Study on the transient characteristic measurement system of current transformer

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Abstract. Nowadays, thirteen ultra-high voltage direct current (UHVDC) transmission projects have commissioned in China, including Jinping-Sunan, Fulong-Fengxian, Yibin-Jinhua project, and so forth. Meanwhile, another two UHVDC transmission projects are under construction. The highest UHVDC voltage level is ±1100kV. The HVDC transmission is superior in high capacity and long transmission distance, and its control response put forward higher requirements for the transient characteristics of DC current transformer. At present, there is no test method and equipment for testing the transient characteristics of the DC current transformer. Therefore, mastering the transient response characteristics of operating DC current transformer remains to be a challenge. In this paper, a transient test system of DC current transformer is developed, which includes a step current output unit, a high precision acquisition unit and a calibrator algorithm. The system was used to test the rising time, maximum overshoot and transient delay of the DC current transformers installed on the pole line and valve outlet. This study can clarify the influence factors of the transient characteristics of DC transformer on the control and protection system of UHVDC, and can define the principle of selecting the transformer parameters to meet the requirements of the control and protection system of UHVDC. The results of this study have great significance to improve the performance of UHVDC control and protection system.

1. Introduction

In the aspect of high voltage level, long distance and high power transmission HVDC transmission method is superior in economic efficiency and flexible control, so it is now selected as an essential approach of trans-regional power transmission [1-5]. Currently, in China, 13 UHVDC projects have commissioned in China, including Jinping-Sunan, Fulong-Fengxian, and Yibin-Jinhua project, etc, in which the highest voltage level is ±1100kV. The existing UHVDC lines constitutes a significant hub of EHV and UHV transmission network in China [6-7]. As a piece of indispensable primary equipment in HVDC transmission project, DC current transformer plays a vital role in the control and protection of the UHVDC system, as well as the monitoring of the operating condition. The on-site calibration of DC current transformer is also getting more and more attention [8]. Due to the lack of appropriate calibration equipment, it is still unable to carry out the on-site calibration test to obtain the transient characteristics of DC current transformer, which lays a hidden danger for the stable and reliable operation of converter station [9].

Even though the international standard IEC61869.14 [10] has defined the transient characteristics and the corresponding test method of DC transformer, however, the transient characteristics test is hard to
be normally conducted due to the lack of relevant theoretical research and testing equipment [11].

Besides, to reach the goal of digital output, the combined units of the primary and secondary parts of the DC transformer are usually required to be measured as a whole [12]. Due to the lack of test conditions, it is often to disassemble the DC current transformer in the laboratory or manufacturer and then measure the primary current by multiple turns with equal ampere-turns method on the optical fiber current-sensing ring or the hollow core dc current transformer. The test is complex and it is difficult to carry out without affecting the performance index and field conditions. Furthermore, for dc current transformers installed by shunt meter or pipe master, the ampere-turn method is challenging to carry out [13].

In recent years, a series of researches have been done on the aspects of field test technology and equipment development for DC transformer [14], which are mainly based on field calibration and simultaneous measurement. By using the equipment such as high precision voltage / current ratio standard and high precision digital multimeter, in Sichuan Deyang converter station and Fulong converter station, the field calibrations of ±500 kV and ±800 kV HVDC voltage/current transformers competed for the first time. The development and application of DC transformer field calibration system were also achieved at the moment [15 - 16]. At present, the existing test equipment and technical means are mainly aimed at the test and measurement of the steady-state characteristics of DC transformer, making it difficult to support the on-site test and detection of transient characteristics [17]. Therefore, it is necessary to study the on-site detection technology for the protection characteristics of extra-high/ultra-high voltage DC current measuring equipment.

In order to solve the above problems, this paper started with the transient characteristic test device of DC current transformer; the conducted an in-depth study on the protection characteristic test of DC current transformer based on the square wave step current response. Then a prototype of DC current transformer transient square wave current source was developed, and the protection characteristics of DC current transformer were tested. This paper provides important support for solving the problem that the protection transient characteristics of DC current transformer cannot be evaluated according to the standard. Research results help clarify the influence factors of the transient characteristics of DC transformer on the UHVDC control and protection system, and can define the principle of selecting the transformer parameters to meet the requirements of the DC control and protection system. This research has great significance to improve the performance of DC control and protection system.

