A novel AC Protection Scheme in electronic power system

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Abstract. The application of a large number of power electronic devices has caused great changes in the fault characteristics of the AC system, and the existing protection schemes are facing great challenges. This paper first analyzes the transient current waveform characteristics of AC line faults in different scenarios such as pure AC system, DC transmission system, and new energy grid connection, and then uses the correlation coefficient to identify the transient current waveform, and a new protection principle is proposed. Finally, the new protection scheme requirements on the transformer, sampling frequency and data window length are analyzed. The correctness of the analysis conclusion is verified based on EMTDC / PSCAD simulation.

1. Introduction
With the large-scale grid connection of new energy sources and the continuous operation of DC projects, a large number of power electronic devices are used. The power electronic characteristics of power systems are more obvious, the fault characteristics of power systems are more complicated, and AC relay protection faces severe challenges [1].

Ref. [2] research shows that due to the irregularity of the fault current phase angle during the failure of LCC-HVDC commutation, the sensitivity of the optical fiber current differential protection decreases, and there is a risk of internal fault rejection; Ref. [3] studies LCC-HVDC The influence of the inverter station on the direction longitudinal protection in different AC outgoing scenarios, pointed out that the AC single-circuit line longitudinal direction protection is no longer applicable; Ref. [4] studied the impact of new energy inverter power supply on distance protection, and the analysis pointed out The distance protection on the new energy side is greatly affected by the inverter-type power supply. The protection may not operate correctly and needs to be withdrawn from operation; the Ref. [5-6] studied the impact of the AC and DC hybrid system on the differential protection of the converter, and pointed out that Due to the influence of DC bias, the converter transformer has the risk of internal fault rejection; the Ref. [7, 8] studied the DC protection scheme in the straight transmission environment, and proposed protection based on transient current similarity and transient distance signal identification Scheme, but lack of analysis and countermeasure research on the impact of AC protection; Ref. [9] based on the characteristics of inconsistent current waveform deformation on both sides of the fault line, proposed a protection action speed Data filtering algorithm windows and strong anti-interference ability to quickly pilot protection algorithms, but the scene for a pure AC system, not to carry out analysis at the AC grid power electronics protect the background. In summary, under the background of a large amount of direct current and new energy connected to the grid, it is increasingly urgent to study new protection schemes for the AC power grid that are suitable for the trend of power electronics.
This paper first analyzes the difference in transient current waveforms between internal and external faults in different fault scenarios such as pure AC systems, DC transmission systems, and new energy grid connection, and then uses Poisson correlation coefficients to identify transient current waveforms, and then proposes new protection criteria and configuration scheme, and analyzes the requirements of the new protection scheme on the selection of transformer, sampling frequency and data window length. The correctness of the analysis conclusion is verified based on PSCAD simulation results.

2. Analysis of current waveform characteristics in different scenes

2.1. Pure AC system

Fig. 1 shows a analysis diagram of a double-ended AC system. In the Fig. 1, F₁ indicates the internal fault of the transmission line, F₂ indicates the external fault of the line, and Iₘ and Iₙ respectively indicate the current flowing through the CT (current transformer) on both sides of the line.

![Figure 1: AC system analysis diagram](image)

From Fig. 2(a), it can be seen that in the internal fault, the overall difference of the current waveforms on both sides is small, and there is only a certain phase angle offset, which is caused by the difference of the power angles on both sides of the system, and presents a positive correlation feature. From Fig. 2(b), it can be seen that in the case of an external fault, since the fault current is a through current at this time, the current waveforms on both sides are completely opposite, exhibiting a negative correlation characteristic.

![Figure 2: AC system waveform comparison chart](image)

2.2. HVDC near-field failure

Fig. 3(a) shows the topology structure of the HVDC transmission system by taking LCC-HVDC as an example, and Fig. 3(b) shows the equivalent diagram of the AC system of the transmitting end of Fig. 3(a). It should be noted that if the thyristor in the LCC-HVDC is changed to the fully-controlled device IGBT, FIG. 3(a) becomes a schematic diagram of the flexible direct current transmission system.
Receiving system
Sending system
LCC-HVDC Thyristor

(a) dc system topology diagram

(b) equivalent diagram of the sending and receiving system

Figure.3 HVDC transmission system wiring diagram

(1) Receiving system fault

Fig.4 shows the current waveforms on both sides of the line when F₁ and F₂ are faulty in the receiving end system. The fault time is 0.3s. Obviously, in the case of external fault, the fault current on both sides of the line is still the through current, and the waveform is just the opposite, as shown in Fig.4 (a). In the internal fault, the current Iₙ is supplied by the DC system with short-circuit current, and the current Iₘ is received by the receiving AC system. The short-circuit current is provided. Considering the influence of the control strategy of the DC system during the fault, the difference between the short-circuit current waveforms on both sides is large, as shown in Fig. 4(b).

