Research on Digital Output Verification Technology of Electronic DC Current Transformer

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Abstract. Aiming at the error of calibration system when conducting field calibration by electronic DC current transformer’s digital calibration system, an electronic DC current transformer’s digital calibration system based on protocol conversion is proposed and researched. Data frames outputted from merging unit are collected and converted by the system, the digital synchronization is realized by using the synchronous clock device to trigger the second pulse, and it is verified by the virtual instrument design software. The field calibration is conducted to some converter station digital dc current transformer under the rated current of 500A by using the calibration system. By calibrating and analyzing errors, the error is less than 0.075% when tested current is more than 40% of the rated current. According to the standard in literature[1], performance of the calibration system is perfect, measured results perfectly meet the requirements of design, and the calibration system has great practical application value.

1. Introduction
As an effective complement to the AC transmission, DC transmission technology has found its wide application in the long-distance and large-capacity transmission, power system networking, urban underground power transmission cable, etc.[2]. In DC transmission system, DC transformer, as the main equipment for measuring DC current/voltage, provides accurate and reliable guarantee for energy metering, power monitoring, control system protection and so on. Therefore, the verification of DC transformer is to ensure the reliable operation of HVDC system.

Because of the specificity of DC electronic transformer structure and its communication, it should meet high requirements of accurate error check devices and methods when compared with the traditional transformer. At present, many research institutes at home and abroad, such as ABB, Xi'an High Voltage Research Institute, Xu Ji, NARI-RELAYS, NARI and so on, have developed their own DC current transformer calibration devices[3]. According to different applications, DC transformer digital calibration system can be devided into laboratory verification, onsite verification and online verification and others[4]. But onsite verification on the DC electronic current transformer is less conducted for the lack of the corresponding calibration device. In order to verify the precision of system error, such as synchronous method, protocol conversion, calibration and so on, when the DC current digital transformer system is calibrated in the field, the paper presents a digital electronic DC current transformer output calibration system based on protocol conversion. The system converges outputed data frames from the merging unit through the optical fiber, and digital synchronism is
realized by synchronous clock triggering second pulses. Finally, the digital filter algorithm is verified by the virtual instrument in the PC. By calibrating and analyzing errors, the error is less than 0.075% when tested current is more than 40% of the rated current, the error is less than accuracy standard in China whose error is generally 0.2 level[5]. That shows, the calibration system has perfect real-time capability, high accuracy, good reliability.

1.1. System Features
1) When the secondary output of the measured DC electronic transformer contains digital output, for the far side distance of the verified DCCT between the first time and the second time, by the use of synchronous clock device, the two signals are simultaneously measured to get the high synchronization precision, and by averaging the testing values of repeated measurements and the way of intercom manual synchronization reading[6], the error caused by reading delay can be obviously reduced, compared with the traditional DC digital current transformer field test.

2) To the communication design of the measured protocol conversion digital output interface, the paper involves a way to realize the digital interface of the protocol conversion. The frame format of the merging unit is captured, converted and synchronized, and then packaged into the protocol stack and transferred to PC through the Ethernet in order to ensure the real-time capability and reliability of the system. The calibration algorithm uses the moving average method to correct the results.

2. The overall design of Calibration system
The principle structure of DC transformer digital check shown in Figure 1. The test system consists of DC source, DC current proportional standard, high-precision digital multimeter, protocol converter, shunt resistor, clock synchronization device and calibrator. The basic principle is: at the same time, the synchronous clock device is used as the trigger signal, sampling the secondary output signal that is the proportion of the standard DC current and DC electronic transformers to be measured respectively. It takes the secondary current output signal of the standard current/voltage transformer and the calibrated current/voltage transformer. Through the standard channel and the measured channel, which sends to the calibrator platform (PC). In order to obtain the ratio error, the calibrator receives the sampled data packets, and then analyzes and processes the two digital signal.

The selection of the calibration system meets the following requirements: the standard accuracy level of at least two levels higher than the measured transformer, and the calibrator error should be less than the measured transformer error of 1/10[7].

