A Novel Line Circuit Breaker Failure Protection Scheme Based on Substation Area Information

NENG JIN, JIAWEI XING, LE CHEN, YINGFA HE, JINGGUANG HUANG
and XIANGNING LIN

ABSTRACT

The circuit breaker failure protection with compound voltage blocking has the problem of refusing to trip due to the insufficient sensitivity when a fault happens at the end of the long line. To solve this problem, this paper first analyzes the situation that traditional circuit breaker failure protection refuse to act, then the new line circuit breaker failure protection based on substation area information is put forward: calculating local protection criterion to get acting signal at substation area layer, redundant current information is used to judge whether there is current flow, and the voltage information of enclosure device is used to supplement the compound voltage blocking method of circuit breaker failure protection. Simulation results show that the new scheme of the circuit breaker failure protection based on substation area information sharing has higher reliability.

KEYWORDS
Circuit breaker failure protection, compound voltage blocking, redundancy current, substation area information sharing, enclosure device.

INTRODUCTION

Circuit breaker failure protection is the nearby back-up protection when the circuit breaker doesn’t trip off after receiving the tripping command by the protection or control system. The starting circuit of the circuit breaker failure protection consists of the voltage blocking element, the protection action element and the current discrimination element [1]. With the contact between substation and the system is more and more strong, the bus voltage does not decline a lot when metallic short-circuit fault occurs at the end of the long line, voltage blocking element may block all the time due to the low sensitivity of the setting value, eventually leading to the failure of breaker failure protection, which occurs occasionally in the important substation and results in serious power grid accidents [2].

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At present, there is still no effective and thorough solution to the above problems. For example, [3] proposes a novel circuit breaker failure protection based on current information, but the scheme only relies on the single electrical quantity, which is of low reliability. However, with the development of smart substation, the acquisition of electrical quantities in substation becomes easier [4]. Therefore, in this paper, the protection tripping signal is replaced by the judgment signal of protection criterion, doubling configuration current transformer is used to judge whether there is current flow, based on Kirchhoff's current law, check the current flow with bus redundancy current, and the voltage information of reclosure device is used to supplement the compound voltage blocking method of circuit breaker failure protection. Theoretical analysis and simulation results show that the proposed scheme can effectively protect the whole line and has high reliability.

A NOVEL LINE CIRCUIT BREAKER FAILURE PROTECTION SCHEME BASED ON SUBSTATION AREA INFORMATION

Analysis of the Failure of the Traditional Circuit Breaker Failure Protection.

Figure 1 shows the diagram of regional power grid, when a fault occurs at the end of long line F1, breaker B2 and B4 are tripped by the differential protection, if the circuit breaker B2 fails to trip, then the circuit breaker failure protection of B2 starts, however, Bus1 voltage does not change a lot, which is higher than the setting value of voltage blocking element, therefore the breaker failure protection is blocked. Then it will take a long time for the zero sequence III or IV protection to isolate the fault,
which has a greater impact on the safety of equipment and transformer may be easily burned down.

**Basic Principle.**

Fig. 2 shows the diagram of substation area information sharing, where current transformer has doubling configuration and voltage information of reclosure device is transferred to substation area layer via Ethernet network. The basic principle is as follows.

1. The judgment signal of protection criterion
   
   Based on the acquired local information, the local protection criterion is recalculated at the substation area layer, and the protection operation signal is generated. It is possible to avoid the abnormal protection operation signal caused by the false touch or malfunction of the hardware device by using software calculation.

2. Redundant current information to judge current flow
   
   At $\Delta t$ delay after the operation of local protection criterion, current flow is judged. The setting of $\Delta t$ should take the action time of break in to consideration. In theory, if the circuit breaker is tripped off, the current flow is 0, and if the circuit breaker is not tripped off, the current value is larger than 0. Detecting whether the circuit breaker is broken or not by setting a reasonable current flow threshold. In order to enhance the detection accuracy of circuit breaker state, current information from two transformers near the breaker and the bus redundancy current is used to check each other. As shown in Fig. 2, taking the current transformer TA2 as an example, there is a total of three redundant current information: $I_2$, $I'_2$ and bus redundant current ($I_1-I_3-I_4$). (1) Represents the relative error.
   
   Comparing the value of $e$ and $e'$, and choosing the transformer current related to the smaller one to check the current flow.

   
   $e = I_2 - (I_1 - I_3 - I_4)$
   
   $e' = I'_2 - (I_1 - I_3 - I_4)$

3. The voltage blocking information
   
   Enclosure device is installed at one phase of the line, based on the substation area information sharing, the voltage information of enclosure device can be used.
   