2. Transient characteristics of DC current transformer

2.1. Step response characteristic analysis

According to the working principle, DC current transformer can be divided into two types: zero flux type and photoelectricity type. The step response performance of the DC current measuring device can be used to quickly and accurately transmit signals to the protection system in case of system failure. Based on the national standard of China, for the step whose overshoot is not more than 1.1 times of the rated current, its response time should be less than 400 μs and the stabilization time should be less than 5 ms. It is now constructing DC engineering, especially flexible engineering in China. For flexible system, the loop impedance is smaller and the change rate of fault current is larger, so it raises higher demands for the step response time of DC current measuring device, such as, the delay time should not exceed 150 μs, the step rise time should not exceed 150 μs, and the sampling frequency should be 50 kHz.

According to IEC61869.14, it is required that the rated step response time of the dc current measuring device is shorter than 0.2 times of rising time of the test power supply, and the step response time of the signal measuring system is shorter than 0.05 times of the step response time of the measuring equipment.

2.2. Equipment requirements and its index analysis
According to IEC61869.14, the step response test of a DC current measuring equipment requires a specified step current signal to be applied at the primary end of the sample. Because there is no suitable large current source with square wave step, the standard recommends that a step current wave which is 0.1 times of the rated primary current can be applied. Also, the step current equivalent test is performed by applying a step voltage analog signal at the input port of the voltage signal of the primary converter which is 1.0 time of the rated primary current.

The output of the DC current transformer is digital fiber signal output, so it is difficult to obtain the input voltage port of the primary converter alone, making equivalence of the test to be doubtful. At the same time, the DC current transformer, especially DC all-fiber DC transformer, is non-linearity in some measuring sections, so it is difficult to accurately obtain the response characteristics under large current condition using waveform detection method with a small current. In summary, it is necessary to develop a large current source that meets the requirements of IEC61869.14.

3. Transient calibration technology of DC current transformer

3.1. System structure and principle

In order to meet the requirements of DC current transformer step response test, a test system based on modular power devices is proposed, as shown in figure 1. The transient characteristic test system includes transient power and current source, high precision acquisition unit and calibration system. Under the same load capacity, the broadband current output device is designed with two output ports: 1000A AC/DC, frequency DC-100Hz, step rise time less than 50 μs; 100A AC/DC, frequency DC-5kHz, step rise time less than 20 μs. With this design, the contradiction between output bandwidth and output amplitude of current source is solved effectively.

![Figure 1. Principle block diagram of test system for transient characteristics of DC transformer.](image)

In the test system, the step signal is applied to the DC current transformer by the transient power current source applies. The high precision acquisition device is used to detect the output of a small analog signal or FT3 digital signal from the secondary system of the tested equipment. Upper computer software is installed to process the connected signal. At the same time, the high-precision acquisition device is used to communicate with two broadband power sources through optical fiber and timing respectively, to achieve synchronous output and acquisition.

As the structure diagram shows in Fig. 2, the transient power and current source include four units: software control, main control circuit, signal processing, and current amplifier. The upper computer software is installed in the acquisition device, and the broadband current output device is controlled to start and stop by the optical fiber, and the output current is collected synchronously. The main control circuit communicates with control software, data processing, and logic control. Signal processing converts digital signals into analog signals, transient current power amplifier amplifies analog signal into high power current signal. The main control circuit realizes the communication of the device with the upper computer, data processing, and logic control. Signal processing converts digital signals into analog signals, and transient current power amplifier amplifies analog signals into high-power current signals.

![Figure 2. Step current output device structure diagram.](image)
The structure diagram of high precision acquisition device is shown in figure 3, which includes sampling, main control circuit and acquisition circuit. The acquisition circuit collects the analog signal/digital output of the DC transformer, and the main control circuit parses the collected data, then records and uploads the data to the upper computer. The upper computer software realizes the features of man-machine interaction, data calculation, waveform display and storage.

3.2. On-site test scheme

As shown in figure 4, in the transient test of DC current transformer, the DC transient step source provides the primary transient step signal required for testing. Acting as a standard transformer, the DC transient unit converts the transient current into secondary small voltage signal, then carries on the analog-to-digital conversion and format definition. The final signal is output to the DC current transformer calibrator. At the side of the calibrated transformer, the first transient step signal is not only converted into the digital output voltage signal of its defined format through the primary converter and the secondary converter, and but also transmitted to the DC current transformer calibrator. The DC current transformer calibrator receives the signals of the DC transient unit from the calibrated mutual inductor side, converts it into the corresponding primary current. The maximum overshoot, rising time and other transient characteristics of the dc current transformer are calculated and evaluated by the background analysis system in the upper computer.

