An Operation Time On-line Setting Method of Distance Protection Section II&III for 220kV Transmission Line

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Abstract. Section II and section III of distance protection are widely used as backup protection for 220kV transmission line. In order to ensure that the line distance protection can act correctly and cooperate with each other, it is necessary to set the impedance and time setting value of distance protection. At present, the time setting values of section II and III of power grid distance protection are fixed action time limits calculated by manual calculation or computer setting calculation program offline. In this paper, an on-line setting technology for section II and section III of distance protection is proposed. The operation time of section II and section III of distance protection is determined by measured fault impedance. As long as the distance protection section II and section III operates, the operation time can be calculated according to the formula proposed in this paper, and the operation time of protection section II and section III of the upper and lower level lines can meet the coordination relationship, and the operation time difference meets the requirements. Through modeling and simulation, it is proved that the method proposed in this paper is feasible.

1. Introduction

Traditional three section distance protection has simple working principle and requires no communication channels. According to the standardization requirement, three section ground& phase-phase distance protections are universally deployed on protection devices for transmission line of 220kV and above[1]. Distance protection setting calculation is the key for those protections to operate correctly and work in coordination. The coordination of distance protections is realized by proper setting of the operation zone on impedance plane and operation time limits. The three-section distance protection, specifically section II&III have a lot of setting workload, and the insufficiency of sensitivity when working as back-up protection and loss of coordination between the upper level and lower level protection are very common.

The setting of the distance protection section II has to cooperate with the setting of the distance protection section I of the lower level line, so it’s influenced by the output of the relevant augmentation power source. The variant operation mode of the power grid brings difficulty to the coordination of traditional three section protection.
For some regions in northwest China, the length of the 220kV transmission line is generally too long that even if the impedance setting value is set according to the minimum load impedance, the distance protection sections II and III of the upper level line can’t protect the whole line, which means the back-up protection has serious sensitivity insufficiency problem.

Distance protection online setting has been studied by many experts and scholars [2-5]. At present, the idea of distance protection online setting is usually to calculate and modify the protection setting value online according to the grid structure, power equipment parameters and system operation status, which requires communication and real-time calculation [6-9]. However, it’s too expensive to add communication devices for distance protection especially when it operates as back-up protection.

The traditional distance protection is also sensitive to fault transition resistance. The distance protection sensitivity is greatly reduced during a fault with transition resistance. An adaptive model for fault impedance calculation is proposed in reference [11] and a scheme of adaptive protection based on the adaptive reactance is proposed in reference [12].

This paper presents an online setting method for distance protection section II&III, specifically operation time online setting. The operation zone of distance protection section II&III is still pre-set off line, but the operation time is determined by the fault impedance. The time formula proposed in this

![Figure 1. Flow chart of distance protection with section II&III on-line setting.](image)
paper is the key for operation time online setting. To solve the problem that fault impedance cannot be properly calculated during a phase-ground fault with high transition resistivity, the iteration calculation method based on zero sequence relay is adopted in this paper.

The flow chart of the online setting distance protection is shown in figure 1 above.

2. Fault distance iteration calculation method based on zero sequence impedance relay

2.1. Fault impedance and location calculation method

The basic for online setting is the fault location which is the fault impedance divided by line impedance per unit length:

\[ L_c = \frac{Z_K}{z_{11}} \]  

(1)

Where \( L_c \) is the fault distance, \( z_{11} \) is the positive sequence line impedance per unit length, and \( Z_K \) is the calculated positive sequence fault impedance.

For line-ground short circuit fault, \( Z_K \) is calculated by:

\[ Z_K = \frac{U_\phi}{I_\phi + k3I_0} = \left( U_K + Z_{11}L_c \right) \left( I_\phi + k3I_0 \right) \]  

(2)

For line-line short circuit fault, \( Z_K \) is calculated by:

\[ Z_K = \frac{U_{\phi\phi}}{I_{\phi\phi}} \]  

(3)

Where \( U_\phi \) is the fault phase voltage phasor measured by the protection, \( 3I_0 \) is the fault phase current phasor measured by the protection, \( k = \frac{(z_0 - z_{11})}{3z_{11}} \) is the zero sequence current calculated by the protection, \( Z_{11} \) is the zero sequence compensation coefficient, \( U_K \) is the residual voltage at the fault point, for metallic line-ground short circuit fault, \( U_K = 0 \), \( U_{\phi\phi} \) is the line-line voltage, \( I_{\phi\phi} = I_{\phi1} - I_{\phi2} \).

