Fault Detection and Protection of UHV Transmission Line Based on Negative Sequence Impedance Angle

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Abstract. This paper presents a pilot protection method for UHV transmission lines based on negative sequence impedance angle, which can reflect the total fault type. In this method, the memory function of microprocessor is used to extract window data of one cycle for delay processing. Meanwhile, the variable is introduced to make artificial asymmetric fault and produce negative sequence component, which makes the negative sequence admittance angle discriminator applicable to all types of short circuit faults. Based on PSCAD / EMTDC, a 1000 kV transmission line and its fault model are built. At the same time, a large number of line simulation are carried out. It is verified that the method can reflect different fault conditions and basically meet the requirements of UHV line relay protection.

Keywords: UHV Transmission Line, Negative Sequence Impedance Angle, Fault Detection

1. Introduction
The stability of UHV transmission line is largely determined by relay protection equipment. So higher requirements are put forward for the selectivity, reliability, speed and sensitivity of protection [1-3].

When asymmetric fault occurs, negative sequence component exists in the whole process of fault, so negative sequence component can reliably respond to the occurrence of asymmetric fault. However, there is a disadvantage in the classical negative sequence pilot protection, that is, it can not reliably reflect the three-phase symmetrical type fault [4-5].

Directional protection is widely used as the main protection of UHV transmission lines abroad. In reference [6], a joint comparative protection scheme based on negative sequence is proposed for distribution line protection, which can give correct response to the change of system operating conditions. Reference [7] proposed a method to distinguish fault direction by polarity and size of negative sequence reactance. When the negative voltage is small or even close to zero, the component can identify the direction accurately. The domestic literature [8] uses the phase relationship between zero negative sequence voltage and current after fault to identify the fault direction, and gradually improves the sensitivity of components according to the different differences of faults, thus forming a relatively perfect directional pilot protection measure. In reference [9], the negative sequence protection element is used as the main protection for AC transmission lines with series compensation.
The results show that the negative sequence protection element is suitable for UHV transmission lines, but it is still necessary to overcome the misoperation caused by the oscillation of capacitance and inductance. Some scholars have proposed to improve the directional element, adopt the memory storage function of microprocessor protection, sample and extract the line frequency data by computer, and artificially obtain the negative sequence component in the process of three-phase symmetrical type fault, so as to realize the response of longitudinal directional protection to three-phase symmetrical fault [10].

2. Pilot Protection Method for UHV Transmission Line Based on Negative Sequence Impedance Angle

In this paper, the response of UHV transmission line protection under full fault type is studied and improved. The negative sequence admittance angle discriminator is improved by using microcomputer technology. Under different fault types, the negative sequence direction element can correctly judge the direction of fault, correctly reflect all faults without dead zone, and will not be affected by transition resistance. It will not misoperate when there is no fault, and it can also correctly reflect without refusing to move when there is three-phase symmetrical fault.

2.1. Negative Sequence Impedance Angle Discriminator

According to the location of the fault point, the additional state diagram of negative sequence fault of different fault points can be drawn, as shown in Fig. 1-3, which is the state diagram of system F1, F2 and F3 respectively. The figure shows the equivalent impedance on the left side of bus m, the equivalent impedance on the right side of bus N, the negative sequence fault component EMF at the fault point, RF the transition resistance at the fault point, the equivalent impedance of tie line, the negative sequence fault voltage component at bus m and the negative sequence fault voltage component at bus n. Is the negative sequence fault current component at bus m and the negative sequence fault current component at bus n. The impedance of negative sequence fault component is actually the voltage of negative sequence component divided by the current of negative sequence component.

\[ Z_{\text{M2}} = \frac{U_{\text{mg2}}}{I_{\text{mg2}}} \]  
\[ Z_{\text{MN2}} = \frac{U_{\text{mg2}}}{I_{\text{mg2}}} + \frac{U_{\text{mg2}}}{I_{\text{mg2}}} \]  