Based on the proposed transient test technology of DC current transformer above, the first on-site transient characteristic tests on two active DC current transformer were carried out. The two tested current transformers, which were produced by a certain manufacturer in China, were located at the pole side and the outlet side of the DC valve hall respectively.

4. Test results and analysis

The rated current of the transformer locating at pole line side and valve outlet side is 1000A and 2000A. By applying a step signal thorough the transient step source, and collecting the received signals of both the DC transient unit and the calibrated transformer using a calibrator, the transient
performance test was conducted. The test data analysis was made as is shown in Fig 5 and Fig 6. With the backup optical fiber installed in the remote module of the calibrated transformer, the output of the combined unit in the control room is directly connected to the local test site, which solves the problem of synchronous reading of the standard side signal output, as well as the secondary output of the calibrated transformer.

![Image](a) Output signal of polar current Transformer with step amplitude of 100A

![Image](b) Output signal of polar current Transformer with step amplitude of 300A

**Figure 5.** Transient performance test result of the pole transformer.

![Image](a) Output signal of valve outlet current Transformer with step amplitude of 100A

![Image](b) Output signal of valve outlet current Transformer with step amplitude of 300A

**Figure 6.** Transient performance test result of the valve outlet transformer.

Based on the test results of Fig. 5 and 6, the rise time, maximum overshoot and transient delay time of the transformers in two different sides are calculated by the interpolation method. The calculated results are shown in Table 1.

| Transformer | Transient current (A) | Rise time (μs) | maximum overshoot (%) | transient time delay (μs) |
|-------------|----------------------|----------------|------------------------|--------------------------|
|             | Standard Source | Tested sample | Standard Source | Tested sample | Standard Source | Tested sample | Standard Source | Tested sample |
| polar       | 100                  | 68.9           | 82.5                  | 51.0         | 43.5           | 309.3        |
|             | 300                  | 207.4          | 207.3                 | 10.3         | 6.8            | 307.4        |
| valve outlet| 100                  | 67.0           | 77.3                  | 51.1         | 45.0           | 69.3         |
|             | 300                  | 212.0          | 210.0                 | 10.4         | 9.0            | 76.6         |

From Table 1:

1. When the transient current is 100A, the rising time values of the dc current transformers on the side of the calibrated pole line and the outlet side of the valve are all less than 150 μs, which meets the requirements of the technical specification for HVDC electronic transformers. However, the
adjustment time of the transient step source is relatively short, the amplitude as and the rise time of the step signal is also relatively small, so the maximum overshoot of the standard source as well as the calibrated transformer is relatively larger.

(2) When the transient current is 300A, the amplitude of the step signal increases and the high-frequency component of the signal increases. Since the calibrated transformer was installed at a higher location during operation, the test loop was relatively long, making the overall inductance larger. Under this case, the output standard signal from the transient step source cannot achieve the fast-rising step mutation. Therefore, the rising time of the standard source and the calibrated transformer exceeded 200 μs, which gives the transient step source a longer time to adjust, and thus the maximum overshoot of the standard source and the calibrated transformer is controlled within 10%, meeting the requirements of the standard.

(3) During the calibration, the time when the amplitude of the standard source and the calibrated transformer reaches 90% of the amplitude of the step signal is viewed as the termination time of the step signal. For the 10 kHz output signal during pole-side transformer test, its transient delay is about 300 μs compared with the standard source signal. For the 50 kHz output signal during valve outlet transformer test, the transient signal delay is about 70 μs. According to the instructions provided by the manufacturer, there are about 3 data points of delay in total during the steps of calibrated transformer signal transmission, remote module processing, combined units package processing, output and so on, which is consistent with the test results and verifies the correctness of the test.

5. Conclusion

In this paper, an on-site calibration system for the transient characteristics of UHVDC current measuring equipment based on power module was proposed. The system includes a transient power current source, a high-precision acquisition unit, and a background verification system. The system can be used to generate large step current which satisfies the corresponding standard. The proposed system provides a solution and test set for the test and measure the protection performance of UHVDC measuring equipment. The results of this study are not only valuable for studying the influence of transient characteristics of dc transformer on dc control protection system, but also weighty help put forward the selection principles of transformer parameters, the key performance test assessment scheme as well as the protection setting and coordination technology required by dc control protection system, to propose.

6. References

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