Adaptability of protection principle of converter protection in different protection areas

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Abstract: This paper introduces a method to realize transformer differential protection. In a UHVDC transmission system, the converter transformer protection device adopts the dual configuration. Due to the lack of TA configuration, A set protection configuration of the converter protection device is complete, and B set protection configuration is incomplete. B set protection cannot achieve differential protection, zero sequence differential protection, winding differential protection and connection line differential protection. The two systems can not be completely duplex, which will affect the safe and stable operation of the converter and the daily operation and maintenance. In view of this phenomenon, this paper presents a new method to realize differential protection of converter transformer. The application of this method can solve B set problem of incomplete protection configuration. This method can be used for reference in field application.

1. Introduction
In UHV HVDC transmission system, converter transformer is one of the most important equipment. It is the core equipment of the converter and inverter in AC and DC transmission system. It realizes the electrical insulation and isolation of the AC and DC parts. At the same time, it provides the commutation voltage with the phase difference of 30 degrees for the commutation valve[1-2]. The converter transformer group is usually connected in parallel by a Y/Δ converter transformer and a Y/Y converter transformer[3-4]. The principle and configuration of the converter protection are related to the safe and stable operation of the converter. The dual configuration of protection is the mainstream at present, the two systems can not be completely duplex, which will affect the safe and stable operation of the converter and the daily operation and maintenance[5-6].

In order to meet the actual demand of the north and South Power Grid DC project, we sum up many engineering experiences of Lingbao project, Guiyang II, Yun Guang and Nuo Zhi Du, etc. The CT configuration is insufficient due to the restriction of the structure of the converter, which can not meet the dual configuration requirements. If we can improve the protection principle and configuration, it will greatly improve the safe and reliable operation level of the converter transformer protection device, and it will bring convenience to the daily operation and maintenance of the converter transformer[7-8].

This paper will start from studying the protection principle and protection configuration of converter transformer protection in different regions[9-10], analyze deeply the protection principle of converter transformer, and seek the solution to improve the protection configuration.

2. Description of the situation
Take a converter transformer used in a 800kV DC transmission system as an example, the schematic diagram of the TA distribution of the converter transformer body structure is shown in figure 1: there...
are 4 bushings, AC network side bushing 1.1 and 1.2, valve side bushing 2.1 and 2.2. The distribution of current transformer corresponds to the casing in the converter rheology structure (for the convenience of narration, it is referred to as the casing TA).

![Fig.1 TA distribution diagram of converter transformer](image1)

The schematic diagram of the TA configuration of the structure of the single converter transformer is shown in Figure 2.

![Fig.2 Protection TA configuration diagram for single-phase converter transformer](image2)

Due to the structure problem of the converter transformer, the configuration of Switch TA, the neutral point zero sequence TA of the network side and the valve side TA in Y/Δ converter transformer and Y/Y converter transformer are redundant. The first and end TA of the network side in Y/Δ converter transformer and Y/Y converter transformer are all only one. The dual configuration of the converter transformer protection is shown in Table 1.

| No | Protection                                                        | A set | B set |
|----|------------------------------------------------------------------|-------|-------|
| 1  | converter transformer and connection line differential protection | √     | √     |
| 2  | zero sequence differential protection of converter transformer and connection line | √     | √     |
| 3  | Connection line differential protection                          | √     | —     |
4 Differential protection of Y/Y converter transformer √ —
5 Differential protection of Y/Δ converter transformer √ —
6 Zero sequence differential protection of Y/Y converter transformer √ —
7 Zero sequence differential protection of Y/Δ converter transformer √ —
8 the network side winding differential of Y/Y converter transformer √ —
9 the network side winding differential of Y/Δ converter transformer √ —
10 Back up protection √ —

It is known from table 1, B set can not achieve connection line differential protection, differential protection of converter transformer, zero sequence differential protection of converter transformer and the network side winding differential of converter transformer. When the protection system 1 is broken down or overhauled, the protection system 2 needs to be run separately due to the exit of the protection system 1. At this time, the main protection of the protection system 2 is only converter transformer and connection line differential protection, zero sequence differential protection of converter transformer and connection line. The test results show that protection system 2 has a refusal to act in the following situations:

1) grounding fault of valve side winding;
2) when occurred fault with 300 ohm transition resistance on the network side.

