Research on the Fault Location Method of Double-terminal MMC-HVDC Transmission Line without the Influence of Wave Velocity

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Abstract. Due to its own advantages, MMC-HVDC transmission system has been widely used in power transmission and grid connection. According to the existing double-terminal traveling wave fault location method of MMC-HVDC transmission lines, a double-terminal traveling wave location method is proposed, which is not affected by wave velocity. The wavelet transform is performed on the voltage traveling wave signals at both ends to determine the time when the traveling wave reaches both ends of the line, and the distance of the fault point is calculated. It effectively reduces the influence of the uncertainty of traveling wave velocity on the positioning results and improves the positioning accuracy. The simulation of PSCAD and Matlab software proves the effectiveness and correctness of the method.

Keywords: MMC-HVDC; Double-terminal fault location; Travelling waves; Wavelet transform.

1. Introduction
HVDC power transmission based on modular multilevel converter (High Voltage Direct Current Based on MMC, MMC-HVDC) is a flexible HVDC power transmission technology, MMC-HVDC technology can quickly and independently control the active power and reactive power. Moreover, the voltage of ac network connected with it can be adjusted flexibly, and the transmission mode is flexible and reliable. MMC-HVDC transmission of new energy can alleviate the fluctuation and impact of intermittent and random renewable energy on the power grid, reduce the phenomenon of wind and light abandoning, and improve the utilization efficiency of renewable energy, which is effective means to realize large-scale clean energy power transmission and grid connection[1-2]. Dc transmission lines of MMC-HVDC are generally long in distance and prone to faults. Therefore, to ensure safe operation of transmission lines, it is of great significance to locate faults timely and accurately when faults occur. At present, there are two main methods for fault location of dc transmission lines: failure analysis method and traveling wave method[3-5]. The principle of the fault analysis method is to calculate the fault distance of the line according to the system structure and parameters when the line fails[6]. Traveling wave distance measurement is divided into single-terminal measurement method and double-terminal measurement method. When fault distance is measured by the traveling wave method, it is mainly calculated by combining the time when the fault traveling wave reaches the bus.
faulted DC transmission line will produce voltage traveling wave and current wave propagating to both terminals of the line at the fault point[7]. In [8], a new traveling wave fault ranging algorithm considering the variation characteristics of wave velocity was proposed to extract the linear relationship between wave velocity and distance in the transmission line, and then the fault distance was obtained through the fault ranging algorithm. However, in practical engineering applications, the uncertainty of earth resistivity and the variation of line sag will lead to the difficulty in obtaining the actual wave velocity - distance curve, which will lead to the failure of ranging. In [9], a single-terminal fault location method for HVDC transmission lines is proposed, which is not affected by wave velocity. The fault distance is calculated by detecting the time when the initial traveling wave of the fault and the reflected wave of the fault point reach the distance bus. The short circuit of the metal performance or the transition resistance is very small, making the measuring device unable to capture the arrival time of the traveling wave head well, which will increase the measured data error by [10].

In this paper, by improving the traditional MMC-HVDC DC transmission line traveling wave ranging algorithm, a two-terminal fault location method that is not affected by wave speed is derived. The improved ranging method does not need to consider the actual parameters of the transmission line, and does not need to consider the traveling wave speed along the transmission line. It only needs to obtain the initial traveling wave of the fault, the reflected wave at the fault point, and the time when the traveling wave reaches the ranging points at both ends. Detect the time when the fault's initial traveling wave and the reflected traveling wave at the fault point reached the measurement points at both ends of the line to calculate the location of the fault. The MMC-HVDC transmission system model is built to verify the algorithm. The ranging method has high positioning accuracy.