(a) Comparison diagram of external fault current waveform under ICC-HVDC receiving system

(b) Comparison diagram of waveform of the receiving system under internal fault

Figure.4 Contrast diagram of the current waveform of the receiving end system

(2) Sending system fault

Fig. 5 shows the current waveforms on both sides of the line when F₁ and F₂ are faulty in the delivery system. The fault time is 0.3s. Obviously, in the case of external fault, the fault current on both sides of the line is still the through current, and the waveform is just the opposite, as shown in Fig. 5(a). In the internal fault, the current Iₙ is connected to the DC system, and the current Iₘ is connected to the AC system. The nature of the short-circuit current varies greatly, as shown in Fig. 5(b).
2.3. Analysis of fault waveforms in the near zone

Due to the use of fully controlled device IGBT, flexible DC does not have the problem of commutation failure, and the fault characteristics of the transmitting and receiving terminals are not significantly different. The converter adopts a double closed-loop control system, the outer loop control mainly adopts constant DC voltage control, constant AC voltage control, constant active power control and constant reactive power control, the inner loop control uses current control, and has a low voltage ride-through function. Fig.6 shows a comparison of current waveforms when internal and external faults occur in the near area of the flexure. The fault time is 0.3s. As shown in Fig.6 (a), during external faults, the fault currents on both sides of the line are still penetrating currents, and the waveform is exactly the opposite. The short circuit current immc amplitude provided by the soft side is significantly smaller than the short circuit current is provided by the system side, but the change trend is approximately the same, as shown in Fig.6(b). Obviously, compared with LCC-HVDC, the current waveform change trend is more similar in the internal faults of the flexure near zone, as shown in Fig.4 (b), 5 (b) and 6 (b).

It should be pointed out that compared with LCC-HVDC, the flexible DC transmission VSC-HVDC adopts a fully-controlled device, and its control strategy is more complicated. The line connecting the flexible converter side is still greatly affected by the control strategy. When the internal fault of the line is different, the current waveform difference between the two sides of the line is still large, and the external fault waveform is still the opposite. The analysis conclusion is similar to that of LCC-HVDC, and will not be described here.

(a) Comparison diagram of external fault current waveform under VSC-HVDC
2.4. Analysis of fault transient current waveform when new energy is connected to the grid

Fig. 7 shows the fault current waveform of the new energy (wind power plant) grid-connected internal and external faults. The fault time is 0.3s. Direct-drive permanent magnet fans are used, and the generator-side converter uses electromagnetic power / machine-side reactive power control. The grid-side converter adopts DC voltage / reactive power control of the power grid and has a low-voltage control function. In Fig.7, the solid blue line indicates the short-circuit current provided by the system side, and The red dotted line indicates the short-circuit current provided by the new energy side. As the new energy inverter device and the VSC-HVDC both adopt IGBT, the transient current waveform during the internal and external faults is similar to the VSC-HVDC, so it is no longer tired here.

3. Research on new protection principle based on Poisson correlation coefficient

3.1. Poisson correlation coefficient

It can be seen from the analysis in Section 1 that no matter whether it is in a pure AC system or a scenario where power electronic devices are frequently used, compared to the current waveform on both sides of the internal fault line, the fault currents during the out-of-zone faults are all traversing currents. The current waveforms on both sides of the line are exactly opposite. Therefore, it is necessary to realize the identification of the transient current waveform during the fault. It should be pointed out that the control strategy will affect the short-circuit current characteristics provided by the power electronic device, but
regardless of the control strategy, the short-circuit current provided by the power electronic device is limited and irregular, and will not show up when an internal fault occurs like the regular characteristic that the current waveforms on both sides are exactly opposite when an external fault occurs.

The Poisson correlation coefficient is mainly used to measure the linear relationship between two data sets. The larger the absolute value of the correlation coefficient is, the higher the correlation is, the closer the absolute value is to 0, and the weaker the correlation is, the expression is as follows (1) Show [10].

\[
r = \frac{\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{\left(\sum_{i=1}^{n} x_i^2 \right) \left(\sum_{i=1}^{n} y_i^2 \right) - \left(\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i \right)^2}}
\]

In equation (1), \(r\) is the Poisson correlation coefficient, \(n\) is the number of sampling points, and \(x_i\) and \(y_i\) are the sample values of the data sets \(x\) and \(y\).

3.2. New protection principle

According to the analysis in Section 1.1, whether in the AC transmission system or in the DC near area, when the line has an external fault, the current waveforms on both sides of the line are opposite, and the correlation coefficient is \(-1\); when the internal fault occurs, in the pure AC system, the current waveforms on both sides of the line are not much different, and the correlation coefficient is very different from \(-1\).