3. Scheme improvement

3.1 Original scheme

The differential current and brake current of A set Y/Y converter transformer are respectively:

\[ I_{dp} = |I_{y1} + I_{y2}| \]
\[ I_{res} = |I_{y1} - I_{y2}|/2 \]

In the formula: \( I_{y1} \) and \( I_{y2} \) is the current of A set Y/Y converter transformer in the network side and the valve side, respectively.

The differential current and brake current of A set Y/Δ converter transformer are respectively:

\[ I_{dp} = |I_{1\Delta} + I_{2\Delta}| \]
\[ I_{res} = |I_{1\Delta} - I_{2\Delta}|/2 \]

In the formula: \( I_{1\Delta} \) and \( I_{2\Delta} \) is the current of A set Y/Δ converter transformer in the network side and the valve side, respectively.

Differential protection of A set Y/Y converter transformer covers Y/Y converter transformer, differential protection of A set Y/Δ converter transformer covers Y/Δ converter transformer. B set protection system unconfigured Y/Y differential protection and Y/Δ differential protection.

3.2 New scheme

In the original scheme, the network side AT of the Y/Y converter transformer and Y/Δ converter transformer are sent to A set protect, but not to B set protect. If the network side AT of the Y/Y converter transformer is sent to A set protect, the network side AT of the Y/Δ converter transformer is sent to B set protect, we can achieve a new differential protection by using the following algorithm.

The differential current and brake current of A set Y/Y converter transformer are respectively:

\[ I_{dp} = |I_{y1} + I_{y2}| \]
\[ I_{\text{res}} = \frac{|I_{y1} - I_{y2}|}{2} \]

In the formula: \( \hat{I}_{y1} \), \( \hat{I}_{2y} \) is the current of A set Y/Y converter transformer in the network side and the valve side, respectively.

The differential current and brake current of A set Y/\( \Delta \) converter transformer are respectively:

\[
I_{\text{op}} = |i_1 - i_2 - y_{1y} + y_{2y}| \\
I_{\text{res}} = \frac{|i_t + i_2 - i_1 - y_{2y}|}{2}
\]

In the formula: \( \hat{I}_{1} \), \( \hat{I}_{2} \) is the switching current of 3/2 connection of AC field. \( \hat{I}_{1y} \) is the current of A set Y/Y converter transformer in the network side, \( \hat{I}_{2\Delta} \) is the current of A set Y/\( \Delta \) converter transformer in the valve side.

The differential current formula of A set Y/\( \Delta \) converter transformer in this scheme:

\[
I_{\text{op}} = |\hat{I}_{1} - \hat{I}_{2} - \hat{I}_{1y} + \hat{I}_{2\Delta}|
\]

The essence of this formula is based on the Kirchhoff’s law of current. After summing two switching currents, subtracting the network side head current of Y/Y converter transformer, the network side head current of Y/\( \Delta \) converter transformer is obtained. However, the condition of Kirchhoff’s current law is not satisfied when faults in the connection protection area occur. The new Y/\( \Delta \) differential protection range actually covers the connection and Y/\( \Delta \), as shown in the dotted box in Figure 3.

\[ \]

![Figure 3: New configuration scheme for A set converter transformer protection](image)

The differential current and brake current of B set Y/\( \Delta \) converter transformer are respectively:

\[
I_{\text{op}} = |\hat{I}_{1\Delta} + \hat{I}_{2\Delta}| \\
I_{\text{res}} = \frac{|\hat{I}_{1\Delta} - \hat{I}_{2\Delta}|}{2}
\]

In the formula: \( \hat{I}_{1\Delta} \), \( \hat{I}_{2\Delta} \) is the current of B set Y/\( \Delta \) converter transformer in the network side and the valve side, respectively.