2. Two-terminal Ranging Algorithm for MMC-HVDC DC Transmission Lines

2.1. MMC-HVDC System Structure

MMC-HVDC systems mainly include voltage source converters, commutation inductors, AC switching equipment, DC capacitors, DC switching equipment, measurement systems, and control and protection devices. According to different engineering needs, it also includes equipment such as transmission lines, AC/DC filters, smoothing reactors, and common-mode suppression reactors. The converter station is the most important part of the MMC-HVDC transmission system. It can be divided into a rectifier station and an inverter station according to its operating state. At present, the main wiring schemes of common flexible DC converter stations mainly include unipolar symmetrical wiring schemes and bipolar symmetrical wiring schemes. Unipolar symmetrical wiring schemes are the most common wiring schemes in current flexible DC power transmission systems. The neutral point potential is clamped by a suitable grounding device on the side, and the potentials of the two DC polar lines are symmetrical positive and negative potentials[11]. Figure 1 is the structure diagram of the MMC-HVDC bipolar system at both terminals. The converter stations on each side of the system adopt the MMC structure. It consists of converter stations, converter transformers, converter reactors and AC filters, DC transmission cables (or overhead lines) and other parts.

![Figure 1. Structure of MMC-HVDC bipolar system.](image-url)
2.2. Double-terminal Ranging Method not Affected by Wave Speed

At present, the conventional two-terminal traveling wave ranging method only uses the moments when the two initial wave heads reach the bus bars at both terminals of the line, respectively, without considering the time information contained in the reflected waves at the bus terminal. It can be known from the electromagnetic theory that when a traveling wave propagates on a transmission line, the reflection and refraction of the wave occurs at the F point where the wave impedance changes. Therefore, the reflected wave of the opposite bus bar may be refracted to the local bus bar before the reflected wave at the fault point, so it is necessary to determine the polarity of the second traveling wave reaching the local bus bar during the measurement. The wavelet transform mode maximum polarity of the reflected wave signal at the fault point is the same as the initial traveling wave polarity, and the refraction of the traveling bus reflected by the opposite bus bar at the fault point is the travelling wave wavelet transform mode maximum polarity and the initial traveling wave polarity instead [12-13].

As shown in Figure 2, let the length of the transmission line be \( L \), the distance from the fault point F to the bus M terminal is \( x \), the distance to the opposite bus N is \( y \), and the traveling wave velocity is \( v \). The time \( t_0 \) is the absolute time when the fault occurred, the time \( t_1 \) when the initial traveling wave at the fault point reaches the M terminal of the bus, the time \( t_2 \) when the traveling wave reflected at the fault point reaches the M terminal of the bus, the time \( t_3 \) when the initial traveling wave at the fault point reaches the N terminal of the bus, and the time \( t_4 \) when the wave reaches the N terminal of the bus.

The equation can be listed according to Figure 2:

\[
x + y = L \tag{1}
\]

\[
\begin{align*}
(t_1 - t_0)v &= x \tag{2} \\
(t_2 - t_0)v &= 3x \\
(t_3 - t_0)v &= y \\
(t_4 - t_0)v &= 3y \tag{3}
\end{align*}
\]

Simultaneous equations (1), (2), (3) can be solved:

\[
\begin{align*}
x &= \frac{t_1 - t_0}{t_1 - 2t_0 + t_3}L \\
y &= \frac{t_3 - t_0}{t_1 - 2t_0 + t_3}L \\
t_0 &= \frac{3t_1 - t_2}{2} \quad \text{or} \quad t_0 = \frac{3t_3 - t_4}{2} \tag{4}
\end{align*}
\]

In the actual measurement process, due to the deviation of the wave heads of the initial traveling wave and the reflected traveling wave, there may be errors. Therefore, the distance between the fault points...
is calculated by using the $t_0$ at both terminals, and then the average value is calculated to minimize the error.

as $t_0 = \frac{3t_1 - t_2}{2}$:

$$x_1 = \frac{(t_2 - t_1)L}{2(t_2 - 2t_1 + t_3)} \quad y_1 = \frac{(t_2 - 3t_3 + 2t_4)L}{2(t_2 - 2t_1 + t_3)}$$

(5)

as $t_0 = \frac{3t_3 - t_4}{2}$:

$$x_2 = \frac{(2t_1 - 3t_3 + t_4)L}{2(t_1 - 2t_2 + t_4)} \quad y_2 = \frac{(t_4 - t_3)L}{2(t_1 - 2t_3 + t_4)}$$

(6)

Then average the equation (5) and (6):

$$x = \frac{x_1 + x_2}{2} = \frac{L}{4} \left( \frac{t_2 - t_4}{t_2 - 2t_1 + t_3} + \frac{2t_1 - 3t_3 + t_4}{t_1 - 2t_3 + t_4} \right)$$