![Figure 1. The principle of structure diagram for digital calibration DC transformer.](image)

3. Key technologies of digital output verification

3.1. standard channel signal digital conversion
3.1.1. High-resolution: For 0.2S electronic DC-type transformer, with the standard calibration accuracy of at least 0.05 in calibration channel, it requires the less uncertainty of the standard resistance and standard A/D converter of the calibration system. The 5000/5A standard DC / DC current comparator is used in the field and its principle is similar to the zero flux TA[8] with high accuracy level of $2 \times 10^{-6}$; the uncertainty of the standard resistance measurement is $1 \times 10^{-5}$. The uncertainty of high-precision digital multimeter can reach $2.25 \times 10^{-5}$, which meets the requirements of the calibration system accuracy.

3.1.2. High dynamic range and high acquisition speed: For the measurement of electronic DC current transformer calibration, there is no clear standard requirements in the appropriate rated range, so GL / T 20840.8-2007 "Transformer Part 8: Electronics Type current transformer " is for reference. To 0.2S accuracy, it is measured within the rated current between 20% to 100%, so the card used in the six semi-high precision digital multimeter can get accurate collection on the secondary voltage signal.

3.2. Synchronization Method Design
The key of Calibration system is to synchronize two channels signal. i.e. The signal of the standard side transformer and the signal of the calibration side transformer must be synchronized sampling with the 1μs range of synchronization signal error.

There are two main ways to solve the synchronization problem, namely: interpolation method and synchronization pulse method. This paper mainly uses the synchronous pulse method. It is by external synchronous clock device to simultaneously trigger the second pulse signal to the standard transformer side and the measured transformer side, and send a sampling value of the electronic instrument transformer on the secondary equipment, thus achieving synchronization. Figure 2[9] is the diagram of the synchronization pulse waveform.

![Synchronous pulse waveform diagram](image)

**Figure 2.** Synchronous pulse waveform diagram.

4. System communication
There are two ways of electronic digital output, point-to-point link mode and the Ethernet communication in IEC61850-9-1[10]. The digital output of DC electronic current transformer unit merges mainly uses the integrated FT3 frame format for data transmission through the optical fiber. And the fiber has the characteristics of anti-jamming, insulation and short response time, which can effectively reduce the instability of the current source and ripple interference.

In this paper, the interface of FT3 frame format receiving and data processing is the protocol converter. It deals with the digital output of the electronic transformer merging unit of the DC converter station. This protocol converter has three main components, as is shown in Figure3:
1) Synchronization module: it is mainly to ensure the synchronization of data acquisition. The counter of the hardware FPGA shows 1 to the FT3 frame sent by the merging unit. When the second pulse signal triggered by the synchronous clock device is received, the counter shows 0 automatically and then places its markers in the data frame module.

2) The FT3 frame format data receiving and processing module: by receiving the merger unit serial transmission asynchronous communication mode, and using FT3 frame format to transmit data, each frame data consists of the start bit, eight valid data bits, even calibration instrument and end bit. With FPGA’s powerful parallel processing capability and real-time capability, the protocol converter captures and processes the FT3 message by FPGA, and accurately records the time of the received synchronous message command, then transmitting the data packet to the communication module.

3) Network communication module: Data packets analyzed by FT3 frame format will be packaged into TCP format by TCP/IP protocol stack running on PowerPC embedded system, and then transmitted to computer for further analysis and calculation through Ethernet communication.

5. Software interface design

In this calibration system, the virtual instrument technology is mainly used to combine hardware and software and finish the analysis of data collection and processing on personal computers (PCs). The virtual digital calibrators function by means of the programs of computers and simplify the hardware device of this system, showing amplitude waveform curve and measuring results and so on forth. This design mainly includes data acquisition module, parameter module, measurement and calculation module, generating curve, etc.

