Study on Calibration Method for Electronic Transformer Test Set

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Abstract. A method for calibration of electronic transformer test set is proposed. The calibration principle of analog function and digital function of electronic transformer test set is analyzed in detail. And the uncertainty evaluation of the ratio error and phase error of electronic transformer test set is introduced. The proposed method can evaluate the measurement performance of electronic transformer test set as a whole. And the method can be used as a reference for calibration of electronic transformer test set.

1. Introduction

With the construction of digital and intelligent substations, the number of electronic transformer applications is increasing. Before the electronic transformer is put into operation, it needs to undergo strict on-site verification. On-site calibration is mainly done with the help of instruments such as standard transformers and electronic transformer calibrators. There are mature methods for the calibration or verification of standard transformers. Since the electronic transformer calibrator is aimed at the calibration of small analog signals and digital quantities, the conventional transformer calibrator cannot meet the on-site calibration requirements.

At present, a lot of work has been carried out at home and abroad for electronic transformer calibrators. Li Tongjie and others conducted error simulation analysis on the algorithm used by the electronic transformer calibrator. Mei Zhigang and others used Fluke 5500 to calibrate the acquisition unit of the developed electronic transformer calibrator. The National High Voltage Metering Station has established an electronic transformer calibrator calibration system, which is mainly composed of power frequency ratio power supply ZJ-B1, digital multimeter 3458A and standard current voltage converter.

The Swedish National Testing Institute (SP) has developed an electronic transformer digital output calibration system, using Agilent 3458A as a data acquisition module. By calibrating each functional module of the electronic transformer calibration system separately, and then synthesizing the uncertainty of the calibration results of each module, it is concluded that the uncertainty of the ratio error of the calibration system is better than 0.01%, and the uncertainty of the phase error is better than 0.4 points. The National Measurement Institute of Canada (NRC) has developed a digital output calibration system for electronic transformers based on digital sampling technology. It uses transfer standards, AD acquisition and protocol conversion modules to replace the electronic transformers being calibrated, and the error test results are obtained by the calibration system. Then through the bridge measurement to obtain the test results of the transmission standard error, by comparing the two measurement results to obtain the ratio error and phase error of the electronic transformer calibration system.

Based on the research status at home and abroad, the current electronic transformer calibrator mainly uses a component-based calibration method. The main problems of this method are: First, only some
components of the calibrator are calibrated, and the overall calibrator is not investigated. Metering performance; second, calibrators with different principle structures, whose components are different, cannot adopt a unified calibration method; third, the calibration operation is relatively complicated, and the degree of automation is not high. In view of the above problems, this paper proposes an overall calibration scheme for the electronic transformer calibrator, introduces the uncertain evaluation method of the calibration result, and provides a reference for the calibration work of the electronic transformer calibrator.

2. Working Principle of Electronic Transformer Calibrator

The structure of the electronic transformer calibrator is shown in Figure 1. It mainly consists of the reference voltage / current input unit, the measured voltage / current input unit, the standard analog quantity acquisition unit, the calibrated analog quantity acquisition unit, and the calibrated digital quantity analysis unit. Clock synchronization unit, signal processing and error calculation unit.

For the analog output type electronic transformer, the standard current / voltage transformer and the electronic current / voltage transformer are connected in series (parallel) at a time. The secondary output of the standard current / voltage transformer is converted into a voltage signal by a standard converter and connected to the standard analog quantity acquisition unit of the calibrator. The secondary output of the electronic current / voltage transformer is directly connected to the calibrated analog quantity acquisition unit. By comparing the measured results of the standard analog and the calibrated analog, the ratio error and phase error of the calibrated electronic transformer are obtained.

For digital output electronic transformers, the primary wiring is exactly the same, the standard current / voltage transformer and the electronic current / voltage transformer are connected in series (parallel) at a time, and the secondary output of the standard current / voltage transformer is converted into a standard converter. The voltage signal is then connected to the standard analog quantity acquisition unit of the calibrator. The digital signal output from the merging unit of the calibrated electronic transformer is transmitted to the digital input unit under test of the calibrator through the optical fiber Ethernet. By comparing standard analog and measured digital measurement results, the ratio error and phase error of the electronic transformer to be calibrated are obtained.

