Identification of Lightning Strike on ±800kV UHVDC Transmission Line
Based on the PSCAD

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Correlation degree, Wavelet transform, Energy.

Abstract. This paper proposed an effective method of lightning stroke recognition. The characteristic of non-faulty lightning is that the correlation degree with the axis voltage approaches 1. This feature can identify lightning interference. The characteristic of the lightning failure is that when the flashover occurs, a large number of high frequency components in the lightning wave are immediately reduced; the characteristic of the ground fault is that contain less high frequency components. After wavelet transform, the ratio of high-frequency components caused by lightning stroke to middle and low frequencies components is larger than that of ground fault. This feature can be used to identify lightning fault and ground fault. This paper is based on the model of ±800kV UHVDC power transmission project from Yunnan to Guangdong, and simulation results show that the proposed method is effective.

Introduction

UHVDC transmission line has a high probability of being struck by lightning. The correct and fast identification technology of lightning interference is very important for the practical application of traveling wave protection and transient protection[1-4]. Paper[5-10]research the different identification methods of lightning faults.

This paper study the characteristics of non-fault lightning, lightning strike and common short-circuit fault of UHVDC transmission line based on the time-domain waveform. The transient energy distribution characteristics of lightning and short-circuit fault signals from UHVDC lines in different frequency bands are further analyzed by wavelet transform. The simulation results show that the proposed method can correctly, quickly and effectively identify the lightning disturbance and lightning fault of UHVDC transmission line.

Lightning Simulation Model of UHVDC Transmission Line

This article adopts parameters that the ±800 kV UHVDC powers transmission project from Yunnan to Guangdong. The system boundary element and the control structure refer to the literature [10]. To build ±800 kV DC transmission line simulation model based on PSCAD/EMTDC electromagnetic transient simulation platform [11-12], as shown in Figure 1.

Figure 1. Model of system simulation.
Analysis of Time—domain Waveform Characteristics of Lightning Fault and Grounding Fault

Sampling frequency selected 20kHz to simulation. The simulation sets the failure time of 0.505 s and the fault is located 500 km from the head of the line.

The correlation between the pole voltage and the axis voltage is larger when non-faulty lightning. The characteristic of lightning fault or grounding fault is: The correlation between the fault pole voltage and the axial voltage is small, and the correlation between the normal voltage and the axial voltage is large.

The simulation waveform is as follows:

(a) Voltage waveforms from two poles when back striking occurred without forming fault
(b) Voltage waveforms from two poles when shielding failure occurred without forming
(c) Voltage waveforms from two poles when back striking occurred with forming fault
(d) Voltage waveforms from two poles when shielding failure occurred with forming fault
(e) Voltage waveforms from two poles when short circuit fault occurred

Figure 2. Voltage time domain waveform.

Extracting Wavelet Transient Energy Characteristics

Select the bipolar DC voltage at the M point of Fig.1 to research, and adopt Karen Bauer phase mode transformation:

\[ S = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}, \quad S^{-1} = \frac{1}{2} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \] (1)

Analysis the difference between the axis line mode voltage and the positive value of transient voltage. Eq is:

\[ u(t) = u_{ml}(t) - u_+, u(t) = (1/2)[u_+(t) - u_-(t)] - u_+ \] (2)

Where: \( u_{ml}(t) \) denote DC linear mode voltage, \( u_+ (t) \) denote Positive line voltage of DC line, \( u_- (t) \) denote negative line voltage of DC line.

The multi-scale wavelet transform is applied to discrete signals with sampling frequency \( f_s \). Now we define the signal wavelet energy at a certain scale as the integral of the wavelet transform coefficient along the time axis, with the following expression:

\[ E_j = \sum_{k=1}^{N} |W_j(k)|^2 \] (3)

Where: \( E_j \) is the j - layer high - frequency signal wavelet energy, \( W_j(k) \)is the wavelet transform coefficient of the j layer high frequency signal, \( N \) denote the time window width. Transient voltage adopt 7 scale wavelet transform in this paper. The wavelet energy spectrum sequence is:
\[ E = [E_1, E_2, E_3, E_4, E_5, E_6, E_7, E_7^0, ] \]  
(4)

Using db3 wavelet to extract high frequency wavelet energy of transient voltage, the figure 3 is Wavelet Decomposition at Different Scales.

Analysis the Characteristics of the Energy Distribution for the Transient Voltage and Lightning Fault

The frequency of \( d_6 \sim d_7 \) and \( a_7 \) have low energy when non-faulty lightning. The frequency of \( a_7 \) have high energy when lightning fault or grounding fault. The frequency of \( d_1 \sim d_3 \) of energy of lightning fault is higher than that of the grounding fault. Waveforms of transient line voltage and its wavelet multi-resolution decomposition is shown in figure 3. Energy distribution of transient voltage is shown in table 1.

