MATEC Web of Conferences 55, 05004 (2016) DOI: 10.1051/matecconf/20165505004
ACPEE 2016

Research on Line Patrol Strategy of 110kV Transmission Line after Lightning Strike

LI Mingjun[1], SONG Kunyu[2,a], OU Yuqiang[1], GAN Tuanjie[1], FAN Yazhou[1] and CHEN Jianping[1]

[1]Guangdong Power Grid Limited Liability Company, Jiangmen Power Supply Bureau, Jiangmen, 529000, China
[2]Wuhan Sunshine Power Science & Technology co., LTD, Wuhan, 430074, China

Abstract. Lightning faults occupy in the majority of instantaneous fault and reclosing can usually be successful, so power supply can be restored without immediate patrol in many cases. Firstly, this paper introduces the lightning fault positioning and identifying method. Then test electrical performance of insulators after lightning strike from 110kV lines. Data shows that lightning strike has little effect on the electric performance of insulator. Finally, illustrating disposal process of the 110 kV transmission line after lightning fault, certifying that the power supply reliability be ensured without line patrol.

1 Introduction

Statistics show that lightning faults occupy more than 50% of the power system faults in general[1]-[4]. Frequent lightning outages bring operation and maintenance personnel heavy task of inspection[5]-[7]. According to operating experience, lightning failure is usually instantaneous fault and reclosing can generally be successful, so patrol is not required when some lightning fault occurs and power supply can be restored[8]-[9]. Therefore, precise positioning and identifying of lightning failure as well as assessing the electrical performance of insulators after strike by lightning can help to make more efficient transmission line strategy, which is important for the safe operation of transmission lines.

Paper[10]-[12] describes principle of fault positioning method basing on travelling wave. However, research on identification of fault is seldom reported.

In terms of insulators' electrical performance evaluation, paper[13] describes electrical performance of composite insulators in operation after several years. While research which focuses on performance of insulators after lightning is not very usual.

This paper firstly introduces basic principles of positioning and identification, analyzing the performance of insulator after lightning fault. Secondly, assesses the performance of insulators froma110kV transmission line after lightning strike, at last develop guideline patrol strategy for the operation and maintenance personnel.

2 Principle of Fault Positioning

[a]Corresponding author : 418668255@qq.com

When fault occurs, travelling wave will spread from lightning point to both ends of transmission, and the position of fault can be obtained through double terminal method which is as shown in Figure.1.

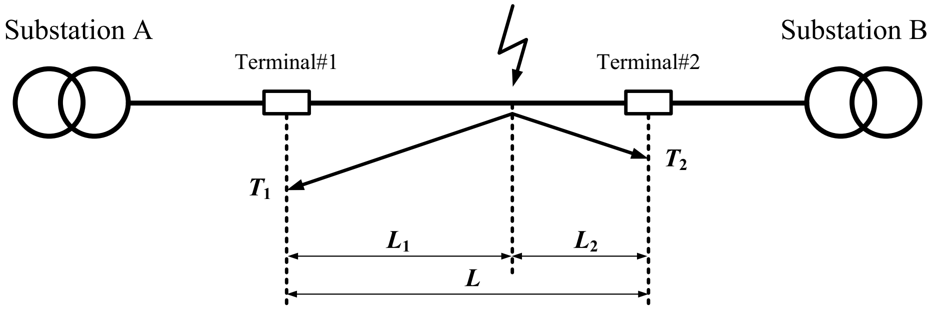


Figure 1. Double Terminal Method Schematic

In Figure.1, #1 and #2 are monitoring terminal devices, which are used to record travelling waveforms[14]. $T_1$and T_2refer to time that travelling wave arrives in #1 and #2 respectively, and L is the distance between #1 and #2 terminals, v is velocity of travelling wave. The distance of L_1 which is between fault point and #1 terminal can be obtained by formula (1), and L_2can be obtained by (2):

$$L_1 = (L + (T_1 - T_2)v)/2 \tag{1}$$

$$L_2 = (L - (T_1 - T_2)v)/2 \tag{2}$$

If there is only one monitoring terminal device on transmission line, we can also get the distance between lightning point and terminal through single terminal method[15], the principle of which is as shown in Figure.2.