![Figure 1. Structure diagram of electronic transformer calibrator](image-url)
3. Calibration method of electronic transformer calibrator

3.1. Calibration method for analog quantity verification function of electronic transformer calibrator

The calibration of the analog verification function of the electronic transformer calibrator adopts the overall calibration method shown in Figure 2 and Figure 3. Connect the reference voltage or current output port (U or I) of the overall calibration device to the reference voltage or current loop of the calibrator under test, and connect the analog voltage (U + ΔU or I + ΔI) output port and calibration of the overall calibration device the tested voltage circuit of the tester. Adjust the reference voltage or current to each rated reference value, adjust the standard error value (ΔU or ΔI) of the overall calibration device, and record the error indication value of the calibrator. The error indication value of the calibrator minus the standard error value of the overall calibration device is the calibration result of the calibrator to be inspected.

![Figure 2. Calibration principle diagram of analog voltage verification function](image)

![Figure 3. Calibration schematic diagram of analog current verification function](image)
3.2. Calibration method of digital quantity verification function of electronic transformer calibrator

For the calibration of the digital verification function of the electronic transformer calibrator, the overall calibration method shown in Figures 4 and 5 is used. Connect the reference voltage or current (U or I) output port of the overall calibration device to the reference voltage or current loop of the calibrator under test, and connect the digital (U + ΔU or I + ΔI) output port and verification of the overall calibration device Digital loop of the instrument. Adjust the reference voltage or current to each rated reference value, adjust the standard error value (ΔU or ΔI) of the overall calibration device, and record the error indication value of the calibrator. The error indication value of the calibrator minus the standard error value of the overall calibration device is the calibration result of the calibrator to be inspected.

Figure 4. Calibration principle diagram of digital voltage verification function

Figure 5. Calibration principle diagram of digital current verification function
4. Uncertainty assessment

4.1. Mathematical model
The measurement model of the ratio error of the inspected calibrator is:

\[ \Delta f = f_s - f_0 \]  
(1)

The measurement model of the phase error of the inspected calibrator is:

\[ \Delta \delta = \delta_s - \delta_0 \]  
(2)

4.2. Uncertainty evaluation of ratio error measurement

4.2.1. Sources of measurement uncertainty

(A). The uncertainty component \( u_1 \) introduced by the repeatability of the tested calibrator

Take a certain calibration point as an example for analysis. The overall calibration device outputs a standard error value of \( 11 \times 10^{-4} \), and records the error display value of the inspected calibrator 10 times. The measurement results are shown in Table 1.

| Measurement times | Standard error value of the overall calibration device \( (10^{-4}) \) | Indication value of calibrator under test \( (10^{-4}) \) | Ratio error of tested calibrator \( (10^{-4}) \) |
|-------------------|-------------------------------------------------|-------------------------------------------------|----------------------------------|
| 1                 | 11.0                                            | 11.1                                            | +0.1                             |
| 2                 | 11.0                                            | 11.4                                            | +0.4                             |
| 3                 | 11.0                                            | 11.3                                            | +0.3                             |
| 4                 | 11.0                                            | 10.9                                            | -0.1                             |
| 5                 | 11.0                                            | 11.1                                            | +0.1                             |
| 6                 | 11.0                                            | 11.2                                            | +0.2                             |
| 7                 | 11.0                                            | 10.8                                            | -0.2                             |
| 8                 | 11.0                                            | 11.2                                            | +0.2                             |
| 9                 | 11.0                                            | 11.1                                            | +0.1                             |
| 10                | 11.0                                            | 10.9                                            | -0.1                             |

The calculation of the standard deviation of a single measurement result is shown in formula (3).

\[ s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \approx 0.19 \times 10^{-4} \]  
(3)

Standard uncertainty: \( u_1 = s = 0.19 \times 10^{-4} \).

