การประเมินสมรรถนะระบบป้องกันฟ้าผ่าเพื่อปรับปรุงระบบป้องกันฟ้าผ่าสายเหนือดิน 115 กิโลโวลท์

Lightning Performance Assessment to Improve Lightning Protection System of 115 kV Overhead Lines

นาตยา คล้ายเรือง[1], สุดารัตน์ สมคะเน[1] และอรรถพงศ์ เสาะสุวรรณ[1]

Nattaya Klairuang[1], Sudarat Somkane[1], and Arthapong Sokesuwan[1]

บทคัดย่อ

บทความนี้เป็นการประเมินหาดัชนีแสดงสมรรถนะระบบป้องกันฟ้าผ่า ทั้งก่อนและหลังการปรับปรุงสำหรับระบบป้องกันฟ้าผ่าของสายจำหน่ายเหนือดินระบบ 115 กิโลโวลท์ กับสาย 7 รูปแบบ ตามมาตรฐานการจัดวางสายของการไฟฟ้าส่วนภูมิภาค(กฟภ.) ค่าดัชนีแสดงด้วยอัตราการเกิดวาบไฟที่ผิวฉนวนเมื่อมุมป้องกันล้มเหลวทำให้ฟ้าผ่าลงสายเฟสตัวนำ และอัตราการเกิดวาบไฟตามผิวย้อนกลับกรณีฟ้าผ่าลงสายดินป้องกัน แล้วนำมาหาอัตราการเกิดวาบไฟรวม เราสามารถลดอัตราการเกิดไฟดับเนื่องจากฟ้าผ่าลงได้โดยการเพิ่มระดับการฉนวนหรือการปรับปรุงระบบป้องกันฟ้าผ่าให้มีประสิทธิภาพดีขึ้น ซึ่งในบทความนี้ได้นำเสนอวิธีการปรับปรุงไว้ 5 วิธีด้วยกัน คือ การลดค่าความต้านทานการต่อลงดินที่ฐานเสา เพิ่มจำนวนลูกถ้วยแขวน เพิ่มขนาดสายตัวนำลงดินข้างเสา ลดมุมป้องกันโดยการเพิ่มสายดินเป็น 2 เส้น และการติดตั้งกับดักฟ้าผ่าที่เฟสล่างสุด จากผลการวิเคราะห์พบว่า ก่อนการปรับปรุงระบบป้องกันฟ้าผ่า อัตราการเกิดวาบไฟที่ผิวฉนวนของการจัดวางสายทุกรูปแบบมีค่าอยู่ในช่วง 13-15 ครั้ง/100 กิโลเมตร/ปี และอัตราการเกิดวาบไฟลดลงเหลือ 4-13 ครั้ง/100 กิโลเมตร/ปี หลังจากปรับปรุงระบบป้องกันฟ้าผ่า

ABSTRACT

This paper determines proper a lightning performance index for lightning protection system of 115 kV overhead distribution lines before/after improving with 7 types of line configurations, following construction standard of Provincial Electricity Authority (PEA). Shielding failure flashover rate(SFFR) calculate from the case of lightning strike to the line phase due to shielding failure, Back flashover rate(BFR) due to direct strike on overhead ground wire, and Total flashover rate(TFR) were indicated as lightning performance index. Outage rate caused by lightning could reduce by lightning performance improvement or increase insulation level. This paper was introduced improvement and flashover rate analysis from lightning with 5 methods include with reduce footing resistance, increase number of suspension insulators, increase diameter of down conductor, reduce shielding angle and Install surge arrester on the lowest phase conductor. The results showed that before improving the total flashover rate of several overhead distribution line arrangement schemes is very closely that to be 13-15 flashes/100 km/year and after improving to be 4-13 flashes/100 km/year.

