A CT break identifying method based on fault characteristics in current differential protection

Yu Yue, Liu Huanzhang, Wang Xingguo, Zhan Rongrong
State Key Laboratory of Power Grid Safety and Energy Conservation, Relay Protection Research Department, China Electric Power Research Institute, Beijing 100192, China

Abstract. CT second circuit break will cause the malfunction of current differential protection, so the current differential protection need to be blocked after CT break. Therefore, it is very important to identify the CT break correctly for the performance of current differential protection. This paper proposed a CT break identifying method based on fault characteristics, including two parts, the multi-CT current starting element and the CT break identifying element. Assuming the protection is started by a CT break, if there is any fault characteristic, jump out of the CT break identifying element immediately and determine as a fault. The method can distinguish high resistant grounding fault and CT break accurately, and identify CT break correctly in 20ms. That improves the accuracy and rapidity of CT break identification, furthermore improves the performance of current differential protection.

1. Introduction
CT second circuit break will cause malfunction of current differential protection, and the long-term operation after that will give a great risk to the safety of equipments. Therefore, in order to prevent the sudden loss of load without fault, the current differential protection need to be blocked after CT break, and give an alarm of CT break to remind the maintainer as soon as possible. Therefore, it is very important to identify the CT break correctly for the device security and the performance of current differential protection[1-2].

At present, current differential protection for distinguishing CT break is mainly divided into two categories, the first category is using zero sequence current to determine CT break, another is using differential current to determine the CT break. Both of their essence are to find out whether there are characteristics of CT break. These characteristics are influenced by the operating state of the system before CT break, and it also needs to be confirmed by long time delay in order to prevent miscarriage of distinguishing. As above, the identification of CT break has the following problems. First, the CT break criterion may not work after all CT break. Second, CT break identifying delay is too long, usually 8~12s. Third, the high resistance grounding fault would be easily mistaken for slight CT break and blocked the protection incorrectly. Therefore, it is necessary to carry out the research of CT break identifying method, and improve the sensitivity and reliability of CT break identification[3-5].

To solve the above problems, this paper proposes a new CT break identifying method in differential protection based on fault characteristics, which can effectively improve the sensitivity and reliability of CT break identification.

2. CT Break Identifying Method Based on Fault Characteristics
The research on the CT break identifying method should first confirm the research boundary, namely the general principle. CT second circuit break is a small probability event. In the course of the study, several small probability events happening at the same time are not considered. Such as, CT and PT break at the same time, two or three phases of CT break at the same time, more than one CT break at the same time, and CT break and fault happening at the same time. In this paper, the CT break identifying process, the starting criterion and the CT break criterion of the differential protection are studied and optimized under this principle.

To optimizing the low sensitivity of CT break identifying criterion, we set a high sensitivity CT break identifying criterion when the startup relay do not start. We use a multi-CT starting element combined with a differential protection starting element (not given in detail in this paper). After starting, before going into the fault processing program, we identify if it is started by fault or not. If any fault characteristics are found, the program will jump out of the CT break identifying element and going into the fault processing program. If no fault characteristic is found, we can determine it as a CT break. According to the value of the differential current and phase current, CT break can be divided into two levels, respectively, serious CT break and slight CT break. The differential protection should be blocked after serious CT break. Whereas the set value of differential protection should be raised after slight CT break.

The identifying process of the main program in differential protection is shown in Fig. 1.

![Figure 1](image-url)

Figure 1. The identifying process of the main program in differential protection

The CT break identification in differential protection based on the fault characteristics includes two parts, the multi-CT current starting element and the CT break identifying element.
3. Multi-CT Current Starting element

Current differential protection is generally composed of a number of CT current. If two or more current is variable, it can be determined as a fault, accessing to the fault processing program directly. Therefore, we proposed a multi-CT current starting element, which will act if no less than two CT current is variable.

3.1 Multi-CT current starting element

Choose the largest absolute value of the current variable quantity of the branch in differential protection as the $L_{\text{MAX}}$. By defining $L_{\text{MAX}}$ one side and $L_{\text{MIN}}$ another side every sample point, the multi-sides differential protection can be converted to two-sides differential protection.