2.2. Zero sequence impedance relay operation principal

The fault impedance calculation method shown in equation (2) is no longer accurate during a phase-ground fault with transition resistance, which could greatly influence the performance of online setting method based on the fault impedance.

To solve the major problem, the iteration calculation method based on zero sequence iteration method is adopted in this paper. The working principles are introduced below.

![Figure 2. Schematic diagram of line transit resistance phase A grounding fault.](image)

As is shown in figure 2, phase A-ground short circuit fault with transition resistance of Rg occurs on point K of transmission line MN, all the electrical quantities are annotated on the figure.

The operation criterion of zero sequence impedance relay is shown in equation (4):
Where the operation voltage $\dot{U}_{opA}$ and polarization voltage $\dot{U}_f$ are:

$$\dot{U}_{opA} = U_A - \left( I_A + k3I_0^{(1)} \right) Z_{set}$$

$$\dot{U}_f = I_0^{(1)} 3R_g$$

Let nominator and denominator of equation (5) be divided by $I_A + k3I_0^{(1)}$ at the same time, and the zero sequence impedance relay operation criterion is modified as:

$$-180° - \beta \leq \arg(Z_M - Z_{set}) \leq -\beta$$

Where $Z_{set} = R_{set} + jX_{set}$ is the setting impedance of the distance protection. While $Z_M$ is the measured impedance of the protection, it is composed of two impedances. The first impedance are determined by fault resistance and zero sequence network, while the second impedance reflects the true fault distance, as is shown in equation (8):

$$Z_M = \frac{3I_0^{(1)} R_0^{(1)}}{(I_A + k3I_0^{(1)})} + Z_{11}L_k$$

$$\beta = \arg\left(\frac{3I_0^{(1)}}{(I_A + k3I_0^{(1)})}\right)$$

As is shown in equation (8)-(9), the operation line of zero sequence impedance relay on impedance plane is defined by a straight line passing through point $(R_{set}, jX_{set})$, and has a slope of $-\beta$. Figure 3 shows the operation characteristics of the zero sequence impedance relay.

![Figure 3](url_to_image)

(a) ZM inside of operation zone

(b) ZM outside of operation zone

Figure 3. Impedance plane diagram of high resistance single-phase line-ground fault within the zero sequence reactance relay operation zone.

### 2.3. Iteration calculation method based on zero sequence iteration method

The zero sequence impedance relay theoretically is not influenced by the transition resistance and can determine whether a line-ground fault is within the protection range no matter how big the transition resistivity is. Using this characteristic, the iteration calculation method for fault distance of line-ground short circuit fault are introduced.

When the phase A line-ground fault occurs on the protection range of distance protection section II. As protection range of section II is generally longer than that of section III, distance protection section III will operates as well.

The start point of the iteration is:
Where \( U_{mA}, I_{mA} \) are the measured voltage and current phasor of the distance protection device. \( \theta \) is the positive sequence impedance angle. \( Z_{C(k)} \) is the \( Z_{set} \) of the zero sequence impedance relay operation criterion in each iteration.

The iteration criterion is:

\[
-180^\circ \leq \arg \left( \frac{U_{mA} - (I_{mA} + k3I_{0}^{(1)})Z_{C(k)}}{3I_{0}^{(1)}} \right) \leq 0^\circ
\]

For the \( k^{th} \) iteration, if the criterion is met, it means the current measured impedance is inside the operation zone of the zero sequence impedance relay determined by the, thus the actual impedance reflecting the real fault distance is smaller than the current iteration calculation results \( Z_{C(k)} \), vice versa. So after each iteration, manipulate the measured impedance by:

\[
Z_{C(k+1)} = \begin{cases} 
Z_{C(k)} - \left( \frac{1}{2} \right)^k Z_{a}^* & \text{criterion met} \\
Z_{C(k)} + \left( \frac{1}{2} \right)^k Z_{a}^* & \text{criterion not met}
\end{cases}
\]

Considering the CPU workload and the rapidity of the protection, it only takes 10 iterations to get the final measured impedance \( Z_{C(10)} \), and the protection fault distance is calculated by:

\[
L_C = \left| Z_{C(10)} \right| / Z_1
\]

3. Operation time calculation method based on calculated fault distance

While reserving the operation impedance setting offline, the online setting distance protection proposed in this paper has no operation time setting vale for section II & III. If the distance protection section I operated during a fault, the protection sends trip signal with no internal delay. However, if the distance protection section III or section II&III operate, the operation time limit is set online using the fault distance \( L_C \) calculated in chapter II.