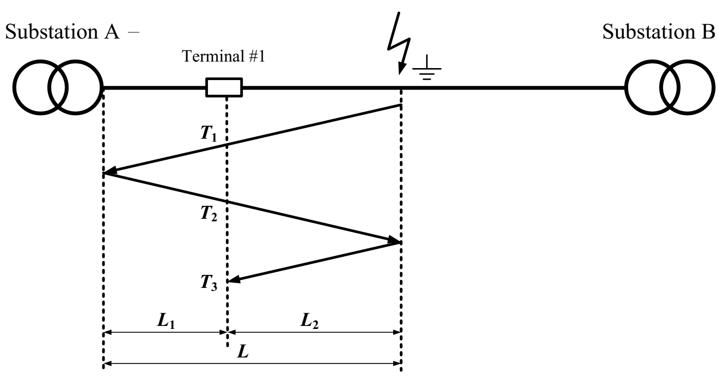


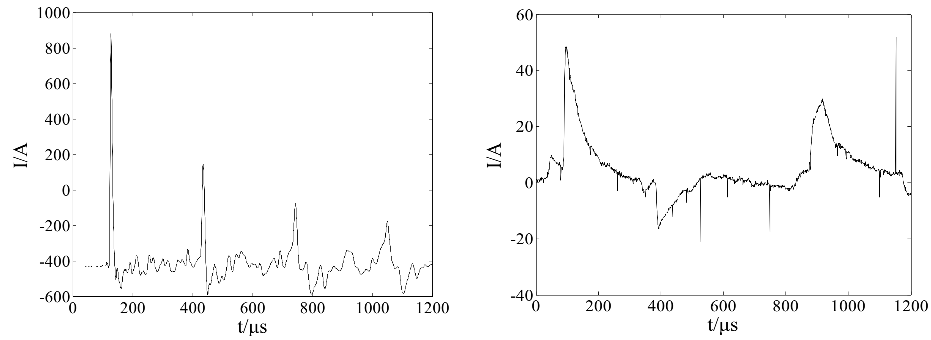
Figure 2. Single Terminal Method Schematic

When travelling wave reaches substation, it will be reflected by substation and then spreads to lightning point. When waveform reaches lightning point, then second reflection occurs and waveform spreads to both end of transmission line. In Figure.2, L_2can be given out by (3):

$$L_2 = \frac{(T_3 - T_2)v}{2} \tag{3}$$

3 Principle of Fault Recognition

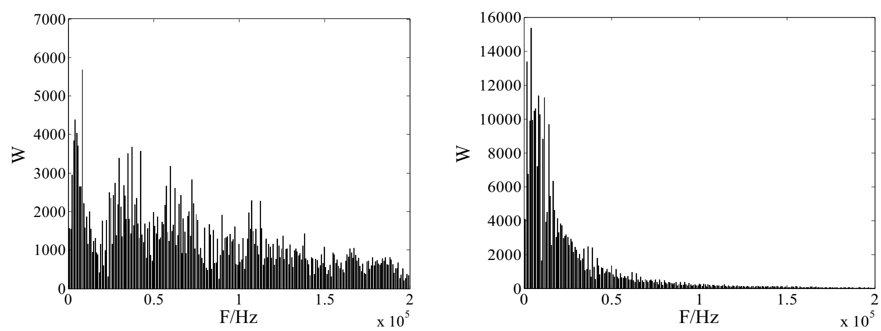
In order to find out the difference between lightning and non-lightning travelling wave, distributed fault diagnosis devices installed on transmission lines are used to monitor kinds of fault for a long time. As a result, we have recorded and obtained many lightning and non-lightning travelling waveforms. Such waveforms are as shown as Figure.3.



(a)lightning (b)non-lightning

Figure 3. Lightning And Non-Lightning Travelling Wave

From Figure.3 we can see that lightning travelling wave is quite different from non-lightning travelling wave, such as large waveform amplitude, narrow pulse width, large steepness and so on. The tail time of lightning waveform tends to be less than 40μs, while the tail time of non-lightning wave is mostly more than 40μs, which can help to identify the lightning and non-lightning waveform. In addition, the fast Fourier transform (FFT)is adopted to convert the time domain waveform to the frequency domain[16]-[17]. And lightning and non-lightning travelling wave spectrum analysis results are as follows:



(a)lightning strike (b)non-lightning strike

Figure 4. Frequency Graph Of Lightning And Non-Lighting Wave

The output of FFT results are discrete data points and each point corresponds to a frequency of the AC component. The energy of each point can be obtained by(4):

$$W(i) = |Y(i)|^2 \ (i = 0, \Delta f, 2\Delta f, 3\Delta f ......) \tag{4}$$

$Y(i)$ is the modulus of point. $\Delta f = f_M / NFFT$, f_M is sampling rate.

