A New Principle of Breaker Failure Protection Based on Station Information Sharing

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Abstract. In the case of terminal fault of long line, the failure protection of traditional circuit breaker has the problem of refusing to operate due to the insufficient sensitivity of voltage locking elements. A new circuit breaker failure protection scheme based on station area information sharing is proposed in this paper. The new scheme will replace the protection export signal with the actual protection criterion. In addition, it sets up two current transformers to detect whether the breaker is cut off after the circuit breaker is cut off, and checks the redundant current of the bus, which can improve the accuracy of the current detection. Besides, it uses reclosing checkout voltage device signal to supplement the original compound blocking signal. Theoretical analysis and simulation results show that the scheme can effectively cover the full length of the transmission line and has high reliability.

1. Introduction
Circuit breaker failure protection, as a backup protection after protection action, it cannot remove faults due to various reasons\cite{1-4}. At present, line breaker failure protection consists of voltage blocking elements, starting circuit composed of protection action and current discrimination, time element and trip outlet circuit. In order to avoid the protection outlet contacts being jammed and not returned, and to start the failure protection by mis-touching or mis-energizing the terminals, the voltage element is usually used as the locking element in the action logic of the failure protection\cite{5-8}. However, with the growing strength of the power system, more and more substations are connected with the system. When the metal short circuit fault occurs at the end of the long line of the substation, the bus voltage is also difficult to decrease, which will lead to the failure protection being refused to operate due to the inadequate sensitivity of the compound voltage blocking element.
At present, there is no effective and thorough solution to the problem of insufficient sensitivity of compound voltage blocking for circuit breaker failure protection\cite{9-10}. Therefore, exploring a new and reliable criterion of circuit breaker failure protection, getting rid of the dependence of using single electrical quantity of voltage or current as blocking element, and thoroughly resolving the risk of rejection of current failure protection due to sensitivity of blocking element, will be important for protecting electrical equipment and maintaining stable operation of the system.
With the development of smart substation, station protection is becoming more and more mature, and the acquisition of various electrical quantities in the station becomes easier\cite{11-15}. On this basis, a new circuit breaker failure protection scheme based on station and information sharing is proposed in this paper. The new scheme will replace the protective export signal in the criterion with the actual...
protection criterion. In addition, two current transformers are set up to detect whether the breaker is cut off, and the redundant current of the bus is used to check. It uses reclosing checkout voltage device signal to supplement the original compound blocking signal.

2. Analysis of failure scenario of breaker failure protection
The malfunction of the breaker failure protection will have serious consequences. To prevent it from malfunctioning, the voltage component should be used as the blocking component in the action logic of the failure protection. Compound voltage blocking component ports consisting of phase low voltage, zero-sequence voltage and negative-sequence voltage or logic are generally used. This method is proved to be simple and reliable by practice and can effectively prevent maloperation of failure protection. However, with the increasingly strong power system, more and more substations are strongly connected with the system. When a metal short circuit fault occurs at the end of the long line of the station, the bus voltage is also difficult to drop, which will cause the failure protection to refuse to operate because of the inadequate sensitivity of the voltage locking elements. The substation with this problem is usually a hub substation or an important substation. Once the protection fails, it will lead to serious power grid accidents.

![Diagram of substation](image)

**Figure 1.** The diagram of substation

Case: As shown in Fig 1, when a fault occurs at point F1 at the end of a long outlet line in a substation, the pilot protection removes the circuit breakers B2 and B4. If the circuit breaker B2 fails, the circuit breaker B2 failure protection is started. The current circuit breaker failure protection needs to be blocked by Bus-1 compound voltage value. When the terminal of the long line fails, the Bus-1 voltage changes little, so the failure protection cannot be opened. At this time, it needs to wait for the upper level zero-sequence current III or IV protection to be removed. The removal time is longer, which has a greater impact on equipment safety. In order to solve the problem of insufficient sensitivity of compound voltage blocking, the current countermeasures are mainly carried out from two aspects: A and B.

A. Reduce the setting value of compound voltage blocking elements
According to the regulation, the setting value of the compound voltage locking element should synthetically ensure that there is enough sensitivity when any terminal of the line connected by the busbar fails. The negative sequence voltage and the zero sequence voltage should reliably avoid the unbalanced voltage under normal conditions, so the space of reducing the voltage setting value is limited and the problem cannot be solved completely. In addition, the low value setting will reduce the reliability of failure protection and cause the possibility of misoperation.

B. Increase the function of reopening and locking
For lines with insufficient voltage sensitivity, voltage locking can be relieved by adding protective action contacts. The essence of this method is to cancel the voltage lock in a short time, which can effectively guarantee the failure protection to be open. However, this method cannot solve the problem of non-six-unit failure protection, for which the additional secondary circuit will also leave operating hidden trouble with the change of system structure.

