Application of distributed traveling wave ranging technology in fault diagnosis of HVDC transmission line

JIN Heng¹, LU Bingbing¹, TAN Fali², CHEN Peilin², SI Wenrong¹, YANG Lei²

¹State Grid Shanghai Electric Power Research Institute, Shanghai, 200437, China
²Wuhan sunshine power Science &Technology co., LTD, Wuhan, 430074, China

Abstract: Traveling wave ranging technology has been widely used in DC transmission line fault diagnosis. However, since the transmission distance of HVDC transmission lines is very far, the influence of line parameters and traveling wave attenuation effect on the ranging accuracy is more obvious, which makes the positioning accuracy of the DC-line traveling wave ranging technology insufficient, and the cause of failure cannot be identified. In addition, in case of some non-lightning failures, it is difficult for traveling wave monitoring equipment in the substation to detect the fault traveling wave, resulting in failure to locate fault points. This article describes a new type of traveling wave location technology, which is called distributed traveling wave ranging technology. The technology uses distributed monitoring terminals installed on the conductors of HVDC transmission lines to collect operating current and traveling wave current waveforms on the conductors, and accurately locates the fault points through single-end and double-end traveling wave positioning technology, reducing the influence of line span and traveling wave attenuation effect on the fault location accuracy. Finally, a lightning flash fault and a mountain fire fault diagnosis case for a ±500 kV DC transmission line are analyzed. The analysis results show that the distributed traveling wave ranging technology can reliably diagnose the fault of the HVDC transmission line.

1. Introduction

HVDC transmission lines are very long and most of them pass through complex terrain and changeable climate areas[1]. Fast and accurate ranging is conducive to finding out the fault of HVDC transmission lines quickly, restoring power supply as soon as possible, and ensuring the safety and stability of the power grid[2-3].

At present, there are mainly impedance location method and traveling wave location method. The impedance ranging method is complex and easy to be affected by the distribution parameters of lines, the operation mode of the system, the size of the load and the grounding condition, which makes the accuracy of location are not high. Traveling wave distance measuring technology is easily affected by the line span, and traveling wave attenuation effect, besides, due to the small amplitude of traveling waves of some non-lightning failures, such as mountain fires and tree failures, substation monitoring equipment is hard to monitor, which usually makes fault location fail[4-5].

Distributed traveling wave ranging technology uses distributed monitoring terminals installed on the conductors of HVDC transmission lines to collect operating current and traveling wave current waveforms on the conductors, accurately locating the fault points through single-end and double-end traveling wave positioning technology, and identifying cause of fault[6]. In this paper, two tripping fault of the State Grid Jiangcheng 500kV DC line is analyzed. The result proved that the application of distributed traveling wave ranging technology can quickly and accurately diagnose fault tripping, which will greatly enhance the management level of power transmission line operation and
maintenance, improve the reliability of power supply, and reduce operation and maintenance costs.

2. Introduction of distributed fault monitoring system
As shown in Figure 1, the distributed fault monitoring system is composed of workstation, data center and monitoring terminals. Monitoring terminals are distributed installed on the conductor of transmission lines, monitoring running current and high frequency transient current in real time, sending such data to data center by the way of GPRS. Data center is used to collate and analyze the data and output the diagnostic results.

![Figure 1: Structure diagram of the distributed fault monitoring system](image1)

The length of State Grid Jiangcheng 500kV DC line is 940.696 km long. Monitoring terminals are distributed installed in #212 tower, #613 tower, #1033 tower, #1107 tower, #2005 tower, #2071 tower, #2270 tower and #2334 tower, which is shown as Figure.2.

![Figure 2: Configuration diagram of device on Jiangcheng transmission line](image2)

Monitoring terminal is composed of conditioning circuit, battery, wireless transmitting module, high-speed processing circuit and so on. The monitoring terminal shell is a cylindrical aluminum alloy metal container with all the electronic components installed inside it. In the actual operation, the terminal shell and the wire are connected to protect the internal functional modules from the interference of the high voltage electromagnetic environment. The sensor adopts the self integral Roche coil, which has the advantages of good high frequency response, good linearity, wide measurement band and strong anti-interference ability. The principle of measuring current by Roche coil is shown in Figure 3.

![Figure 3: Principle of rogowski coil current measurement](image3)

In Figure 3, \( i(t) \) is the current value on the wire. The output of the sensor is a voltage signal. If the current is time-varying, the value of the output of the sensor can be obtained as formula (1):

\[
e(t) = -M \frac{di_1(t)}{dt} = L_0 \frac{di_2(t)}{dt} + (R_0 + r)i_2(t)
\]

In formula (1), \(M\) represents the mutual inductance between the coil and the tested conductor. \(L_0\) and \(R_0\) are the self inductance and internal resistance of the coil respectively. \(C_0\) and \(R\) are the...
distribution capacitance and the sampling resistance of the coil respectively. $i_z(t)$ is the current of the sampling resistor[7-10]. When frequency of measured current is very high, $wL\frac{R}{R_0} + r$, it can be deduced that:

$$e(t) = i_z(t)r \approx -\frac{M_r}{L_0}i_z(t)$$

By formula (2), the output of the sensor is approximately proportional to the current of the conductor[11-12]. Traveling wave current and fault transient current are both time variables, which can be obtained by collecting the output of the sensor, while for normal operating DC current, $\frac{di_z(t)}{dt} = 0$, so $e(t) = 0$.