The differential current and brake current of B set Y/Y converter transformer are respectively:

\[
I_{\text{op}} = |i_1 + i_2 - i_{1\Delta} + i_{2\Delta}| \\
I_{\text{res}} = \frac{|i_1 + i_2 - i_{1\Delta} - i_{2\Delta}|}{2}
\]
In the formula: $\dot{I}_1$, $\dot{I}_2$ is the switching current of 3/2 connection of AC field. $\dot{I}_{1\Delta}$ is the current of A set Y/Δ converter transformer in the network side, $\dot{I}_{2\gamma}$ is the current of A set Y/Y converter transformer in the valve side.

The new Y/Y differential protection range actually covers the connection and Y/ Y, as shown in the dotted box in Figure 4.

![Figure 4: New configuration scheme for B set converter transformer protection](image)

As shown in Figure 3 and Figure 4:

A set converter transformer protection: the Y/Y network side head current and end current access Y/Y converter transformer, and they don’t access Y/Δ converter transformer.

B set converter transformer protection: the Y/Δ network side head current and end current access Y/Δ converter transformer, and they don’t access Y/Y converter transformer.

The difference between specific protection TA configurations in different protection systems is shown in Table 2.

| No | TA configuration                  | A set | B set |
|----|----------------------------------|-------|-------|
| 1  | Switch current TA                | ✓     | ✓     |
| 2  | Y/Y network side head current TA | ✓     | -     |
| 3  | Y/Y network side end current TA  | ✓     | -     |
| 4  | Y/Δ network side head current TA | -     | ✓     |
| 5  | Y/Δ network side end current TA  | -     | ✓     |
| 6  | Y/Y valve side head current TA   | ✓     | ✓     |
| 7  | Y/Y valve side end current TA    | -     | -     |
| 8  | Y/Δ valve side head current TA   | ✓     | ✓     |
| 9  | Y/Δ valve side end current TA    | -     | -     |
| 10 | Y/Y network side neutral point TA| ✓     | ✓     |
| 11 | Y/Δ network side neutral point TA| ✓     | ✓     |

Protection configuration of A set and B set is shown in Table 3.
Table.3 protection configuration differences of A set and B set

| No | configuration                                                                 | A set | B set |
|----|-------------------------------------------------------------------------------|------|------|
| 1  | converter transformer and connection line differential protection              | √    | √    |
| 2  | zero sequence differential protection of converter transformer and connection line | √    | √    |
| 3  | Connection line differential protection                                        | —    | —    |
| 4  | Differential protection of Y/Y converter transformer                          | √    | —    |
| 5  | Differential protection of Y/△ converter transformer                          | —    | √    |
| 6  | zero sequence differential protection of Y/Y converter transformer            | √    | —    |
| 7  | zero sequence differential protection of Y/△ converter transformer            | —    | √    |
| 8  | connection line and Y/Y converter transformer differential protection (Fig 4)   | —    | √    |
| 9  | connection line and Y/△ converter transformer differential protection (Fig 3)   | √    | —    |
| 10 | connection line and Y/Y converter transformer zero sequence differential protection (Fig 4) | — | √ |
| 11 | connection line and Y/△ converter transformer zero sequence differential protection (Fig 3) | √ | — |
| 12 | the network side winding differential of Y/Y converter transformer           | √    | —    |
| 13 | the network side winding differential of Y/△ converter transformer            | —    | √    |

It can be seen from table 3: the improved A set is compared with the original full set of protection configurations, reduced Connection line differential protection, Y/△ converter transformer differential protection, Y/△ converter transformer zero sequence, the Y/△ network side winding differential, Increased connection line and Y/△ converter transformer differential protection, connection line and Y/△ converter transformer zero sequence differential protection.

The improved B set is compared with the original full set of protection configurations, reduced Connection line differential protection, Y/Y converter transformer differential protection, Y/Y converter transformer zero sequence, the Y/Y network side winding differential, Increased connection line and Y/Y converter transformer differential protection, connection line and Y/Y converter transformer zero sequence differential protection.

If the scheme is adopted, it is necessary to study whether the two additional protection can cover the original protection range and sensitivity of the four protection.

4. Simulation analysis
The scheme is verified by the RTDS test model of a ±800KV UHVDC transmission project shown in Figure 5.

