the EMTP. The link between two programs is possible because the EMTP is performed in a disk operating system (DOS) environment using EMTP code written as text, while MATLAB provides the simulating function in the DOS environment. Fig. 4 is part of MATLAB m-fle. After finalizing the simulation, we can find the simulation result in workspace of MATLAB.

2.3 Comparison with previous methods

To highlight the proposed method, the advantages and disadvantages of previous and proposed methods are compared as shown in Table 2. The proposed simulation method can consider the various system configurations such as the existence, installation spacing, and grounding resistance of lightning arrester, however, IEEE Flash 2 method can't consider them. Also, the proposed simulation method can use arbitrary cumulative probability function for lightning strikes and randomly set the lightning strike location, however, IEEE Flash 2 method is impossible. IEEE Flash 2 can only use the cumulative probability of a lightning strike median value with 31kA. The proposed methods requires a lot of time to calculate the flashover rate. The time taken for calculation with 500 simulation numbers is about 3hour at specification of computer with Intel core i3-2100, CPU 3.10GHz, and 4GB RAM. It takes about 20sec at 1 simulation number.

Table 2. Comparison of the proposed and previous method

Item / Method	Advantages	Disadvantages
IEEE Flash 2.0 [7-9]	It has short calculation time.	1) It can't consider the existence of lightning arrester. 2) It can use only specified cumulative probability function for lightning strikes. 3) It can't change the configuration of system.
LIOV-EMTP [6]	It is latest skill to calculate the flashover rate.	It has a difficulty of use by closed source.
Proposed method	1) It can change the configuration of system. 2) It can use arbitrary cumulative probability function for lightning strikes. 3) It can randomly set the lightning strike location	It requires a lot of time to calculate the flashover rate.

3. Simulation in Korean Distribution System

3.1 System model and simulation conditions

The configuration of simulated Korean distribution system model is represented in Fig. 5. The total length is 2km. The type of distribution line is ASCR-OC 95mm^2.

The KEPCO distribution system is a multi-grounded neutral system [21]. The neutral wire is grounded at each pole and the grounding resistance is 300 Ω. In addition, the KEPCO distribution system has an OHGW. The spacing between two adjacent grounds of the OHGW is 200 m and the grounding resistance of the OHGW is 50 Ω. Lightning arresters are installed every 500 m and the grounding resistance of the lightning arresters is 25 Ω.

This paper simulates the flashover rate by the variation of footing resistance according to the existence of OHGW. The footing resistance considered is 10, 50, 100, and 300 Ω.

3.2 Simulation results in case of indirect lightning

The simulation of the flashover rate due to indirect lightning yields a value of 0. To find the reason for this result, we analyze the overvoltage due to indirect lightning. As shown in Fig. 6, when the OHGW exists, the cases which overvoltage above 180kV is not occurred.

When the OHGW does not exist, as shown in Fig. 7, the overvoltage above 180kV is occurred when the magnitude of lightning strike is 100kA and the distance between lightning location and line is 110m~160m .

Even though the magnitude of lightning is 100kA, the range of distance between lightning locations and line which overvoltage above 180kV is occurred is narrow. The probability of lightning with 100kA is just 0.6% as shown in Table 1 and hence the probability of lightning with 100kA in distance of above discussion is very rare. Therefore, the flashover does not occur in simulation number of 1000 and if the simulation number is increased, the possibility of flashover due to indirect lightning exists.

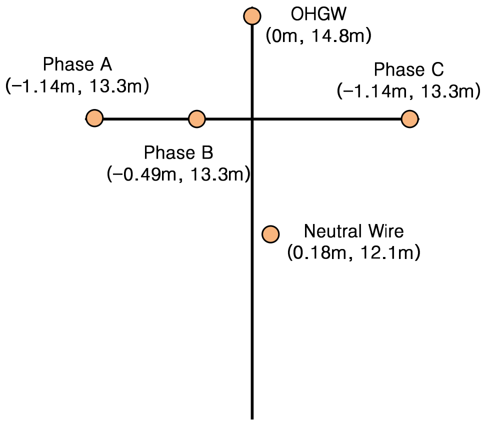

Fig. 5 Configuration of Korean distribution system

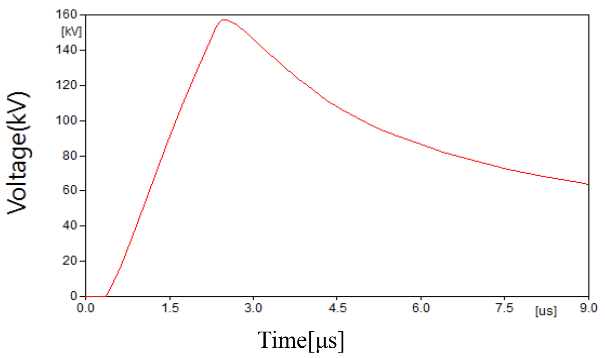

Fig. 6 Magnitude of overvoltage when the magnitude of indirect lightning is 100kA and GW exists

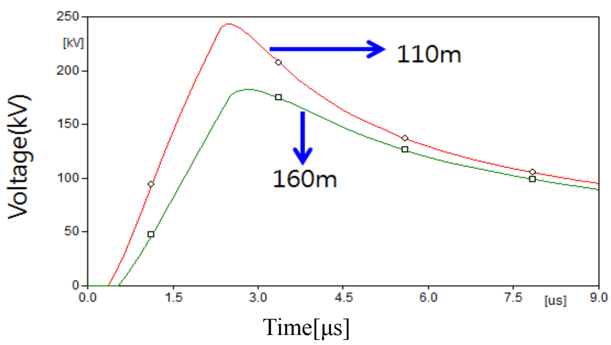

Fig. 7 Magnitude of overvoltage according to the distance between lightning location and distribution line when the magnitude of indirect lightning is 100kA and GW does not exist

3.3 Simulation results in case of direct lightning

The flashover rate due to direct lightning according to the footing resistance is shown in Table 3. When the footing resistance is 10 Ω, 50 Ω, and 100 Ω, the flashover rate with an OHGW is smaller than that without an OHGW. For the case where the footing resistance is 100 Ω and the critical flash overvoltage (CFO) is smaller than 200 kV, the flashover rate with an OHGW is larger than that without an OHGW. In addition, in the case where the footing resistance is 300 Ω, the flashover rate with an OHGW is larger than that without an OHGW.