Figure 1. Negative sequence additional state in case of fault at F1, F2, F3
When a fault occurs at position F1, the impedance value and impedance angle range of defined impedance can be obtained according to Fig. 1.

\[
Z_{M2} = \frac{U_{ng2}}{I_{ng2}} = Z_L + Z_{sn2}
\]
\[
Z_{MN2} = \frac{U_{ng2}}{I_{ng2}} + \frac{U_{ng2}}{I_{ng2}} = Z_L + Z_{sn2} + (-Z_{sn2}) = Z_L
\]
\[
0^\circ < \arg(Z_{M2}) = \arg(Z_L + Z_{sn2}) < 90^\circ
\]
\[
0^\circ < \arg(Z_{MN2}) = \arg(Z_L) < 90^\circ
\]

When a fault occurs at position F2, the impedance value and impedance angle range of defined impedance can be obtained according to Fig. 1.

\[
Z_{M2} = \frac{U_{ng2}}{I_{ng2}} = -Z_{sn2}
\]
\[
Z_{MN2} = \frac{U_{ng2}}{I_{ng2}} + \frac{U_{ng2}}{I_{ng2}} = -Z_{sn2} + Z_{sn2} = Z_L
\]

For \( \arg(Z_{M2}) = \arg(-Z_{sn2}) = 180^\circ + \arg(Z_{sn2}), \)
\[
180^\circ < \arg(Z_{M2}) < 270^\circ
\]
\[
180^\circ < \arg(Z_{MN2}) < 270^\circ
\]

When a fault occurs at position F3, the impedance value and impedance angle range of defined impedance can be obtained according to Fig. 1.

\[
Z_{M2} = \frac{U_{ng2}}{I_{ng2}} = -Z_{sn2}
\]
\[
Z_{MN2} = \frac{U_{ng2}}{I_{ng2}} + \frac{U_{ng2}}{I_{ng2}} = -Z_{sn2} + (Z_L + Z_{sn2}) = Z_L
\]
\[
180^\circ < \arg(Z_{M2}) < 270^\circ
\]
\[
0^\circ < \arg(Z_{MN2}) < 90^\circ
\]

The results are shown in Table 1.

| Fault Location | F1                  | F2                  | F3                  |
|----------------|---------------------|---------------------|---------------------|
| \(Z_{M2}\)    | \(Z_L + Z_{sn2}\)  | \(-Z_{sn2}\)       | \(-Z_{sn2}\)       |
| \(Z_{MN2}\)   | \(Z_L\)            | \(-Z_{sn2} + Z_{sn2}\) | \(Z_L\)            |

To set \(\phi_1 = \arg(Z_{M2})\), \(\phi_2 = \arg(Z_{MN2})\), the results are shown in Table 2.
Table 2. Impedance angle range of defined impedance at different locations

| Fault Location | F1           | F2           | F3           |
|----------------|--------------|--------------|--------------|
| $\varphi_{d1}$ | (0°, 90°)    | (180°, 270°) | (180°, 270°) |
| $\varphi_{d2}$ | (0°, 90°)    | (180°, 270°) | (0°, 90°)    |

According to the analysis in Table 2, when fault occurs at F1, the range of impedance angle defined is (0°, 90°) and the range of impedance angle is (0°, 90°). Similarly, when the fault occurs at F2, the range of the defined impedance angle is (180°, 270°), and the range of the impedance angle is (180°, 270°). When fault occurs at F3, the range of impedance angle defined is (180°, 270°), and the range of impedance angle is (0°, 90°).

Therefore, the criteria for judging the external fault of UHV transmission lines can be expressed as follows.

$$0° < \varphi_{d1} < 90°$$  \hspace{1cm} (15)

$$180° < \varphi_{d2} < 270°$$ \hspace{1cm} (16)

2.2. Fault Detection Criterion and Protection Process

Previously, the criterion for judging whether the fault occurs or not and the criterion for the location of the fault have been found out. The last thing to do is to combine the two criteria. Through the effective combination of the two criteria, an effective way to judge the external fault can be formed, through which the protection of UHV transmission lines can be formed.