3. Lightning fault diagnosis

Figure.4 is the current of State Grid Jiangcheng 500kV DC line monitored by distributed fault monitoring system at 2014-06-19 12:18:08, from which we can see that the current kept fluctuating for 125ms and then returned to zero, which accords with the characteristic of fault current waveform of DC transmission line, therefore, it is judged that the Jiangcheng 500kV DC line has a failure in 2014-06-19 12:18:08.

![Figure.4 Waveform of fault current](image)

The traveling wave generated at the fault point propagates to both of the two substations. The black curve in Figure.5 is the fault travelling wave detected by the monitoring terminal of #1007 tower. The time when the traveling wave first reaches the #1107 tower is $T_1$, and the second time of travelling wave reaches the #1107 tower after returning from the Echeng converter station is $T_2$. The time difference of $T_1$ and $T_2$ is 104 microseconds. Single-end traveling wave location method can be used to locate the fault point which is 15080 meters from the Echeng converter station, and further calculated the point of failure at #2300 tower.

Because the tail time of the lightning current is short, the tail time of the traveling wave current in the measured lightning fault is generally less than 40 microseconds, while the non-lightning fault traveling wave is more than 40 microseconds. In addition, the magnitude of lightning fault travelling wave is very large, generally more than 1000A, while non-lightning fault traveling wave is less than 1000A. It is possible to judge whether a fault is a lightning strike or a non-lightning strike by the size of the tail time and amplitude of the fault travelling wave. In Figure.5, the red curve is the main pulse of the travelling wave with its tail time $t_f$ less than 40μs and amplitude more than 1000A, so the fault was judged to be a lightning fault.
Shortly after the lightning strike, the line inspector inspected the lines near the #2300 tower, and found traces of burn after the discharge of the insulator under the #2301 tower. The scene of the insulator is as shown in Figure 6.

As is shown in Figure 6, there were obvious discharge burn marks on the first and 16th to 18th insulators, meanwhile similar conditions were not found in the tower near #2301. Therefore, it can be concluded that the actual fault point is located in the #2301 tower, which is only one tower away from the calculated fault point location, therefore, it can be considered that the fault diagnosis is accurate.

Near the time of the occurrence of this fault, multiple lightning faults on the transmission line were detected by the distributed fault monitoring system. The monitored lightning travelling waveforms are shown in the Figure below.
4. Non-lightning fault diagnosis
A non-lightning trip fault occurred on 2014-04-15 19:30:42 in Jiangcheng 500kV DC line. The current of monitored by distributed fault monitoring system is shown in the Figure below.
In the above Figure, pulse 1 and 1' are the main pulses of fault traveling wave monitored by #1107 and #2005 monitoring terminals respectively, while pulse 2, 3, 2', 3' are the pulses formed after the fault main wave is reflected by the substation or the fault point. According to the traveling wave transmission principle, the line wave reflection process is obtained.

The time for the fault traveling current wave reaching the #1107 tower is 2014-04-15 19:30:42 311 milliseconds and 914 microseconds, while for #2005 tower it is 2014-04-15 19:30:42 311 milliseconds and 557 microseconds. The time difference of the fault traveling wave current passing from the fault point to both of the two towers is 357 microseconds, and the fault point is located in the #1670 tower by the traveling wave location method.

The following diagram is an enlarged view of the main pulse of the fault wave. The tail time $t_f$ of the main pulse of the travelling wave is less than 40μs and amplitude more than 1000A, so it can be concluded that this fault is a non-lightning fault. The actual location of the fault point is #1670 tower and the scene photo of the fault point is shown as Figure.12.
5. Conclusion

1) By arranging a number of monitoring points on the transmission line, the distributed traveling wave ranging technology divides transmission into several intervals. The fault data and signals of each interval are monitored and recorded, respectively, which reduces the influence of transmission line length and wire sag on positioning error and suppresses the errors caused by the variation of the travelling wave speed and propagation attenuation distortion, thus, the accuracy of the fault location of the transmission line is greatly improved and the identification of the fault causes can be realized.

2) Since the distributed fault monitoring system was put into operation on the DC River City line, two faults have been detected, of which the 2014-06-19 12:18:08 fault is a lightning fault and the fault point is located in the #2301 tower. The fault on April 4, 2014 was a hill fire fault with the fault point located at #1670 tower. Both faults are located correctly, and the cause of the fault is correctly judged. Practical experience shows that the distributed fault monitoring system can efficiently and accurately troubleshoot DC transmission lines.

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