The FFT results are fully symmetric, so the proportion of total energy between point 1 to i can be expressed by the following equation (5):

$$R(i) = \sum_{j=0}^{i} W(j) / \sum_{j=0}^{f_M/2} W(j)(i = 0, \Delta f, 2\Delta f, 3\Delta f ... f_M/2;) \tag{5}$$

Figure.4 shows that lightning travelling wave contains much high frequency component, which component of F>30kHzaccounts for a significant proportion, while component of F>30kHz for non-lightning travelling wave occupies very small.

In order to further analyze the numerical difference between the two values, the present paper analyzed more than 20 lightning travelling waves and 30 non-lightning travelling waves. The results show that R(0-30kHz) of lightning travelling wave is between 0.1 and 0.9, while R(0-30kHz) exceeds 0.93 for non-lightning travelling wave.

Overall, we can use these two methods to identify lightning and non-lightning travelling wave. Experience shows that recognizing accuracy ratio is over 95%.

4 Experimental Details

4.1 Experimental Equipment

4 glass insulators and 4 composite insulators are applied in the experiment, which are all under operation about 4 years. Before experiment, we number all these insulators, then 4 composite insulators are marked as 1, 2, 3, 4 and glass insulators marked as 5, 6, 7, 8. Insulator marked 1and 5 are normal, while other insulators have been struck by lightning.

A 1000kVA power frequency test transformer is adopted for the AC flashover experiment, which rated voltage and current is 1000kV and 1A respectively. While in the impulse flashover experiment we use a 2400kV/210kJ impulse generator, which waveform generated meet the requirements of IEC60060[18].

4.2 Test Results and Analysis

4.2.1 Lightning Impulse Experimental

Lightning flashover experiments are carried out under the prescribed procedures according to GB/T 775.2-2003[19], and each test has been repeated for 26~35 times. The lightning impulse $U_{50\%}$ is determined by formula (6)

$$U_{50\%} = \frac{\sum n_i U_i}{\sum n_i} \tag{6}$$

The test results are as shown in table 1:

Table 1. Insulator Lightning Impulse $U_{50\%}$

Type	Number	$U_{50\%}$/kV
Composite Insulator	1	798.6
	2	806.1
	3	792.7
	4	779.2
Glass Insulator	5	765.2
	6	766.6
	7	761.9
	8	771.0

Table 1shows that lightning impulse $U_{50\%}$ of composite insulators change from 779.2 to 806.1 kV, while $U_{50\%}$ of glass insulators are 765.2 to 771kV.

There are certain differences in $U_{50\%}$ of different composite insulators and the deviation is within 2.4%compared with the #1 insulator, while $U_{50\%}$ of #2 is higher than the normal insulator #1, so lightning fault has little effect on lightning impulse insulation level for composite insulator, and almost no effect on glass insulators.

4.2.2 Switching Impulse experimental

Test methods and data processing is similar to 3.2.1, the results are as shown in Table 2:

Table 2. Switching Impulse $U_{50\%}$

Type	Number	$U_{50\%}$/kV
Composite insulator	1	725.6
	2	727.9
	3	721.2
	4	712.5
Glass insulator	5	692.6
	6	689.7
	7	693.8
	8	696.5

Composite insulators switching impulse $U_{50\%}$ are between 712.5 and 727.9kV,while $U_{50\%}$ of glass insulators are 689.7 to 696.5kV. Compared with #1 insulator, deviation of $U_{50\%}$ of #2~#4 is between -1.8%~0.3%, while -0.4%~0.4% for glass insulators.

4.2.3 Dry-Band Arcing Discharge Characteristic Experiment under Power Frequency

According to [18]-[19], dry-band arcing discharge voltage U_d of eight insulators are as shown in table 3.