The key of the online setting method is the calculation of the operation time limit \( t_{op} \) of distance protection section II, and the operation time limit of distance protection section III can then be calculated by adding a simple time difference, the calculation formula is shown in equation (14)-(15):

\[
t_{op,II} = \begin{cases} 
\min \left( \frac{T_0}{0.3} \sum_{j=1}^{4} t_j, 3.0 \right), & L_C > 1.5L \\
\min \left( \frac{T_0}{0.3} \sum_{j=1}^{4} t_j, 2.5 \right), & 1.1L < L_C \leq 1.5L \\
\min \left( \frac{T_0}{0.3} \sum_{j=1}^{4} t_j, 0.5 \right), & 0.6L < L_C \leq 1.1L \\
t_1, & 0 < L_C \leq 0.6L
\end{cases}
\]

\[
t_{op,III} = t_{op,II} + 1.5
\]
Where $t_{op,II}$ and $t_{op,III}$ are the operation time of distance protection section II&III, $T_0$ is the minimum operation time difference defined by users, $L$ is the length of the protected line, $L_C$ is the iteration calculation result, $t_j$ is defined as:

$$
\begin{align*}
    t_1 &= 0.05 \sqrt{100L_C / L}, \\
    t_2 &= 0.1 \sqrt{2(L_C - 0.6L)}, \\
    t_3 &= 0.16 \sqrt{2(L_C - 0.6L)}, \\
    t_4 &= 0.15 \sqrt{2(L_C - 1.1L)}, \\
    t_5 &= 0.1 \sqrt{2(L_C - 1.5L)}, \\
    t_6 &= 0.1 \sqrt{2(L_C - L)}, \\
\end{align*}
$$

(16)

The operation time of distance protection section II&III calculated with the formula above can work in coordination automatically, and the operation time difference can meet the requirements of the standards.

4. Test and verification

To verify the on-line setting method proposed in the paper, a lot of tests have been conducted. In this chapter, only one case which is most representative is presented.

The electromagnetic transient model with three different lines is established on RTDS digital simulator, As is shown in figure 4. Protection 1, 3, 5 are the protection being studied, if power flows from source M to source N, then protection 1, 3, 5 are on sending end, otherwise protection 1, 3, 5 are on the receiving end.

![Figure 4. Three lines transmission system diagram.](image)

The parameters of the model are listed below:

| Parameters                                | Values        |
|-------------------------------------------|---------------|
| Base apparent power                       | 100MVA        |
| Base voltage                              | 220kV         |
| Positive sequence impedance               | 0.424 Ω/km    |
| Zero sequence impedance                   | 1 Ω/km        |
| Impedance angle                           | 82°           |
| Length of line L1                         | 200km         |
| Length of line L2                         | 20km          |
| Length of line L3                         | 6km           |
| Source 1 positive sequence reactance      | 0.02pu        |
Parameters | Values
--- | ---
Source 1 zero sequence reactance | 0.03pu
Source 2 positive sequence reactance | 0.06pu
Source 2 zero sequence reactance | 0.18pu

The setting values of distance protection are listed in table 2:

Table 2. Distance Protection Setting Values.

| Parameters | Impedance setting values (Primary) | Distance setting values (in kilometers) |
| --- | --- | --- |
| | L1 | L2 | L3 | L1 | L2 | L3 |
| Section I | 59.3Ω | 5.9Ω | 1.8Ω | 140 | 14 | 4.2 |
| Section II | 114.5Ω | 12.7Ω | 5.1Ω | 190.8 | 30 | 12 |
| Section III | 133.3Ω | 133.3Ω | 133.3Ω | 314.5 | 314.5 | 314.5 |

Simulate phase ABC short circuit fault, phase AB short circuit fault, and phase A line-ground fault with different transition resistance on different fault locations on line 3, and records the waveform accordingly.

The performance of the online setting method is then evaluated based on the simulation waveforms by programming. A lot of experiments have been conducted, the fault distance of phase-phase fault can always be calculated correctly, so only line-ground fault with different transition resistivity is demonstrated in this paper.