Key words: Lightning performance, Shielding failure flashover rate, Back flashover rate

N. Klairuang : esrcnyk@ku.ac.th

[1] สาขาวิชาวิศวกรรมไฟฟ้า คณะวิศวกรรมศาสตร์ศรีราชา มหาวิทยาลัยเกษตรศาสตร์ วิทยาเขตศรีราชา

Department of Electrical Engineering, Faculty of Engineering at Sriracha, Kasetsart University Sriracha Campus

INTRODUCTION

Safe, reliable, and minimal investments of distribution system were the major purpose of Electricity Distribution Utility. One important reason to obstruct service was outage from lightning. Lightning could occur on overhead ground wire, on phase, and strike on object or directly to nearby ground. It could create in-line overvoltage and flashover could occur by exceeding withstand voltage of insulator. Design on lightning protection system was purpose on lightning strike on ground wire, insulators could withstand if lightning current was in standard range. Second, lightning strike on phase could happen on shielding failure situation, when low lightning peak current occurred. Third, lightning strike on object or directly to nearby ground would appear regularly and generate in-line induce voltage. Induce overvoltage would rise in high lightning peak current or lightning strike near phase wire situations. The voltage on suspension insulator was greater than insulator withstanding, flashover on insulator surface would become visible and outage would be the result. However, overvoltage in the last case had a very low comparing with lightning on first two cases. (Klairuang, N., 2003) The reason was right of way setting on standard of distribution system, there were no chance of tree or object to be close to lines, which create overvoltage that insulator could not withstand.

Thailand was in tropical zone, thunderstorm would frequently and more severe than European country. European standard, which used for designing lightning protection system in Thailand, could not be applied effectively. Lightning was the major cause of outage in distribution system, lightning protection system improvement should vitally consider for reducing outage rate. This paper introduces procedure and generates proper solution to improve lightning protection system on 115 kV distribution systems

MATERIALS AND METHODS

This paper contains analysis on lightning performance index with various types of overhead distribution system, following construction standard of Provincial Electricity Authority (PEA), before and after lightning protection system improvement. Following line configuration standard of PEA, 115 kV structures as in figure 1 include

- Single Circuit Double Conductor Tangent Structure TYPE SD-TG-3
- Single Circuit Double Conductor Tangent Structure TYPE SD-TG-5
- Single Circuit Double Conductor Tangent Structure TYPE SD-TG-8
- Single Circuit Single Conductor Tangent Structure TYPE SS-TG-3
- Single Circuit Single Conductor Tangent Structure TYPE SS-TG-8
- Double Circuit Double Conductor Tangent Structure TYPE DD-TG-1
- Double Circuit Single Conductor Tangent Structure TYPE DS-TG-1