Therefore, this paper will explore a new and reliable circuit breaker failure protection blocking principle, get rid of the dependence of the single electrical quantity using voltage as a blocking component, and completely solve the current failure protection risk due to the sensitivity problem of the blocking component.
3. New scheme for breaker failure protection

With the development of smart substation, the station area protection is becoming more and more mature, and the acquisition of electrical quantities in the substation becomes easier. Fig 2. shows the schematic diagram of station-area information sharing in 220 kV substation. The transformer is configured in a dual way, and the checkout voltage signal of reclosing check is uploaded to the station control layer via intra-station Ethernet.

This scheme considers replacing the protection exit signal in the failure protection starting criterion with the actual protection criterion judgment signal. Two current transformers are set up to detect the current or no-current of the circuit breaker. At the same time, based on the Kirchhoff current law, the bus redundant current is used for verification, which can improve the accuracy of the current and no-current detection. The checkout voltage of reclosing non-voltage device is used to supplement the original double-voltage locking signal, which greatly improves the reliability of failure protection. Fig 3. shows the logic of the new scheme for breaker failure protection, which consists of three parts: A~C.

A. Protection criteria judgment section

In the station control layer, the local protection criterion is completely copied, and the same protection principle, protection logic and setting value are adopted. Based on the collected local information, the local protection criterion is calculated to generate the action signal of the local protection outlet. The scheme of local protection outlet calculated by software can effectively avoid the collision of hardware devices and abnormal signal of protection outlet caused by misoperation.

B. Redundant detection section with current

The scheme adopts the local protection criterion and delays $\Delta t$ after startup, and then carries out detection whether the breaker is cut off. The setting of $\Delta t$ should consider both the calculation time of the local protection criterion and the breaking time of the circuit breaker. In theory, if the circuit breaker is cut off, the current is 0. If the circuit breaker is not cut off, the current is a value greater than 0. By setting reasonable current threshold to detect whether the circuit breaker is cut off. In order to

Figure 2. The diagram of substation area information sharing

Figure 3. The logic of new scheme
enhance the accuracy and reliability of the detection, two current transformers are arranged around each circuit breaker for current/no current detection, and the redundant current of busbar is used for checking. As shown in Figure 4, there are three redundant current information: I2, I2' and bus redundancy current (I1 - I3 - I4) for the current transformer TA2. Setting check error e is:

\[ e = I_2 - (I_1 - I_3 - I_4) \]
\[ e' = I_2' - (I_1 - I_3 - I_4) \]

The current corresponding to the smaller value in the formula 1 is the result of the judgement of whether there is a current or not. If the protection criterion detects a current when it lasts for \( \Delta t \) after the protection criterion starts, it is judged that the circuit breaker is not cut off, and then opens failure protection; if there is no current, it is judged that the circuit breaker is cut off, and then blocks failure protection.

C. checkout voltage signal section of Reclosing

When the line reclosing is to be performed, it is first necessary to detect whether the line voltage is 0. Generally, a voltage transformer is installed on the single phase to detect whether there is voltage. Based on information sharing in station area, the checkout voltage detection signal can be reliably utilized to complement the bus voltage locking logic without additional economic cost.

As shown in Figure 2, assume that fault location F1 is the critical fault point for detecting checkout voltage signal and F2 is the critical point for the busbar recompression lockout. Adopting "and" blocking logic, the new scheme can reliably block and open circuit breaker failure protection after failure. When the phase failures occur without checkout voltage devices, the voltage locking criterion is not added, and the scheme of detecting redundant current is still reliable. Voltage blocking can be used for the phase with checkout voltage device, which can further enhance the reliability of failure protection without additional economic cost.

4. Simulation studies

In PSCAD / EMTDC, the 220kV system model as shown in Fig 4. is built. The length of each line are L1=60km, L2=20km, L3=50km. The positive sequence parameters of the circuit are \( r = 0.012 \Omega/km \), \( x = 0.1045 \Omega/km \), \( c = 0.01272 uF/km \). The zero sequence parameters of the circuit are \( r_0 = 0.0948 \Omega/km \), \( x_0 = 0.2894 \Omega/km \), \( c_0 = 0.009 uF/km \). The threshold of current or no current is set to 0.5 A. Bus voltage closed phase locked voltage threshold is set to 50 V. No-voltage threshold is set to 20 V. The criterion of line differential protection action is: \(|I_2 + I_3| > 0.5 \times (|I_2| + |I_3|)\)

The single phase grounding fault is located at different locations of the line to verify the effectiveness of the proposed scheme.
CASE 1. The fault location is at the outlet of the circuit breaker (4 km).

