Identification of Lightning Strikes on Transmission Lines Based on Time-frequency Joint Analysis

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Abstract. Identifying the lightning and short-circuit fault of transmission lines correctly is important for the transient protection. To address the problem, this paper adopts a multi-resolution analysis of wavelet packet and finds that energy distribution of additional components of the transient currents differs a lot when the data windows moves, if define K value as the principal component proportion, according to the differences among the K values of the different transient signals, the lightning and short-circuit fault can be identified by using the coefficient of variation. The theory of the proposed method is intuitive, simple and EMTP simulations are provided to verify its correctness.

Introduction

Identifying the lightning and short-circuit fault of transmission lines correctly is important for the transient protection. Therefore, scholars have done a lot of researches about lightning stroke fault recognition on the transmission line. [1] only analyzes the induced lightning, regardless of the direct lightning. [2] uses high frequency and low frequency energy ratio of the traveling wave signal to identify whether the fault occurs. However no shielding failure and the corresponding current traveling wave energy ratio is similar to fault current energy ratio, so it is unable to distinguish.

Aiming at the existing problem of the above methods, this paper uses differences of the energy distribution between the lightning strikes and short circuit to identify the lightning and short-circuit.

Wavelet packet theory and energy analysis

Wavelet packet theory. Define second-scale relationship [3]:

$$\begin{aligned} w_{2n}(t) &= \sqrt{2}\sum_{k\in Z} h_{ok} w_n(2t-k) \\ w_{2n+1}(t) &= \sqrt{2}\sum_{k\in Z} h_{1k} w_n(2t-k) \end{aligned} \tag{1}$$

where $h_{0\mathrm{k}}$ and $h_{1\mathrm{k}}$ are filter coefficients of multi-resolution analysis, $n=0$, $w_0(t)=\phi(t)$, $w_1=\psi(t)$, $\phi(t)$ is scaling function and $\psi(t)$ is wavelet function. Wavelet packets analysis not only can decompose the low-frequency portion of the signal, but also decompose high-frequency parts.

Energy analysis method based on wavelet packet. Assume that $d_{i,j}(k)$ (k=1,2, …,N,1≤i≤N,j=1, …,2i) is reconstructed signal of each node in some layer of wavelet packet decomposition of the signal $x(t)$. Define a sliding window in reconstructed signal of each node of the wavelet packet, and assume the window length $w \in N$, sliding factor $\sigma \in N$, so the sliding data window can be expressed as:

$$w(m,w,\delta) = \{d_{i,j}(k), k = 1+m\delta,\cdots,w+m\delta\} \tag{2}$$

Where m=1, 2… (L-w)/σ, m is a sliding data window sliding frequency; L is data length of $x(t)$. Then $E(m)=\sum_{j=1}^{2^i} E_m(j)$ is the sum of energy of the reconstructed signal in the data time window at the center of ($m\sigma$+w/2) (window width for $w \in N$), where $E_m(j)=\sum_{k=1+m\delta}^{w+m\delta}(d_{i,j}(k))^2$.

Assume $Z(m)$ is the maximum of energy of signal decomposition in the i layer and call it principal component. Namely $Z(m)$=max(E_m (j)). K is defined as the proportion of the principal component:

$$K(m)=Z(m)/E(m) \tag{3}$$

Recognition principle and the recognition algorithm

Recognition principle. In this paper, the simulation model of a 500kV power system set up with the application of EMTP shows in Fig.1 and lightning interference, fault of lightning and short-circuit fault are respectively simulated. The measuring lines last for 120 kilometers and adopt the Marti frequency dependent model. Meanwhile, the arresters make use of the model approved by IEEE [4] and locate at both sides of the transmission line. Towers in the model utilize the conventional horizontal arrangement, double shielding wire furnished on the top. Simulation of lightning current by Heiler model [5] and the wave impedance of lightning channel is 300Ω. Insulator intersection method is used to determine whether the flashover exists [6].

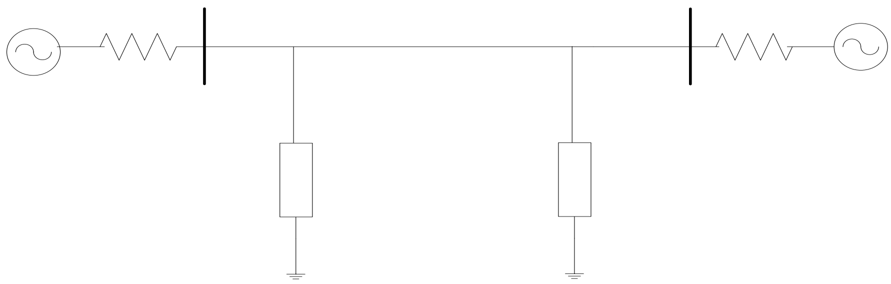
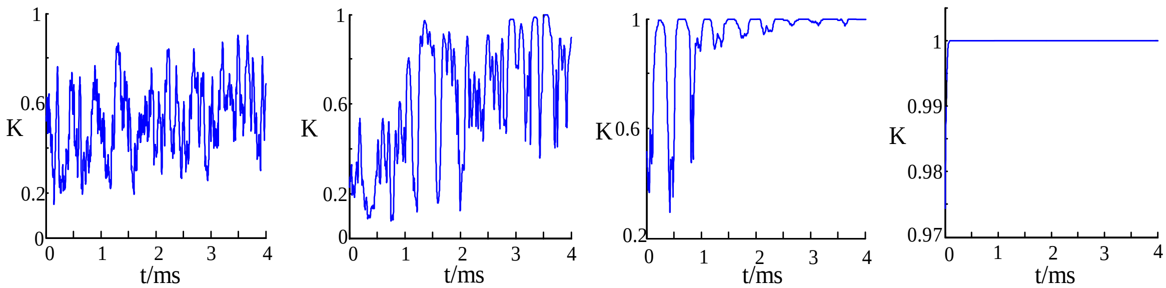