When the DC near-field internal fault occurs, the currents on both sides are provided by the AC system and the DC system respectively. The correlation between the current waveforms on both sides of the line is small, and the correlation coefficient is \(-1\) still differs greatly. To this end, the correlation coefficient of the current waveform at the internal and external faults can be utilized to form a novel protection principle. Taking into account the errors in the measurement and calculation of the transformer, the following criteria are formed:

\[
\begin{align*}
 r & \in (-1, -0.8) \text{ external fault} \\
 r & \notin (-1, -0.8) \text{ internal fault}
\end{align*}
\]

(2)

In summary, it can be concluded that the flow chart of the new protection principle is shown in Fig.8. Firstly, the protection device is in the self-test state. When the protection start element is activated, firstly calculate the correlation coefficient on both sides of the current by using formula (1), and then judge whether the correlation coefficient (absolute value) satisfies the internal failure criterion based on the criterion (2). If it is satisfied, the protection operates; otherwise the protection does not operate.

![Figure 8: New protection flow chart](image-url)
3.3. Analysis of protection configuration scheme and influencing factors

The existing protection configuration scheme adopts the "main protection + backup protection" method, the main protection adopts current differential protection, and the backup protection is generally distance protection and zero sequence protection. The new protection configuration scheme still uses the "main protection + backup protection" architecture, but it is optimized in terms of protection principles: in addition to the current differential, the main protection principle can be increased based on the similarity of waveforms, and the two constitute an "or" logic: on the one hand, it can ensure that it does not malfunction when out-of-zone faults, on the other hand, it can ensure that internal faults are reliably and quickly removed when the sensitivity of the differential protection decreases. After the new main protection principle is mature, the differential protection can be withdrawn. In terms of backup protection, existing literature has pointed out that distance protection is greatly affected by power electronics. In the future, with the deepening of research, the backup protection scheme can be further optimized. The following analyzes the technical requirements of the new protection configuration scheme for transformers, sampling frequency, and data window length.

(a) Sampling frequency design. The new protection principle takes advantage of the waveform differences between internal and external faults, eliminating the need for high frequency sampling in terms of protection principles. However, in order to calculate the correlation coefficient more accurately, the sampling frequency can be appropriately increased, for example, 40 points are sampled per week, that is, the sampling frequency is designed to be 2000 Hz.

(b) Data window length design. Compared with the traditional power frequency protection 20ms or 10ms data window length, the new protection principle based on Poisson correlation coefficient does not need to extract the power frequency, so the data window length can be shortened appropriately. For example, the calculation data window length can be designed as 6 points, that is, each calculation window is 3 ms long. If the correlation coefficient calculated by four consecutive data windows satisfies the protection action condition, the exit is protected; otherwise the protection does not operate.

4. Simulation analysis

The simulation model shown in Fig.1 and Fig.3 is constructed by using PSCAD. The DC control adopts the control mode in the CIGRE model, that is, the rectifier side is constant current control, and the inverter side includes fixed off angle control, constant current control, and low voltage current limit. Link and constant current deviation control. In steady state operation, the inverter side adopts the fixed off angle control. During the transient process, several control modes on the inverter side are coordinated and converted according to the transient process.

Table 1 shows the waveform correlation coefficients of the currents Im and In in Figs. 2, 4 and 5. In Table 1, 0.72, 0.68, and 0.70 represent correlation coefficient values calculated by four consecutive data windows. It can be seen from Table 1 that in the near DC region, the absolute value of the correlation coefficient becomes smaller and smaller with the movement of the data window, which is because the effect of DC control is more obvious with time. The correlation of the current waveforms on both sides will decrease.

| Correlation Coefficients | r         |
|--------------------------|-----------|
|                          | Internal fault | External fault |
| AC system                | 0.70, 0.65, 0.71, 0.68 | -1, -1, -1, -1 |
| Sending System           | 0.63, 0.45, -0.15, -0.02 | -1, -1, -1, -1 |
| Receiver System          | 0.56, -0.27, -0.12, -0.25 | -1, -1, -1 |

5. Summary

This paper first analyzes the current waveform characteristics on both sides of the line under different fault scenarios, and then realizes the identification of the transient current map based on the Poisson correlation coefficient, and then proposes a new main protection principle, and then builds an AC
The main research conclusions are as follows:

1. The protection configuration scheme is universal. The new protection configuration scheme can be applied not only in areas where power electronic equipment is dense, but also in pure AC systems, which is universal.

2. Protect exports faster. The data window length of the new protection principle can be 4ms, which is much lower than the protection data window length based on power frequency, and the protection export speed is accelerated.

3. Simple implementation and strong practicability. The new protection principle has no special requirements on the hardware and sampling frequency of the protection device. It only needs to realize the identification of the transient current map, so it is practical.

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