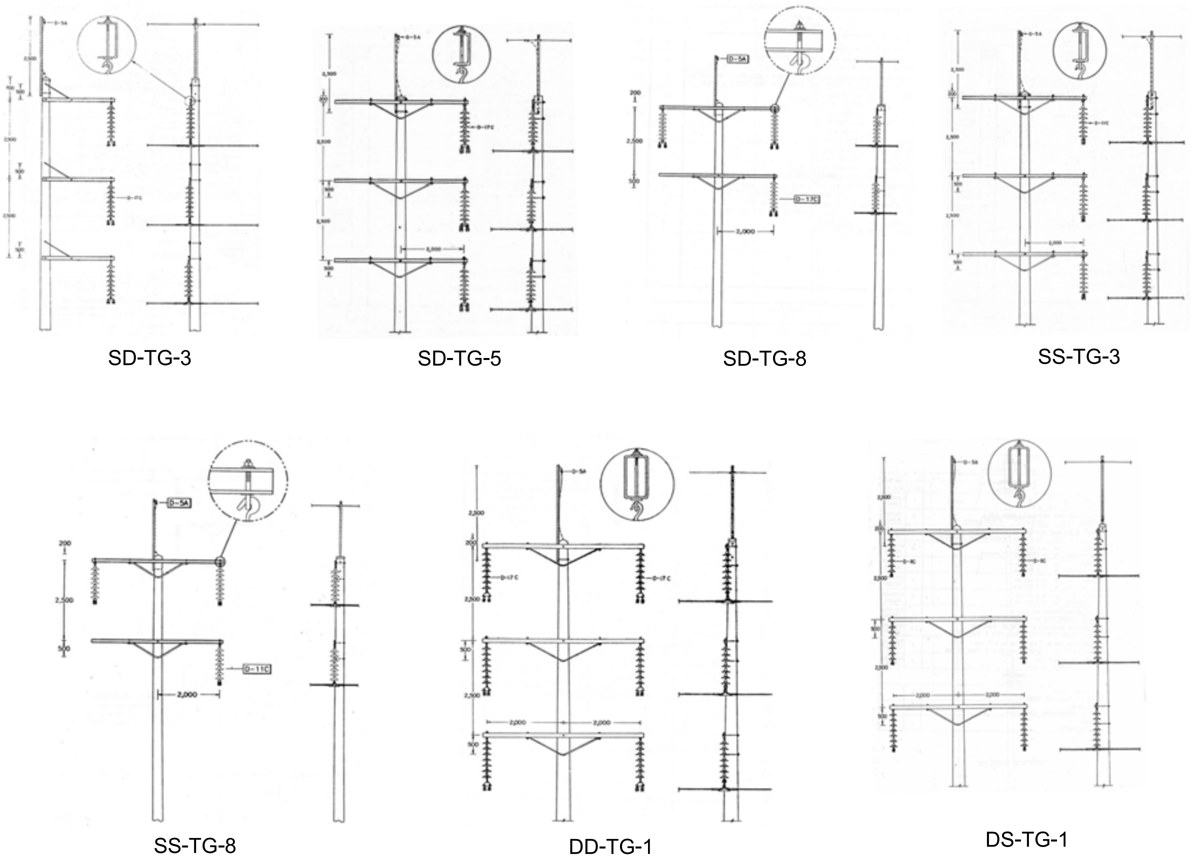

Figure 1: Overhead line configuration standard in 115 kV PEA distribution system.

1. Lightning Performance Indices

Overvoltage could occur when lightning strike on overhead distribution line. When voltage on insulator overreached withstands voltage on suspension insulator, outage would present. Analysis of overvoltage in term of lightning performance index was developed based on striking position, which was the main factor to examine outage rate. Outage from lightning could divide in many situations as follow

1.1 Lightning strike on ground wires

Insulator on overhead distribution system was designed to sustain overvoltage on insulator created by lightning strike on ground wire. In this case, voltage on insulator was exceeding limitation effected by very high lightning current. Flashover on insulator surface would appear on ground wire back to phase wire. Analysis could be done by finding maximum lightning current that suspension insulator could bear or adjusting overvoltage on insulator to become critical flashover voltage. Critical flashover voltage could be evaluated by using ATPDraw program.

Critical lightning peak current from analysis would apply with lightning statistic data in Thailand. From Thai Meteorological Department (TMD) data, thunderstorm in Thailand was 60 day annually. Probability of lightning on different lightning current was expressed as function on (1) (IEEE Standard

1410, 2004) based on lightning location system (LLS) from Electricity Generating Authority of Thailand (EGAT). Average lightning peak current (I_{50}) would be 20 kA. Number of lightning strike directly to ground and on overhead wire could determine by (2) and (3) respectively.

$$P(I \geq i_0) = \frac{1}{1 + \left(\frac{i_0}{I_{50}}\right)^{2.68}} \qquad (1)$$

$$N_g = 6.5 \times 10^{-5} T_d^{2.277} \qquad (2)$$

$$N_L = N_g \left(\frac{28h^{0.6} + b}{10}\right) \qquad (3)$$

$$BFR = N_L P(I \geq I_c) \qquad (4)$$

Where

$P(I \geq i_0)$: Probability of lightning peak current over i_0

I_{50} : Average lightning peak current (kA)

N_g : Number of lightning strike directly to ground (flash/km^2/year) (B. Samitthileela, 1999)

T_d : Number of thunderstorm day per year

N_L : Number of lightning strike on wire (flash/100 km/year) (IEEE Standard 1243, 1997)

h : Height of Pole (meter)

b : Structure width (meter)

BFR : Back flashover rate (flash/100 km/year)

$P(I \geq I_c)$: Probability of lightning peak current over critical peak current I_c