Table 3. Dry-Band Arcing Discharge Voltage U_d under Power Frequency

Type	Number	U_d/kV
Composite insulator	1	417.5
	2	414.2
	3	396.1
	4	401.3
Glass insulator	5	382.4
	6	386.0
	7	371.5
	8	361.7

We can see from Table 3 that lightning fault has little effect on dry-band arcing discharge voltage of composite insulators and glass insulators. Compared with the normal case, the maximum deviation of U_d of composite insulators is -3.8%, while it is-5.5% for glass insulators. The value of U_d of insulators is all above 300kV, which is much higher than actual operating voltage of the 110kV transmission line.

4.2.4 Wet-Band Arcing Discharge Characteristic Experiment under Power Frequency

Vertical component of artificial rain is 1.4mm/min, the horizontal component is 1.3mm / min, rainfall temperature is 15℃, rain resistance is 114Ω·m, the experimental results are as shown in Table 4[18]-[19].

Table 4. Wet-Band Arcing Discharge Voltage U_w Under Power Frequency

Type	Number	U_w/kV
Composite Insulator	1	344.1
	2	352.2

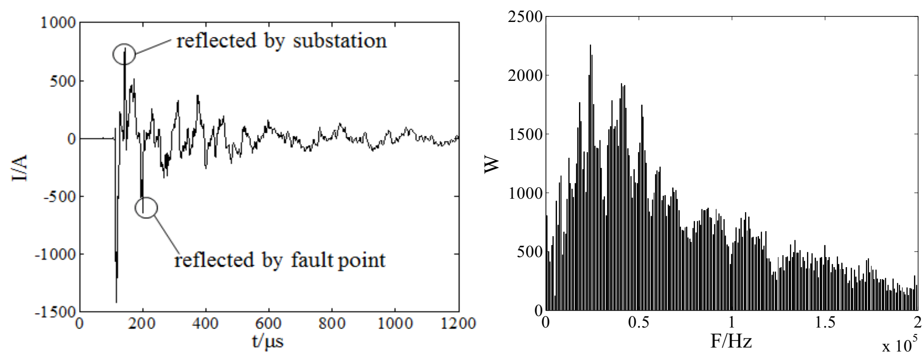
	3	329.9
	4	333.4
Glass Insulator	5	317.5
	6	321.4
	7	306.5
	8	311.7

As it can be seen from Table 4, wet-band arcing discharge voltage of each insulator in power frequency is lower than its dry-band arcing discharge voltage. U_w of Composite Insulators is between 329.9 and 352.2kV, while glass insulators is 306.5~321.4 kV. All are above300kV.Therefore, wet-band arcing discharge will not happen on 110kV transmission line even though lightning strike occurs.

Synthesizing table 1-4 data and analysis, we can conclude that insulation performance of 110kV glass insulators and composite insulators changes little after lightning strike. Even though lightning fault occurs, such insulators still remains a high degree of insulation margin, which may still continue operating for a while longer.

5 Lightning Fault Line Patrol Strategy and Practical Case

A diagnosis case of 110kV lightning fault is as follows. Fault happened on a 110kV transmission line, and Figure.5(a) is the fault travelling wave, which FFT frequency graph is shown as Figure.5(b).



(a) travelling wave(b) FFT frequency graph

Figure 5. Travelling Wave and Its FFT Frequency Graph

The tail time of the fault travelling wave of Figure.5 (a) is 17μs, and *R*(0-30kHz)=0.45, so it can be concluded that the fault is lightning fault.

From Figure.5(a), T_3-T_2=71.2μs. Take the velocity of travelling wave as *v*=290m/μs. Single terminal method is used to determine the distance between terminal and fault point, $L_2 = 71.2 \times 290 / 2 = 10324m$, and it may be easily found out that the fault point is located in #27 tower A phase, which insulator is the same as #1~#4 in the experiment. From the experiment results mentioned above, lightning strike has little influence on electric performance of 110kV composite insulator, and it reclosed successfully, so it doesn't need line patrol. The following running experience shows that this insulator runs well, which has proved that the line patrol strategy is correct.

6 Conclusion

(1)Compared with non-lightning fault travelling wave, lightning fault travelling wave has characteristics such as a large component of high frequency components, tail time <40μs, and *R*(0-30kHz) between 0.1 and 0.9, which can be used to distinguish lightning and non-lightning fault.