The reason for the obtained results is the consideration of the height of the OHGW when the striking distance and flashover rate are calculated. In Table 4, the striking distance in the case with an OHGW is longer than that without an OHGW. Hence, the probability of direct lightning in case with an OHGW is increased. In addition, for the case with an OHGW, flashover rate by direct lightning, F_{direct}, becomes larger. Eqs. (2) and (3) show the calculation process for the flashover rate according to the existence of an OHGW. In (2) and (3), the second term for the case with an OHGW is 14.22, while the second term for the case without an OHGW is 13.34.

Table 3 Flashover rate according to the footing resistance

Footing resist. / CFO(kV)	10 Ω With GW	10 Ω Without GW	50 Ω With GW	50 Ω Without GW
180	1.9074	2.3463	2.2872	2.4946
200	1.7952	2.3058	2.1216	2.4115
220	1.5227	2.2484	1.6702	2.2927
240	1.3463	2.0948	1.4896	2.1264
260	1.1219	1.8612	1.3693	1.9007
280	0.8654	1.6587	1.2489	1.7937
300	0.7371	1.511	1.0232	1.6987
Footing resist. / CFO(kV)	**100 Ω With GW**	**100 Ω Without GW**	**300 Ω With GW**	**300 Ω Without GW**
180	2.6458	2.558	2.7179	2.7131
200	2.5496	2.543	2.6939	2.7131
220	2.4533	2.4903	2.5977	2.5044
240	2.3571	2.3849	2.5496	2.5044
260	2.2128	2.2345	2.5015	2.5044
280	1.9723	2.0614	2.3812	2.3479
300	1.8207	2.0539	2.309	2.2435

Table 4 Striking distance according to the existence of an OHGW

Lightning Current (kA)	Striking distance With OHGW (m)	Striking distance Without OHGW (m)
4.4	24.68	24.09
10	36.74	35.66
20	50.81	49.34
30	61.58	59.90
40	70.77	68.95
50	78.99	77.06
100	112.52	110.29

- With GW:

$$F_{direct} = \frac{n_{direct}}{n_{tot}} \times N_g \left(\frac{28h^{0.6} + b}{10} \right) = \frac{n_{direct}}{n_{tot}} \times N_g \left(\frac{28(14.8)^{0.6} + 1.14}{10} \right) = \frac{n_{direct}}{n_{tot}} \times 14.22 N_g \quad (2)$$

- Without GW:

$$F_{direct} = \frac{n_{direct}}{n_{tot}} \times N_g \left(\frac{28h^{0.6} + b}{10} \right) = \frac{n_{direct}}{n_{tot}} \times N_g \left(\frac{28(13.3)^{0.6} + 1.14}{10} \right) = \frac{n_{direct}}{n_{tot}} \times 13.34 N_g \quad (3)$$

where

F_{direct}: flashover rate by direct lightning (flashovers / 100km/yr)
n_{direct} : number of flashover by direct lightning
n_{tot} : total simulation number
N_g : ground flash density (flashes/km^2/yr)
B : structure width(m)

To verify these results, the obtained findings were compared with the results attained with the IEEE Flash 2.0 program. IEEE Flash 2.0 estimates the lightning flashover rates of overhead electric power transmission and distribution lines according to IEEE Standards 1243 and 1410 [7-9]. The results obtained using IEEE Flash 2.0 according to the footing resistance are shown in Table 5. The inputted parameters such as the overhead distribution line, the shield wire, span, and etc. in IEEE Flash 2.0 are equal to the parameters used in the simulations. The ground flash density (GFD) is also based on the value measured by KLDNet.

The immediate comparison of values between the results of Table 5 and Table 3 is impossible because the system configuration, especially existence of lightning arrester and the cumulative probability of lightning strike considered are different. The comparison of trends is only possible between two results. When the footing resistance is larger than 100 Ω, the flashover rate with an OHGW is larger than that without an OHGW. Very good agreement is observed between our simulation findings and the results obtained with IEEE Flash 2.0. For reference, the value in Table 5 is larger than that in our simulation results because IEEE Flash 2.0 does not consider the existence of a lightning arrester, and the median value with 31kA on the cumulative probability of a lightning strike considered by IEEE Flash 2 is larger than the value with 19.75kA in (1) for our simulations.

Table 5. Results using IEEE Flash 2.0 according to the footing resistance

Footing resistance	With GW [flashovers/100km/yr]	Without GW [flashovers/100km/yr]
10 Ω	1.97	2.64
50 Ω	10.48	10.88
100 Ω	12.08	11.9
300 Ω	13.14	12.49

4. Conclusions

The previous study of flashover rate calculation is very difficult to both beginner and expert in power corporations. Therefore, this paper proposes the new and easy simulation method to calculate the flashover rate using connection of EMTP and MATLAB. The roles of EMTP and MATLAB are discussed. The proposed method is applied to the Korean distribution system. The flashover rate by direct and indirect lightning is simulated and the simulation results are discussed to verify the accurateness of proposed method. It will be possible to simulate the flashover rate at any configuration of lightning protection system using proposed method.

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