The fault time is 0.125 s, and the fault is removed at 0.25 s time. Simulation shows that the current and voltage waveforms are shown in Fig 5 and 6.

The simulation results show that the differential current is 19.59 A, greater than the braking current 9.89 A, and so the circuit breaker failure protection starts. Table 1 shows the current and voltage signals before and after the circuit breaker is cut off.

Table 1. The current and voltage signals before and after the circuit breaker disconnected in case 1

|                | circuit breaker state |
|----------------|-----------------------|
|                | not disconnected      | disconnected         |
| Current/A      |                       |                       |
| Busbar redundancy | 13.1455               | 0.0004               |
| Line redundancy 1 | 13.1438               | 0.0002               |
| Line redundancy 2 | 13.1826               | 0.5382               |
| Error 1        | 0.0019                | 0.0006               |
| Error 2        | 0.4561                | 0.5382               |
| Voltage/V      |                       |                       |
| Bus phase low voltage | 17.1154               | 192919               |
| Check no-voltage device | 16.6368               | 0.0005               |

Table 1 shows that the error 1 of circuit breaker before and after interruption is small, then the line redundant current 1 is selected to judge whether the breaker is cut off. When the circuit breaker is not cut off, the redundant current 1 is 13.1438 A, which is larger than the threshold value. The phase low voltage of bus compound voltage blocking is 17.1154 V, and the voltage of checkout voltage device is 16.6386 V. Therefore, it opens circuit breaker failure protection. Redundant current of circuit breaker after disconnection is 0.0002 A, phase low voltage of line compound voltage blocking is 192919 V, and voltage of checkout voltage device is 0.0005 V. Therefore, the failure protection is blocked.
CASE2. The fault location is at the middle of line L1(30km).

![Figure 7. Current waveform in case 2](image)

Table 2 shows that the error 1 of circuit breaker before and after disconnection is small, then the line redundant current 1 is selected to judge whether the breaker is cut off. When the circuit breaker is not cut off, the redundant current 1 is 11.0793 A, which is larger than the threshold value. The phase low voltage of bus compound voltage blocking is 45.7035 V, and the voltage of checkout voltage device is 45.4133 V. Therefore, it opens circuit breaker failure protection. Redundant current of circuit breaker after disconnection is 0.0002 A, phase low voltage of line compound voltage blocking is...
199085.4 V, and voltage of checkout voltage device is 0.003 V. Therefore, the failure protection is blocked.

**CASE3. The fault location is at the end of line L1(59km).**

![Figure 9. Current waveform in case 3](image1)

![Figure 10. Voltage waveform in case 3](image2)

The fault location is located in the end 59 km of line L1. Simulation shows that the current and voltage waveforms are shown in Fig 9 and 10. It show that the differential current is 15.23A, greater than the braking current 7.71A, and so the circuit breaker failure protection starts. Table 3 shows the current and voltage signals before and after the circuit breaker disconnected.

**Table 3.** The current and voltage signals before and after the circuit breaker disconnected in case 3

|                      | circuit breaker state | not disconnected | disconnected |
|----------------------|-----------------------|------------------|--------------|
| **Current/A**        |                       |                  |              |
| Busbar redundancy    | 8.7677                | 0.0004           |              |
| Line redundancy 1    | 8.7682                | 0.0002           |              |
| Line redundancy 2    | 8.8318                | 0.5382           |              |
| Error 1              | 0.0012                | 0.0006           |              |
| Error 2              | 0.5008                | 0.5382           |              |
| **Voltage/V**        |                       |                  |              |
| Bus phase low voltage| 75.0536               | 199630.5         |              |
| Check no-voltage device | 74.9214              | 0.0068           |              |

Table 3 shows that the error 1 of circuit breaker before and after interruption is small, then the line redundant current 1 is selected to judge whether there is current or no current. When the circuit breaker is not disconnected, the redundant current 1 is 8.7682 A, which is larger than the threshold value. The phase low voltage of bus compound voltage blocking is 75.0536 V, and the voltage of
checkout voltage device is 74.9214 V. Therefore, it opens circuit breaker failure protection. Redundant current of circuit breaker after disconnection is 0.0002 A, phase low voltage of line compound voltage blocking is 191630.5 V, and voltage of checkout voltage device is 0.0068 V. Therefore, the failure protection is blocked.

5. Conclusion
A new circuit breaker failure protection scheme based on station area information sharing is proposed in this paper. High-precision current/no-current detection is realized by using sampling information of dual-configuration current transformer and current information of back bus. At the same time, for the phase equipped with checkout voltage device, the checkout voltage signal is used to supplement the original compound voltage blocking signal. The theoretical analysis and simulation results show that the scheme can effectively cover the whole length of the line and has high reliability. The new scheme makes full use of the advantages of information sharing in the station domain and has a high practical prospect.

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