1.2 Lightning strike on phase wires

Ground wire protection system was installed in distribution system for preventing lightning directly on phase wires. Lightning protection performance would depend on line arrangement or protection angle. Shielding angle failure could happen on low lightning peak current , the lowest striking distance(S) or radius of rolling sphere which protected by ground wire would be determined from line configuration on figure 1 with equation (5) and (6).

$$S = \frac{1}{2}\left[H_G + H_P + \frac{A(2W - A)}{H_G - H_P}\right] \qquad (5)$$

$$W = \frac{H_G A + \sqrt{H_G H_P\left(A^2 + \left(H_G - H_P\right)^2\right)}}{H_G - H_P} \qquad (6)$$

Where

S : Critical striking distance for effective ground wire (meter)

H_G : Height of ground wire (meter)

H_P : Height of phase wire (meter)

A : Horizontal distance between ground wire and phase wire (meter)

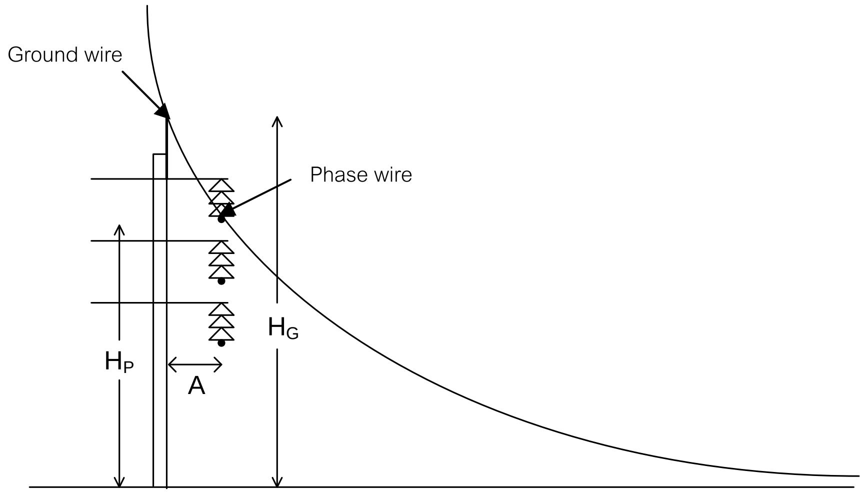

Figure 2: Critical striking distance, which ground wire could prevent from lightning directly on phase wire.

Table 1: Relationship between striking distance and lightning peak current (R.Hileman, 1999)

Source	Parameters ($S = KI^B$)	
	K	B
Armstrong and Whitehead	6.7	0.8
Brown and Whitehead	7.1	0.75
Wagner	14.2	0.42
IEEE-1992	10.0	0.65
Love	10.0	0.65
Berger (ฟ้าผ่าลบ)	$S^- = I + 15\left(1 - e^{-0.15I}\right)$	
(ฟ้าผ่าบวก)	$S^+ = 1.5I + 20\left(1 - e^{-0.15I}\right)$	

Lightning distance relationships with lightning peak current value with formula $S = KI^B$ when S is lightning distance (meters), I is the lightning peak current (kA), where K and B are constant values and that those who do research related to the equation on the relationship follow to table 1. The lightning distance can lead to a critical lightning peak current that ground wire can protect phase wire from a selection formula for the maximum value because it is likely that the ground wire will have the minimum performance to calculated shielding failure flashover rate.

$$SFFR = N_L(P(I < I_P))(P(I > I_C)) \quad (7)$$

Where S : Striking distance (meter)

I_P : Critical lightning peak current that protection with ground wire (kA)

I_C : Critical lightning peak current from lightning directly to phase wire (kA)

SFFR : Shielding Failure Flashover Rate (flashes/100 km/Year)

2. Lightning Performance improvement

Outage rate caused by lightning could be reduced by lightning performance improvement or increase insulation level. This paper proposed improvement lightning performance and flashover rate analysis from lightning with several methods.

i) Reduce grounding resistance of footing pole from 5 ohms to 2 ohms
ii) Increase number of suspension insulators from 7 to 8 insulators
iii) Increase diameter size of down conductor from 50 mm^2 to 95 mm^2
iv) Reduce shielding angle by adding number of ground wire from 1 to 2
v) Install surge arrester on the lowest phase on 200 m interval

RESULTS AND DISCUSSION

Maximum lightning current in case of lightning strike on ground wire was shown on table 2. Results from table show that lightning on top of the pole, which happens frequently on higher ground, could produce lower critical current than lightning over phase wire. So, we can consider only lightning strike on top of pole when find back flashover rate.