(2)Experimental data shows that lightning strike has little effect on insulation performance of composite insulator and glass insulator. The actual operation result proves the patrol strategy is correct. Therefore, it is not necessary to immediately patrol for most transmission line after lightning failures.
(3) To make the results more convincing, more insulators after lightning fault need to be collected and tested. Research needs to be put forward further. The present study can provide some certain guidance for the operation and maintenance of transmission lines.

References

1. A. T. Johns and S. K. Salman, *Digital Protection for Power Systems*,1st ed. London, U.K.: Peregrinus, 1997.
2. H. Suad, G. Ferdinand, and F. G. Andrej, "Prediction of power systemsecurity levels," *IEEE Trans Power Syst*, vol. 24, no. 1, pp. 368–377,Feb. 200
3. *IEEE Standard Dictionary of Electrical and Electronics Terms*, ANSI/IEEE Standard 100, 1996.
4. A. A. M. Zin and S. P. A. Karim, "Protection system analysis usingfault signatures in Malaysia," *Int J Elect. Power Energy Syst.*, vol. 45,pp. 194–205, 2013.
5. G. Diendorfer and W. Shulz, "Ground flash density and lightning exposureof power transmission lines," presented at the IEEE Power TechConf., Bologna, Italy, 2003.
6. G. Andersson, P. Donalek, R. Farmer, N. Hatziargyriou, I. Kamwa,P. Kundur, N. Martins, J. Paserba, P. Pourbeik, J. Sanchez-Gasca, R.Schulz, and A. Stankovic, "Causes of the 2003 major grid blackoutsin North America and Europe andrecommended means to improvesystem dynamic performance," *IEEE Trans Power Syst*, vol. 20, no. 4,pp. 1922–1928, Nov.2005.
7. EventsAnalysis: System Disturbance Reports NorthAmerican ElectricReliability Corporation (NERC), USA, 1992–2010.
8. M. Evan, "Extreme grid disruptions and extreme weather," presentedat the U.S. Disaster Reanalysis Workshop, Asheville, NC, USA, May3–4, 2012.
9. J. O. Adepitan and E. O. Oladiran, "Analysis of the dependence ofpower outages on lightning events within the ijebu province, Nigeria,"*J. Environ. Earth Sci.*, pp. 850–856, 2012.
10. Magnago F H，Abur A. Fault location using wavelets[J]. IEEE Transactions on Power Delivery，1998，13(4)：1475-1480.
11. Y. F. Li and P. Chen, "The Principle of the Modem Travelling Wave Based on Fault Location and the Applications to Actual Fault Analysis," in Proc. 2009 Asia-Pacific Power and Energy Engineering Conference.
12. F. H. Magnago and A. Abur, " Fault location using wavelets," IEEE Trans. Power Delivery, vo13, pp. 1475-1480, Oct. 1998.
13. de T ourrei l C , Roberge R, Bourdon P .Long-Term Mechanical Properties of High Voltage Composite Insulators [J] .IEEE Transactions on Power Apparatus and Systems , 1985 , 104 (10):2918-2921 .
14. M. Vitins, "A Correlation Method for Transmission Line Protection," IEEE Trans. Power Apparatus and Systems, vol. PAS-97, pp. 1607-1617, Sep. 1978.
15. L. Jie, S. Elangovan and 1. B. X. Devotta, "Adaptive travelling wave protection algorithm using two correlation functions," IEEE Trans Power Delivery, vol. 14, pp. 126-131, Jan. 1999.
16. Y. Suzuki, Toshio Sone, and K. Kido, "A new FFT algorithm of radix 3,6, and 12," Acoustics, Speech and Signal Processing, IEEE Transactions on, vol. 34, no.2, pp. 380–383, Apr 1986.
17. T. Patyk, D. Guevorkian, T. Pitkanen, P. Jaaskelainen, and J. Takala, "Low-power application-specific FFT processor for LTE applications," in Embedded Computer Systems: Architectures, Modeling, and Simulation(SAMOS XIII), 2013 International Conference on, July 2013, pp. 28–32.
18. IEC 60060-1-1989, High-voltage test techniques Part 1：general definitions and test requirements[S].
19. GB/T 775.2-2003, Test method for insulators--Part 2: Electrical test methods