Fig. 1 500kV transmission line model

Considering the current transformers can effectively transmit high frequency components, so current is used to identify the lightning. The sampling frequency is 1MHz, because of the electromagnetic coupling between the respective phases, the line mode transformation of [7] is applied to decouple the additional current and aerial mode components are studied.

After the non-fault of lightning, lightning or short circuit faults is in a transmission line, db4 wavelet is used to decompose the line mode with 6 layers wavelet packet, considering the complexity of lightning frequency. 50μs data window of non-fault of lightning and short circuit fault are analyzed, when the data window sliding factor δ is 1μs, with moving the data window, the induction thunder and lightning, non-fault of lightning and short circuit fault of K value change as shown in Fig.2.



(a) Induction thunder (b) Non-fault of lightning (c) Failure of lightning (d) Short circuit fault

Fig. 2 The transient current K value curve

As you can see from Figure 2: the change of K value of non-fault is irregular and change of the amplitude is relatively big. For the fault of lightning, at the beginning of a period of time, the change of K value is irregular which presents the lightning characteristics. Because the lightning belongs to high frequency transient component which decays faster, the subsequent period of K value is around 1 and fluctuation range is not big which shows short circuit characteristics. For short circuit fault, as the short circuit has high-frequency components at the beginning, K value has a rising process. But the overall distribution is above 0.95. In order to count differences of the K value between them, cite the coefficient of variation in statistics:

$$\text{the coefficient of variation } C = SD/MN$$

Where SD is the standard deviation, MN is the mean value. For non-fault lightning, SD is larger and MN is the relatively small, so the variation coefficient C value is larger. For short circuit fault, SD is relatively small and MN is large, so C value is relatively small. For the lightning failures, because at the beginning of a period of time it shows the lightning characteristics and gradually it shows short circuit characteristics, it can use the coefficient of variation of K value in 1 ms after failure to identify the lightning and in 3-4 ms after failure to identify short circuit.

Identify steps. According to the analysis above, the identification steps are summarized as follows:

1) Start the fault components, read data of 4 ms and compute phase-model components, carry on the decomposition of 6 layers of wavelet packet and reconstruction of wavelet packet coefficients.

2) Create a sliding window of data (the window width is 50μs and the sliding step is 1μs), and calculate K value.

3) Move the sliding window of data in 1μs step along the time axis to get new data and repeat Step2.

4) Calculate variation coefficients in 1 ms and 3-4 ms, C1 and C2.

5) If C1>KS1*K0 (K0, according to the back of the simulation can be 0.05, KS1 is the reliable coefficient), and C2>KS2*K1 (K1, according to the back of the simulation can be 0.05, KS2 is the reliable coefficient), the result can be judged to be non-fault of lightning; if C1>KS1*K0 and C2<KS2*K1, the result can be fault lightning; if C1 < KS1 * K0 and C2 < KS2 * K1, the result can be short circuit fault.

The simulation model validation

Simulations of lightning faults under different current waveforms and peaks and short-circuit faults under various transition resistances have been carried out according to the 500kV system shown in Fig1. And part of results are displayed in Table 1. Table 1 shows that the C1 and C2 value of the non-fault of lightning are relatively large and above 0.1 under different conditions. For failure of lightning, C1 value is large and also above 0.1, while the C2 value is relatively small and under 0.01. For short circuit faults, C1 and C2 value are relatively small and under 0.01. Through a large number of simulations, considering the three transient types, C1 value and C2 value for 0.05 can correctly identify the non-fault of lightning, lightning stroke and short circuit fault.

Tab.1 Simulation results for identifying lightning and fault

The Fault Type	Conditions		C1	C2
Lightning trouble-free	2.6/50us(I0=40kA)	60km	0.4714	02296.
	1.2/40us(I0=50kA)	40km	0.5474	0.2473
	4/100us(I0=70kA)	20km	0.3797	0.1998
Lightning failures	2.6/50us(I_0=140kA)	20km	0.2254	0.0038
	1.2/40us(I_0=154kA)	40km	0.2103	0.0002
	4/100us(I_0=220kA)	60km	0.1640	0.004
Short circuit fault	R=0Ω	60km	0.0031	0
	R=10Ω	60km	0.0078	0
	R=100Ω	40km	0.0027	0.0004

Summary

Correct recognition of lightning stroke and short circuit faults is significant for transient protection. The analysis and simulations show that the energy distribution of transient current additional components has great differences with moving data window when lightning and short circuit transient traveling waves are decomposed by the wavelet packet. Based on the differences of the K value, put forward to use the variation coefficient for the identification of lightning and short circuit faults. A large number of simulations considering of numerous fault conditions have proved the synthesized method proposed in this paper is effective and reliable.

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