Table 2: Critical lightning current in case of lightning strike on ground wire

Line configuration	Critical lightning peak current, I_C [kA]	
	Strike to top pole	Strike to middle span
SD-TG-3	80.10	90.42
SD-TG-5	80.10	90.42
SD-TG-8	81.53	88.09
SS-TG-3	80.34	91.20
SS-TG-8	81.53	88.09
DD-TG-1	78.07	83.79
DS-TG-1	78.17	83.63

Critical lightning peak current with ground wire protection was calculated from equation on table 1. Critical lightning peak current in case of striking on phase conductor and then flashover on insulator surface, we can analyze with ATPDraw. Result from analysis and shielding failure flashover rate (SFFR) were determined from (7), result was shown on table 3

Backflashover and shielding failure flashover rate with different structures were almost identical, around 13 flashes/100 km/year and 1.5 flashes/100 km/year respectively. Double circuit double conductor structure would have greater flashover rate than others configuration.

Table 3: Lightning performance index before improving. [Flashes/100 km/year]

Line configuration	SFFR	BFR	TFR
SD-TG-3	1.01	12.72	13.73
SD-TG-5	1.80	12.41	14.21
SD-TG-8	1.56	12.11	13.67
SS-TG-3	1.48	12.32	13.80
SS-TG-8	1.30	12.02	13.32
DD-TG-1	1.80	13.61	15.41
DS-TG-1	1.48	13.56	15.04

Table 4: Lightning performance index before and after improving. [Flashes/100km/year]

Line	TFR					
Configuration	Before	Method 1	Method 2	Method 3	Method 4	Method 5
SD-TG-3	13.73	9.73	10.20	13.57	-	5.28
SD-TG-5	14.21	10.27	10.76	14.05	-	5.83
SD-TG-8	13.67	11.59	10.30	13.50	11.84	6.18
SS-TG-3	13.80	9.43	10.40	13.67	-	6.25
SS-TG-8	13.32	11.25	9.97	13.14	11.49	6.95
DD-TG-1	15.41	13.10	11.68	15.24	13.92	3.99
DS-TG-1	15.04	12.79	11.32	14.86	13.49	4.19

Note: Additional ground wire installation (Method 4) was not necessary for one-sided conductor system

When flashover rate was considered without investing concern, different structures were required different techniques to improve. According to Table 4, neglecting surge arrester installation methods, SD-TG-3, SD-TG-5 and SS-TG-3 structures were appropriated with grounding resistance reduction method. Increasing insulation level methods was better alternative for SD-TG-8, SS-TG-8, DD-TG-1, and DS-TG-1 structures. However, both changing size of down conductor and adding number of ground wire methods would not decrease flashover rate as good as two previous methods. Surge arrester installation was the best selection for reducing on flashover rate but it costs high investment.

CONCLUSION

Result from analysis of lightning performance index on 115 kV overhead distribution system on all 7 line configuration and 5 improvement methods could lead to conclusion that

1. Back flashover rate on surface would occur on lightning on ground wire. Double circuit structure was the worst structure to produce more back flashover rate.
2. Flashover rate caused by shielding angle failure on each structure was almost identical to 2 flashes/100 km/year due to symmetry alignment between ground wire and top-phase wire.
3. Overall lightning performance index was flashover rate causing by lightning before improving. This index was almost indistinguishable for each structure, which was 13 – 15 flashes/100 km/year.
4. Increasing diameter size of down conductor was minimum performance improvement method.
5. There were several methods to improve lightning performance. The best option from analysis was installing surge arrester on bottom phase with 200-m interval.

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