Data delay is used to improve. The basic method of this method is to delay the processing of one phase data in three-phase, so that the three-phase symmetrical fault produces artificial asymmetric phase. The data processing in this paper adopts A-phase electrical quantity for data delay processing. After this data delay processing method, the three-phase symmetrical fault is transformed into asymmetric fault, and the negative sequence component will be generated in the asymmetric fault, so the negative sequence element can respond to the action.

In the specific implementation, firstly, a data acquisition device is used to collect data on the line, which is similar to the device of voltmeter and ammeter, which can read out the negative sequence voltage value and negative sequence impedance angle value on the tie line. These two signals express whether the line has fault or not and where the fault has occurred, and then the collected data is transmitted to the central calculation through the communication line. Through the data processing of computer, the signal of whether action is needed is transmitted to the relay. Finally, the correct processing is given through the relay, and the circuit is disconnected or not. These are the concrete plans to achieve protection.

The realization of the two criteria can be shown intuitively through the flow chart. When the amplitude of the received negative sequence fault voltage component is greater than the setting value of the criterion, it is judged that the fault occurs. Formula (15) or formula (16) is used to judge whether the fault is external fault. When they are satisfied, it is external fault, and only when both criteria are not satisfied, it is internal fault.

3. Cases Simulation

The simulation line is built according to the basic parameters and known simulation parameters of Jindongnan Jingmen UHV transmission line. As shown in Fig. 2.
The line parameters are set as follows:
M side power supply: EM = 1180kV, RM = 0.0531 Ω, LM = 0.14h, CM = 91 µF.
N side power supply: EM = 1240kV, RM = 0.0106 Ω, LM = 0.03h, CM = 457 µF.
The total length of the line is set at 120km.

At the same time, the fault signal is configured with timed fault logic element, and the fault start time is set as 2 s.

When there is a three-phase fault inside the line, because the memory function of the microprocessor is used to delay the processing of the A-phase data, the unnatural asymmetric fault will be caused, thus the negative sequence component will be generated in the line, which conforms to the action conditions of the negative sequence pilot direction protection, and the negative sequence pilot protection can respond. The response results of negative sequence directional element are shown in Fig. 3.

| Transition resistance value /Ω | 0.01 | 10  | 100 | 500 | 1000 | 2000 |
|-------------------------------|------|-----|-----|-----|------|------|
| Action time of negative sequence element /s | 2.016 | 2.016 | 2.017 | 2.018 | 2.018 | 2.023 |

Obviously, the improved negative sequence pilot directional protection is not affected by the transition resistance.

4. Conclusion

Negative sequence directional pilot protection is commonly used as the main protection of UHV transmission line, but it has the problem of refusing to operate when symmetrical short circuit occurs. In this paper, the defects of negative sequence pilot protection are improved. The basic idea of this paper is: the memory function of microprocessor is used to delay the data of one phase. The original current data and the delayed data are combined with the other two phases for Fourier transform to obtain the negative sequence component of current and voltage, and then the negative sequence component is used as the criterion of negative sequence directional element to judge the protection. Theoretical analysis and simulation results show that the improved negative sequence directional pilot...
Protection can respond to all fault types and can act quickly. The improved directional element makes up for the defect that can not reflect the whole fault type, but also does not reduce its own advantages and improve its original application scope.

The simulation results in PSCAD UHV transmission line show that: when the line produces three-phase symmetrical fault, the improved line produces negative sequence component, thus improving the original defects of negative sequence directional element; at the same time, considering the influence of transition resistance on fault simulation, the fault simulation of setting 500 ohm high resistance is carried out, and the final results show that the improved negative sequence component has negative sequence component. The sequence directional element can adapt to the environment with large transition resistance and improve the reliability of negative sequence pilot protection.

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