The performance of the iteration fault distance calculation method based on zero sequence impedance relay and the results of the calculated online setting time limit is listed in table 3 and table 4:

Table 3. The iterative calculation results of fault distance of line 1~line3 during phase a line-ground fault with different transition resistance on the end of line 3.

| Working mode | Fault location | Transition resistivity/Ω | Iteration fault distance calculation results (Actual fault distance) |
| --- | --- | --- | --- |
| | | | L1 | L2 | L3 |
| Sending end light load (10MW) | F1 | 0 | 230.2 | 22.0 | 1.03 |
| | F1 | 40 | 247.1 | 24.5 | 7.02 |
| | F2 | 0 | 228.6 | 23.3 | 3.05 |
| | F2 | 40 | 261.4 | 27.8 | 8.4 |
| | F3 | 0 | 236.1 | 25.4 | 5.8 |
| | F3 | 40 | 273.9 | 48.1 | 14.1 |
| | F1 | 0 | 246.4 | 23.1 | 6.3 |
| | F1 | 40 | 279 | 53 | 30.1 |
| Receiving end heavy load (300MW) | F2 | 0 | 251.5 | 34 | 10.2 |
| | F2 | 40 | 282 | 54.17 | 33.1 |
| | F3 | 0 | 285 | 57.0 | 34.2 |
| | F3 | 40 | 292 | 60.34 | 37.9 |

It can be concluded that, the iteration fault distance calculation method based on zero sequence impedance relay can effectively solve the problem that fault impedance reflecting true fault distance cannot be correctly calculated during a line-ground fault with transition resistance. Even though the calculated fault distance is not accurate during a line-ground fault with high transition resistivity, the calculated fault distances of the protections further from the faults are always greater than those closer to the faults, which ensures the coordination of all the distance protections.
Using the calculated fault distance, the operation time limit of distance protection section II&III can be calculated, as is shown in table 4:

Table 4. The Section II&III Operation Time Limit Of Line 1~Line3 During Phase A Line-Ground Fault On Line 3.

| Working mode | Fault location | RN/Ω | Calculated operation time limit/s |
|--------------|----------------|------|-----------------------------------|
|              |                |      | L1(146km) | L2(26km) | L3(6km) |
|              |                |      | II | III | II | III | II | III |
| Sending end  | F1              | 0    | 2.5 | 6.31 | 1.06 | 2.84 | 0.14 | 1.84 |
| Light load   | F1              | 40   | 2.5 | 6.85 | 1.14 | 3.12 | 0.72 | 2.63 |
|              | F2              | 0    | 2.5 | 6.23 | 1.20 | 2.9  | 0.25 | 1.95 |
|              | F2              | 40   | 2.5 | 7.01 | 1.41 | 3.05 | 0.81 | 2.70 |
|              | F3              | 0    | 2.5 | 6.45 | 1.30 | 2.98 | 0.6  | 2.3  |
|              | F3              | 40   | /   | 7.11 | /    | 3.54 | /    | 2.91 |
| Receiving end| F1              | 0    | 2.5 | 6.77 | 1.09 | 3.08 | 0.58 | 2.49 |
| Heavy load   | F1              | 40   | /   | 7.23 | /    | 3.61 | /    | 3.28 |
|              | F2              | 0    | 2.5 | 6.89 | 1.4  | 3.0  | 0.98 | 2.38 |
|              | F2              | 40   | /   | 7.32 | /    | 3.77 | /    | 3.36 |
|              | F3              | 0    | /   | 7.50 | /    | 3.84 | /    | 3.47 |
|              | F3              | 40   | /   | 7.62 | /    | 4.03 | /    | 3.53 |

As is shown in table 4, under different working mode, when metallic single-phase line-ground fault occurs on different locations on line 3, the distance protection section II&III on line 1~3 can always work in coordination. As the value of the transition resistivity rises, the calculated operation time limits of the three protection get longer. However, the three protection can always operate in coordination regardless of the operation mode, the transition resistivity and fault location.

5. Conclusions
In this paper, an online setting method for distance protection section II&III is proposed. The operation impedance is still set off-line, but the operation time is set online according to the calculated fault impedance. The relevant distance protections can work in coordination as long as the calculated impedance of the upper level line protection is greater than that of the lower level ones.

The online setting method only needs to use the local current and voltage to calculate the fault impedance, and calculates the operation time limit of the distance protection section II&III online according to the time limit calculation formula. The online setting method requires no time operation settings thus relieves a lot of distance protection workload, and the operation time can coordinate automatically.

Based on the theoretical analysis and simulation verifications, the online setting distance protections can work in coordination under different fault conditions.

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