Table 1. Energy distribution of transient voltage.

<table>
<thead>
<tr>
<th>fault type</th>
<th>( E_1 )</th>
<th>( E_2 )</th>
<th>( E_3 )</th>
<th>( E_4 )</th>
<th>( E_5 )</th>
<th>( E_6 )</th>
<th>( E_7 )</th>
<th>( E_7^0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>back striking without fault</td>
<td>7.122800</td>
<td>7.173044</td>
<td>3.688633</td>
<td>15.186270</td>
<td>0.312123</td>
<td>3.650069</td>
<td>0.616141</td>
<td>11.610060</td>
</tr>
<tr>
<td>shielding failure without fault</td>
<td>9233.706</td>
<td>62685.260</td>
<td>10964.660</td>
<td>20673.450</td>
<td>34653.750</td>
<td>2221.515</td>
<td>3687.126</td>
<td>5032.903</td>
</tr>
<tr>
<td>Grounding fault</td>
<td>13984.64</td>
<td>14241.54</td>
<td>23313.43</td>
<td>60306.45</td>
<td>33813.42</td>
<td>1310613.00</td>
<td>43839.61</td>
<td>4107439.00</td>
</tr>
<tr>
<td>back striking</td>
<td>103733.20</td>
<td>127262.90</td>
<td>32223.03</td>
<td>19443.33</td>
<td>54611.36</td>
<td>912470.00</td>
<td>160896.50</td>
<td>3440406.00</td>
</tr>
<tr>
<td>shielding failure</td>
<td>43283.94</td>
<td>364251.00</td>
<td>82906.26</td>
<td>156289.00</td>
<td>263576.90</td>
<td>1201339.00</td>
<td>28493.90</td>
<td>3886392.00</td>
</tr>
</tbody>
</table>

Identification Criterion

The voltage sampling data within 5 ms of the initial traveling wave is analyzed. The formula is:

\[ \gamma = \left( \frac{\sum_{k=1}^{n} U_i(k) u_i(k)}{\sqrt{\sum_{k=1}^{n} U_i^2(k) \sum_{k=1}^{n} u_i^2(k)}} \right) \]  
(5)

Where: \( U_i \) is the positive and negative voltage axis value, \( U_i \) is the pole voltage sampling value.

\[ k = (E_i + E_y + E_\gamma)/(E_6 + E_\gamma) \]  
(6)

The correlation degree between the bipolar voltage and its axis voltage is more than 0.95 when lightning occurred without forming fault. The correlation between the fault pole voltage and its axis
voltage is less than 0.9 when the fault occurs. The energy ratio $K$ is less than 0.1. When the short circuit fault occurs, and the $K$ value is greater than 0.1 when the impact and the reverse fault occur. So the pole voltage correlation $\gamma = 0.9$ as a set value to identify lightning interference, and with the energy ratio $k = 0.1$ as lightning and short-circuit fault identification set value.

**Simulation Verification**

Table 2 and table 3 for simulation results. And a large number of simulation results show the effectiveness of the criterion.

<table>
<thead>
<tr>
<th>$R_g/\Omega$</th>
<th>Fault distance /km</th>
<th>Lightning type</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>shielding failure occurred without forming fault</td>
<td>back striking occurred without forming fault</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>positive</td>
<td>negative</td>
<td>$k$</td>
<td>determination</td>
<td>positive</td>
</tr>
<tr>
<td>20</td>
<td>200</td>
<td>0.997</td>
<td>0.999</td>
<td>7.48</td>
<td>Lightning interference</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>0.999</td>
<td>0.999</td>
<td>2.75</td>
<td>Lightning interference</td>
</tr>
<tr>
<td>12</td>
<td>300</td>
<td>0.997</td>
<td>0.999</td>
<td>20.5</td>
<td>Lightning interference</td>
</tr>
<tr>
<td></td>
<td>1300</td>
<td>0.999</td>
<td>0.999</td>
<td>30.3</td>
<td>Lightning interference</td>
</tr>
</tbody>
</table>

**Conclusion**

(1) When the UHVDC transmission line is struck by lightning, the voltage dependence of the line is close to 1. This feature can be used as a criterion to identify lightning disturbance.

(2) The high-frequency components rapidly decay after flashover; Ground fault short-circuit fault by wavelet transform, the high-frequency energy than lightning failure small, which can identify lightning or ground fault short-circuit fault.

**References**