![Fig.5 a ±800KV UHVDC Main diagram](image-url)
4.1 Failure point setting
The failure point is set as shown in Figure 6. In this test, the protection device is installed at the pole 1 high of the rectifier station. There are 5 voltages and 32 currents provided by RTDS to protection device, namely TV1, TV2, TV3, TA1, TA2, TA3, TA3', TA4, TA4', TA5, TA6, TA7, TA8.

![Fig.6 A schematic diagram of voltage and current measurement point and fault location](image)

4.2 Introduction of the test
RTDS test is carried out in the way of series protection devices realized by the original scheme and the improved scheme. The test project is shown in Table 4.

| No | Test Project                                    |
|----|-------------------------------------------------|
| 1  | Short circuit fault                             |
| 2  | Unload switching of converter transformer       |
| 3  | Manual switch to fault converter transformer    |
| 4  | Adjustment of converter transformer taps        |
| 5  | TA broken line                                  |
| 6  | TA saturation                                   |
| 7  | TV broken line                                  |
| 8  | Overvoltage of the system                       |
| 9  | Over excitation of converter transformer        |
| 10 | DC bias                                         |
| 11 | Complex combinatorial fault                     |

Through the simulation test and analysis, it is found that: When the two sets of protection systems are all put in, the optimized scheme does not increase the risk of protection misoperation and rejection, and can operate correctly in the internal fault, and can be sensitive to the conversion failure in the external fault. When the protection system 2 is withdrawn, the two additional protection of the protection system 1 can basically cover the four protection areas that were originally reduced.

In short, from the risk caused by a single set of failures, there is a big improvement compared to the improvement. The research project can provide a significant optimization scheme for the converter protection products, and can solve many existing problems, and put forward the optimized implementation scheme, which is beneficial to the promotion of the products.
5. Conclusion
Aiming at the structure problem of converter transformer in a converter station, a new principle of
converter protection is proposed in this paper. According to the improved scheme, we developed a
prototype of the protection device, and carried out a RTDS simulation test on the proposed
optimization scheme, and compared it with the original scheme. The test results show that the
improved change and rheology protection scheme will not increase the risk of misoperation and
rejection when compared with the improvement of the two sets of protection systems. In a single set of
operation, compared with the improvement before, reduce the operational risk.

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References
[1] DAI Xi-jie. DC transmission Foundation[M]. Beijing: Hydraulic power press,1990.
[2] ZHAO Wan-jun. HVDC transmission engineering technology [M].Beijing : China Electric Power
Press,2004.
[3] ZHANG Hong-yue. Thinking of converter connection-transformer differential protection’s
magnetizing inrush current judgement [J].Power system protection and control,2011,20(39):
151-154.
[4] ZHANG Hong-yue,ZHANG Qing-zhi, XIONG Zhang-xue etc. A method of measuring neutral
point DC component of transformer using AC transformer [J].Power system protection and
control,2013,16(41) : 97-102.
[5] ZHU Tao-xi, ZHANG Min, GUO Wei-ming, et al.Analysis of the problems of protection systems
of converter transformers used in HVDC transmission projects in CSG[J]. Power System
Protection and Control, 2010, 38(13): 140-143.
[6] LI Xiao-hua, LIU Yang, CAI Ze-xiang. Analysis of grounding fault at HVDC converter
transformer valve side[J]. Transactions of China Electrotechnical Society, 2012, 27(6):
38-45.
[7] LUO Hai-yun, YU Jiang, OU Kai-jian. Grounding fault analysis at converter transformer valve
side[J]. Electric Power, 2009, 42(6): 84-87.
[8] YANG Fen-yan, XU Zheng. Typical transient responses in HVDC transmission system[J].
Transactions of China Electrotechnical Society, 2005, 20(3): 45-52.
[9] TIAN Qing. Analysis on the symmetry inrush of 12 impulsive convertor transformer[J]. Power
System Protection and Control, 2011, 39(23): 133-137.
[10] ZHANG Wen,ZHOU Xiang-shen, SONG Shu-bo, WONG Chao. Improvement of protection
configuration for converter transformer without redundancy in yun guang[J].Power system
protection and control,2011,20(39): 151-154. 2014, 24(07): 151-154.