Define $i_x^\prime(t)$ the sample value differential current, and $i_M(t)$ the sample value current of the side with maximum variable quantity. And,

$$i_{x-M}(t) = i_x^\prime(t) - i_M(t) \quad (1)$$

(1) Multi-CT current variable quantity starting criterion

Criterion for multi-CT current variable quantity starting element is following.

$$\Delta f(t) = |f(t) - f(t-T/4)| > f_{\text{set}} \quad (2)$$

Where, $\Delta f(t)$ is the action value of criterion (2), $f_{\text{set}}$ is the setting value of criterion (2), and $f(t-T/4)$ is $f(t)$ 1/4 cycle before.

$$f(t) = \left[ \Delta i_{\Sigma-x-M}(t) - \Delta i_{\Sigma-x-M}(t) \right]^2 + \left[ \Delta i_{\Sigma-x-M}(t) - \Delta i_{\Sigma-x-M}(t) \right]^2$$

Where, $\Delta i_{\Sigma-x-M}(t) = i_{\Sigma-x}(t) - i_{\Sigma-M}(t)$, $\Delta i_{\Sigma-x-M}(t) = i_{\Sigma-x}(t) - i_{\Sigma-M}(t)$, $\Delta i_{\Sigma-x-M}(t) = i_{\Sigma-x}(t) - i_{\Sigma-M}(t)$.

$$f_{\text{set}} = (0.25 I_{\text{set}})^2 + 0.5 \Delta f_{\text{max}} \quad (4)$$

Where, $I_{\text{set}}$ is the setting value of differential starting element, $\Delta f_{\text{max}}$ is the maximum value between 1/2 and one cycle before $\Delta f$.

(2) Multi-CT zero sequence current starting criterion

Criterion for multi-CT zero sequence current starting element is following.

$$\Delta f_0(t) = |f_0(t) - f_0(t-T/4)| > f_{0\text{set}} \quad (5)$$

Where, $\Delta f_0(t)$ is the action value of criterion (5), $f_{0\text{set}}$ is the setting value of criterion (2), and $f_0(t-T/4)$ is $f_0(t)$ 1/4 cycle before.

$$f_0(t) = \Delta i_{\Sigma-x-M}(t) + \Delta i_{\Sigma-x-M}(t) + \Delta i_{\Sigma-x-M}(t)$$

$$f_{0\text{set}} = (0.15 I_{\text{set}}) + 0.3 |f_0|_{\text{max}} \quad (7)$$

Where, $|f_0|_{\text{max}}$ is the maximum value between 1/2 and one cycle before $f_0(t)$.

3.2 Simulation and verification

(1) Internal fault

The multi-CT current starting element action curves after a internal B-phase grounding fault are shown in Fig. 2. The solid line in Fig. 2(a) shows the setting value in criterion (2), and the point line...
shows the action curve in criterion (2). The solid line in Fig. 2(b) shows the setting value in criterion (5), and the point line shows the action curve in criterion (5).

![Graph](image)

(a) Criterion (2)  
(b) Criterion (5)

Figure 2. The multi-CT current starting element action curves (internal fault)

(2) External fault
The multi-CT current starting element action curves after a external B-phase grounding fault are shown in Fig. 3. The solid line in Fig. 3(a) shows the setting value in criterion (2), and the point line shows the action curve in criterion (2). The solid line in Fig. 3(b) shows the setting value in criterion (5), and the point line shows the action curve in criterion (5).

![Graph](image)

(a) Criterion (2)  
(b) Criterion (5)

Figure 3. The multi-CT current starting element action curves (external fault)

(3) CT break
The multi-CT current starting element action curves after B-phase CT break are shown in Fig. 4. The solid line in Fig. 4(a) shows the setting value in criterion (2), and the point line shows the action curve in criterion (2). The solid line in Fig. 4(b) shows the setting value in criterion (5), and the point line shows the action curve in criterion (5).
Criterion (2)

Criterion (5)

Figure 4. The multi-CT current starting element action curves (CT break)

According to the simulation results, it is known that when the fault occurs internal or external, the multi-CT current starting element act. Whereas, when the CT break occurs, the multi-CT current starting element do not act.