(7)

$$y = \frac{y_1 + y_2}{2} = \frac{L}{4} \left( \frac{t_2 - 3t_1 + 2t_3}{t_2 - 2t_1 + t_3} + \frac{t_4 - t_3}{t_1 - 2t_3 + t_4} \right)$$

(8)

3. Simulation Verification

In order to verify the positioning accuracy of the fault location method proposed in this paper, this paper uses the electromagnetic transient simulation software PSCAD / EMTDC (power systems computer aided design / electro magnetic transient in DC system) as the simulation analysis platform, and builds 21-level MMC -HVDC bipolar loop system simulation model. Figure 3 is a schematic diagram of the simulation model in PSCAD.

**Figure 3.** System simulation model diagram.

In this system simulation model, the voltage level is 400kV, and the total length of the DC transmission line is 200km. The model is set as a bipolar short-circuit fault, the transition resistance is 1Ω, and 4s the fault starts. The positioning method is analyzed when the fault location is 50km away from the M terminal on the rectification side Feasibility. Figure 4 and Figure 5 show voltage waveform of M and N terminals.

**Figure 4.** Rectifier measurement of M terminal voltage waveform.
Figure 5. Rectifier measurement of N terminal voltage waveform.

3.1. Detection of Fault Traveling Waves
In this paper, the model data simulated in PSCAD is processed, and then the waveform is imported into MATLAB. The db4 wavelet is used for analysis during the simulation. Figure 6 shows a wavelet transform result M terminal voltage of the traveling wave (N-terminal Similarly).

Figure 6. M terminal voltage waveform wavelet transform results.
The fault traveling wave of HVDC transmission line is composed of many high and low frequency harmonics, which has obvious mutability and singularity. In this paper, due to limited space, the system is simulated to obtain the maximum value of wavelet transform mode when the line fails as shown in figure 7 and figure 8.

Figure 7. Modulus maximum of M-terminal wavelet transform.
According to Figure 7 and Figure 8, after the fault occurs, multiple traveling wave heads are detected at the M terminal and the N terminal, respectively. The reflection coefficient of the traveling wave at the fault point changes due to the change of the wave impedance. The initial traveling wave polarity reaching the two terminals of the bus is the same as the reflected traveling wave at the fault point, but it is the same as the refraction traveling wave of the opposite bus at the fault point. According to the wavelet transform modulus maximum value, it can be determined that the first and third wave heads that reach the M terminal have the same polarity, and the first and fourth wave heads that have the N terminal have the same polarity.

According to the simulation data, the corresponding time point can be obtained, $t_1 = 4.00035$, $t_2 = 4.00055$, $t_3 = 4.00065$, $t_4 = 4.0021$. Substituting the time data of the wave head to the two terminals into the ranging formula (7) and (8), which can get the result: $x = 49.2270$, $y = 150.7730$, the error is -0.0155. Table 1 shows the ranging results obtained with different distances of the fault points.

### Table 1. The result of the improved two-terminal distance measurement algorithm.

| Distance from fault to M terminal/km | Distance from fault to N terminal/km | Transition resistance/Ω | M-terminal measurement result/km | N-terminal measurement results/km | error |
|-------------------------------------|-------------------------------------|-------------------------|---------------------------------|----------------------------------|-------|
| 50                                  | 150                                 | 1                       | 56.1852                         | 143.8148                         | 0.1237|
| 80                                  | 120                                 | 1                       | 84.5620                         | 115.4380                         | 0.0570|
| 130                                 | 70                                  | 1                       | 145.3676                        | 54.6324                          | 0.1182|
| 160                                 | 40                                  | 1                       | 168.2591                        | 31.7409                          | 0.0516|

### 4. Conclusion
In this paper, a 21-level MMC-HVDC DC transmission system is established, and a simulation is conducted to draw a conclusion: when a DC transmission line fails, the fault traveling wave generated by the fault point and the wave head extraction of the reflected and refracted waves are accurate for the fault positioning has a great impact, and an improved double-ended fault measurement method is proposed. This method does not consider the influence of traveling wave velocity, making the measurement results more accurate.

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