(B). Uncertainty component \( u_2 \) introduced by the resolution of the inspected calibrator

The resolution of the inspected calibrator is 0.001%, which is \( 0.1 \times 10^{-4} \), and the half-width interval is \( 0.05 \times 10^{-4} \). The probability distribution of the measured value falling in this interval is uniformly distributed, then the standard uncertainty: \( u_2 = 0.05 \times 10^{-4} / \sqrt{3} = 0.029 \times 10^{-4} \).

(C). Uncertainty component \( u_3 \) introduced by the accuracy of the overall calibration device
The accuracy of the overall calibration device is 0.01, that is $1 \times 10^{-4}$, the probability distribution of the measured value falling in this interval is uniformly distributed, then the standard uncertainty: $u_j = 1 \times 10^{-4} / \sqrt{3} = 0.577 \times 10^{-4}$.

4.2.2. Uncertainty synthesis. The uncertainty component of the ratio error measurement of the tested calibrator is shown in Table 2.

| Number | Source of uncertainty                  | Type | Accuracy | Distribution type  | Inclusion factor | Standard uncertainty |
|--------|----------------------------------------|------|----------|--------------------|-----------------|----------------------|
| 1      | Measurement repeatability              | A    | $0.19 \times 10^{-4}$ | /                 | 1               | $0.19 \times 10^{-4}$ |
| 2      | Resolution                             | B    | $0.05 \times 10^{-4}$ | Evenly distributed | $\sqrt{3}$      | $0.03 \times 10^{-4}$ |
| 3      | Global calibration Device accuracy     | B    | $1.00 \times 10^{-4}$ | Evenly distributed | $\sqrt{3}$      | $0.577 \times 10^{-4}$ |

The components are not related, so the calculation of the combined standard uncertainty is shown in equation (4).

$$u_c = \sqrt{\sum_{n=1}^{3} u_j^2} \approx 0.61 \times 10^{-4}$$

4.2.3. Extended uncertainty. Taking the expansion factor $k=2$, the expansion uncertainty: $U = ku_c = 2 \times 1.2 \times 10^{-4} = 2.4 \times 10^{-4}$.

4.3. Evaluation of Uncertainty of Phase Error Measurement

4.3.1. Source and analysis of uncertainty

(A). The uncertainty component $u_1$ introduced by the repeatability of the tested calibrator

Take a certain calibration point as an example for analysis. The overall calibration device outputs a standard error value of $6.6'$, and records the error value of the calibrator under test 10 times.

| Measurement times | Standard error value of overall calibration device ('') | Indication value of tested calibrator ('') | Phase error of tested calibrator ('') |
|-------------------|--------------------------------------------------------|------------------------------------------|--------------------------------------|
| 1                 | 6.0                                                     | 6.1                                      | +0.1                                 |
| 2                 | 6.0                                                     | 6.2                                      | +0.2                                 |
| 3                 | 6.0                                                     | 5.6                                      | -0.4                                 |
| 4                 | 6.0                                                     | 5.9                                      | -0.1                                 |
| 5                 | 6.0                                                     | 6.1                                      | +0.1                                 |
| 6                 | 6.0                                                     | 5.7                                      | -0.3                                 |
| 7                 | 6.0                                                     | 5.9                                      | -0.1                                 |
| 8                 | 6.0                                                     | 6.1                                      | +0.1                                 |
| 9                 | 6.0                                                     | 5.9                                      | -0.1                                 |
| 10                | 6.0                                                     | 6.2                                      | +0.2                                 |
The standard deviation calculation of the single measurement result is shown in formula (5).

\[ s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \approx 0.2' \tag{5} \]

Standard uncertainty: \( u_1 = s = 0.2' \).