3.3 The analysis of action result

If both of the differential protection starting element and the multi-CT current starting element act, it means the protection was started by a fault. So the main program goes into fault processing program directly.

If both of the differential protection starting element and the multi-CT current starting element do not act, we need to calculate the unbalanced differential current. If the unbalanced differential current >0.15Ir, it means there is a slight CT break, and the setting value should be raised to avoid maloperation. If the unbalanced differential current <0.15Ir, return to the entry of the main program. Where, Ir is rated current.

If the differential protection starting element act, but the multi-CT current starting element does not act, the program will go into the CT break identifying element, determine whether there are any fault characteristic.

4. The CT Break Identifying Element

After entering the CT break identifying element, if any fault characteristic is found, the main program will go out of the CT break identification and go into the fault processing program directly. If fault characteristic is found after a cycle, it means there is a CT break.

(1) Calculate the integration of the absolute value of the variable quantity of the three phases current

Taking 24 sample points in each cycle as an example, the differential protection starting element act at t0, and the calculating starts at three sample points before, namely t-3. The shortest integral time is from t-3 to t3 (7 points), and the longest integral time is from t-3 to t24 (28 points), as shown in Fig. 2.
Calculate the integration of the absolute value of the variable quantity of the three phase current.

\[ \sum |\Delta i(t)| = \sum |i(t) - i(t-T)| \quad \text{(8)} \]

Where, \( i(t) \) is the sample value of one phase of one side, \( i(t-T) \) is the sample value a cycle before \( i(t) \). Select the phase with maximum integration of the absolute value of the current variable quantity, and define it as the maximum phase.

(2) Calculate the integration of the variable quantity of the absolute value of the maximum phase current

\[ \sum \Delta |i(t)| = \sum [|i(t)| - |i(t-T)|] \quad \text{(9)} \]

If the integration of the current variable quantity of the absolute value of the maximum phase current \( \sum \Delta |i(t)| > 0 \), it means the phase current raises and there is a fault in the system. So, the main program jumps out of the CT break identifying element, and goes into the fault processing program, and no longer identifying the CT break.

(3) Calculate the absolute value of the variable quantity of the effective value of the maximum phase voltage

\[ |\Delta U(t)| = |U(t) - U(t-T)| \quad \text{(10)} \]

Where, \( U(t) \) is the effective value of the maximum phase voltage, \( U(t-T) \) is the effective value a cycle before \( U(t) \). If the absolute value of the variable quantity of the effective value of the maximum phase voltage \( |\Delta U(t)| > 6V \), it means the voltage is change while the current change and there is a fault in the system. So, the main program jumps out of the CT break identifying element, and goes into the fault processing program, and no longer identifying the CT break.

(4) If \( \sum \Delta |i(t)| \leq 0 \) and \( |\Delta U(t)| \leq 6V \), there is no fault characteristic. If fault characteristic is found after a cycle, we can determined there is a CT break.

If the effective value of maximum phase current <0.1Ir, there is a serious CT break and the differential protection should be blocked to avoid maloperation. If the effective value of maximum phase current >0.1Ir, there is a slight CT break and the setting value of differential protection should be raised.

This CT break identifying criterion had been tested in RTDS, and the performance is very good. Due to the limitation on space, the specific results of simulation test are not mentioned in these paper. The simulation results show that the CT break identifying method based on fault characteristics can distinguish high resistant grounding fault and CT break accurately. It can go into fault processing program in 2.5ms after a serious fault occurring, and identify CT break correctly in 20ms after CT break occurring.

5. Conclusions
This paper proposed a CT break identifying method based on fault characteristics, including multi-CT current starting element and CT break identifying element these two parts. Assuming the protection is started by a CT break, if there is any fault characteristic, jump out of the CT break identifying element immediately and determine as a fault. The method can distinguish high resistant grounding fault and CT break accurately, and identify CT break correctly in 20ms. That improves the accuracy and rapidity of CT break identification, furthermore improves the performance of current differential protection.

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