After the digital multimeter and protocol conversion device receive the second pulse trigger sampling signals sent by time synchronizers, the calibration software will test the samples ten times consecutively (the frequency of samples is 10kHz) and save automatically the average of sample points with time mark provided by the time synchronizers. First, the software of calibration system gets the data, and then collects the sample data and sample frequency from all sample channels by virtue of the users’ interface, and finally has the received multi-frame data of the program chart into queue cache, thus finishing the reduction of signal waveform shown as Figure 4. This thesis employs moving average method in the filtering processing analysis. That is to say, the data processing refers to the frequent tests for the percentage of rated voltage of the direct current signal (Dc signal) and calculating the average. In order to have a convenient calculation, the calibrators function by means of software programing. The following is the formula which can derive the actual ratio error (\( K_{\text{expected}} \) is the expected value, \( K_{\text{standard}} \) is the standard value, \( \gamma \) is the ratio difference value):

\[
\gamma = \frac{K_{\text{expected}} - K_{\text{standard}}}{K_{\text{standard}}}
\]
6. Analysis and Calibration of Field Test Data

The DC (direct current) electronic current transformer with 0.2 accuracy grade can be verified through the field verification of the negative polarity current transformer in some certain converter station. Sampling the digital signal with sample frequency of 10 kHz, this experiment set 12 tests on the basis of the consecutive second pulse signal produced by the time synchronizer. By digital synchronous measurement, it means using moving average filtering of to calculate the ratio error of two input signals under different percentage. The record of field calibration is shown as Figure 5.

![Software flow chart of Calibration system](image)

**Figure 4.** The software flow chart of Calibration system.

![Ratio measurement of DC electronic current transformer with 0.2 accuracy level](image)

**Figure 5.** Ratio measurement of DC electronic current transformer with 0.2 accuracy level.

The result of field calibration shows that this calibrator has 0.2 accuracy grade in the test result of this kind of DC (direct current) current transformer and the measuring error meets the technical demand totally under the circumstance of over 40.1% rated voltage. That is shown as Figure 6, the virtual calibrator has high synchronous accuracy and calculating accuracy in test for the direct currents of different percentage because it is less influenced by external disturbance signals.
7. Conclusion
1) The DC transformer based on virtual technology replaced traditional instruments and finished the signal collecting and data processing with the help of computers and digital multimeters. Not only highly flexible and efficient but also of good quality, it has convenient operation.
2) The synchonous colleting of DC digital signals improves the accuracy of the transformer because the process uses the protocol converter to catch output signals and the synchonous second pulse signals and then verifies the error by moving average method.

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References
[1] GB/T 26216.1-2010 DC current measuring device for HVDC transmission syste—Part 1: Electronic DC current measuring device[S].
[2] Li Qian,Zhang Shu-han,Li Deng-yun et al. Experimental Analysis of the On-site Calibration Technology for ± 500 kV DCPTs[J]. High Voltage Engineering, 2010,36(11):2856-2862.
[3] Zhang Ding-qu,Pan Feng,Liu Guo-ying, et al. Operational Status and On-Site Calibration Technology for HVDC Transformer[J]. Power And Energy, 2015,36(6):787-793.
[4] Hu Hao-liang,Li Qian,Lu Shu-feng,et al.Comparison of Two Electronic Transformer Error Measuring Methods[J].High Voltage Engineering, 2011,37(12):3022-3027.
[5] Wang Leren,Lei Min,Zhang Shuhan,et al.Calibration Methods of Current and Voltage Transducers at HVDC Converter Stations[J].High Voltage Engineering, 2006,32(12):164-167.
[6] Li Qian,Li He,Zhou Yifei,et al.On-site calibration technology of DC current measurement device in converter station of ±800kV UHVDC transmission project[J].High Voltage Engineering,2011,37(12):3053-3058(in Chinese).
[7] GB.T 20840.8-2007, Instrument Transformers- Part8: Electronic Current Transformers[S].
[8] Li Wei-bo,Li Qi-yan,Ren Shi-yan,et al. Research on the modeling and simulation of the novel DC high-current comparator[J]. Journal of Sichuan University of Science and Technology, 2001,20(2):8-11,40.
[9] IEC60044-7-8.Electrical Voltage/Current Transducer.
[10] Feng Na,Shang Qiu-feng.Research development on the digital interface of electronic current transformer[J].Electrical Measurement & Instrumentation,2007,44(6):44-47.