(B). Uncertainty component \( u_2 \) introduced by the resolution of the inspected calibrator

The resolution of the tested calibrator is required to be 0.1' and the half-width interval is 0.05'. The probability distribution of the measured value falling in this interval is uniformly distributed, then the standard uncertainty: \( u_2 = 0.05' \sqrt{3} = 0.029' \).

(C). Uncertainty \( u_3 \) introduced by the accuracy of the overall calibration device

The accuracy of the overall calibration device is 0.01, that is, the maximum phase error is 0.3', and the probability that the measured value falls in this interval is that the distribution is uniformly distributed, then the standard uncertainty: \( u_3 = 0.3' \sqrt{3} = 0.173' \).

4.3.2. Uncertainty synthesis. The uncertainty component of the phase error measurement of the calibrator is shown in Table 4.

| Number | Source of uncertainty | Type | Accuracy | Distribution type | Inclusion factor | Standard uncertainty |
|--------|-----------------------|------|----------|-------------------|-----------------|---------------------|
| 1      | Measurement repeatability | A    | 0.2'     | /                 | 1               | 0.20'               |
| 2      | Resolution            | B    | 0.05'    | Evenly distributed | \( \sqrt{3} \)  | 0.029'              |
| 3      | Overall calibration device accuracy | B    | 0.3'    | Evenly distributed | \( \sqrt{3} \)  | 0.173'              |

The components are not related, so the synthetic standard uncertainty calculation formula (6) is shown.

\[ u_c = \sqrt{\sum_{i=1}^{3} u_i^2} \approx 0.266' \tag{6} \]

4.3.3. Extended uncertainty. Taking the expansion factor \( k = 2 \), the expansion uncertainty: \( U = ku_c = 2 \times 0.266 = 0.532' \).

5. Conclusion

Aiming at the calibration of the electronic transformer calibrator, this paper proposes an overall calibration method, and introduces the calibration principle and the uncertainty assessment method in detail. The method takes into account the calibration of the analog quantity verification function and the digital quantity verification function of the electronic transformer calibrator, and can evaluate the overall measurement performance of the electronic transformer calibrator. Based on this method, an overall calibration device for an electronic transformer calibrator with a program control function can be developed to realize the automation and intelligence of the calibration work of the electronic transformer calibrator.

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\[ \sqrt{\sum_{i=1}^{3} u_i^2} \approx 0.266' \]
References

[1] NING Weihong, YANG Yihan, LI Jing, et al. Review on development of transformer calibration [J]. Power System Protection and Control, 2009, 37 (10): 131 - 135.

[2] IEC 60044-7. Instrument Transformer-part7: Electronic Voltage Transformer [S]. 1999

[3] IEC 60044-8. Instrument Transformer-part8: Electronic Current Transformer [S]. 2002

[4] Li Tongjie, Zhang Xiaogeng. Design and realization of electronic current transformer calibrator based on DSP [J]. Chinese Journal of Scientific Instrument, 2008, (8): 1695 - 1699

[5] NING Weihong, YU Wenbin, ZHANG Guoqing, et al. Design of a Calibrator for Electronic Current Transformer Based on LabVIEW [J]. Power System Technology, 2009, (5): 86 - 89.

[6] GUO Wei, ZHANG Hongchao, YU Zhaohui. A calibration system for electrical transformers with analog output [J]. Power System Protection and Control, 2010, 38 (6): 49 - 51.

[7] Mei Zhigang, Luo Chengmu, Cui Aifang. Design of a virtual transformer calibrator [J]. Transformer, 2006, 43 (10): 23 - 26.

[8] J. I. Juvik. Influence of time delay in calibration systems for instrument transformers with digital output Conference on Precision Electromagnetic Measurements (CPEM 2000), Sydney, Australia, 2000: 359 - 360

[9] Branislav Djokic, Eddy So. Calibration system for electronic instrument transformers with digital output. IEEE Trans. Instrum. Meas., 2005, (2): 479 - 482.

[10] DL / T 1394-2014. Technical conditions of electronic voltage and current transformer calibrator [S].