   When a fault occurs at the end of the line and the circuit breaker is not tripped off, as analyzed before, and the compound voltage blocking element may block the breaker failure protection falsely. At this time, the voltage from enclosure device is big, it can be judged that the circuit breaker is not tripped; when a fault occurs at the exit of circuit breaker and the circuit breaker is not tripped off, the bus voltage decreases a lot and the compound voltage blocking element open the breaker failure protection, while the voltage from enclosure device is nearly 0, it can be judged that the circuit breaker is tripped off and block the breaker failure protection falsely. If the breaker is tripped off successfully after fault, the bus voltage return to normal, then both the blocking methods based on compound voltage and voltage from enclosure device judge that the right breaker state. Therefore, the two blocking methods should use "and" logic, namely the breaker failure protection is blocked when both two methods judge that the breaker is tripped off.
As shown in Fig. 2, F1 and F2 represent the critical fault points of the blocking methods based on compound voltage and voltage from enclosure device respectively, it can be seen that the breaker failure protection can be blocked and opened reliably. For the phase without enclosure device, the method described in (1) and (2) still has high reliability. In summary, the logic diagram of circuit breaker failure protection is as shown in Fig. 3.

CASE STUDY

According to Fig. 1, a simulation model is established in PSCAD with 220kV voltage classes, the line parameters is as follows: r1=0.012Ω/km, x1=0.1045Ω/km, c1=0.01272uF/km, r0=0.0948Ω/km, x0=0.2894Ω/km, c0=0.009uF/km, L1=60km, L2=20km, L3=50km. the threshold value of current flow is set as 0.5A, the threshold value of blocking methods based on compound voltage and voltage from enclosure device is set as 50V and 20V respectively. Assuming single phase to ground fault occurs at different position (4km and 59km). The simulation results are as follows.

(1) The judgment signal of protection criterion

Table 1 shows the differential current and braking current of differential protection at different fault position, it can be got from Table 1 that the differential current is bigger than braking current at different fault position, thus starting the breaker failure protection.

(2) Redundant current information to judge current flow
TABLE 3. VOLTAGE INFORMATION BEFORE AND AFTER THE BREAKER TRIPS.

<table>
<thead>
<tr>
<th>Fault Position</th>
<th>Breaker State</th>
<th>4km Bus Voltage/V</th>
<th>4km Enclosure Voltage /V</th>
<th>59km Bus Voltage/V</th>
<th>59km Enclosure Voltage /V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Close</td>
<td>17.1154</td>
<td>16.6368</td>
<td>Close</td>
<td>75.0536</td>
</tr>
<tr>
<td></td>
<td>Tripped Off</td>
<td>192.9190×10^3</td>
<td>0.0005</td>
<td>Tripped Off</td>
<td>191.6305×10^3</td>
</tr>
</tbody>
</table>

Table 2 shows the current information before and after the breaker is tripped off, choosing the transformer current whose relative error is smaller to check the current flow, and it can be got that the error 1 is smaller than error 2 before and after the breaker is tripped off at different fault position. The current flow is 13.1438A and 8.7682A respectively before the breaker is tripped off at fault position 4km and 59km, which are all bigger than the threshold, thus opening the breaker failure protection. The current flow is all 0.0002A after the breaker is tripped off, which is smaller than the threshold, thus blocking the breaker failure protection.

(3) The voltage blocking information

Table 3 shows the voltage blocking information before and after the breaker trips at different fault position, it can be got that the voltage blocking information of two methods are 17.1154V and 16.6368V at fault position 4km, which are both smaller than the threshold, thus opening the breaker failure protection. At fault position 59km, the voltage blocking information are 75.0536V and 74.9214V, which are both bigger than the threshold, the breaker failure protection can be opened too. It is easy to get from Table 6 that the breaker failure protection can be blocked reliably if the breaker is tripped off at different fault position.

SUMMARY

A novel line circuit breaker failure protection scheme based on substation area information is proposed in this paper. The theoretical analysis and simulation results show that the proposed scheme can effectively avoid the abnormal protection operation signal caused by the false touch or malfunction of the hardware device, the current flow detection precision is improved greatly by using the current information from doubling configuration transformers near the breaker and the bus redundancy current. In addition, voltage information from the enclosure device is used to supplement the compound voltage blocking method, and the dead zone of the breaker failure protection is eliminated greatly. The proposed scheme has high reliably and good practical prospect.

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