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## Article

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Energy Reports

**Provided in Cooperation with:**

Elsevier

*Suggested Citation:* Xu, Dongdong; Zhang, Weiwei; Wang, Nan; Wang, Guangtao; Xu, Guangke (2020) : The power frequency voltage divider calibration device and its uncertainty, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, Iss. 2, pp. 380-384, <https://doi.org/10.1016/j.egyr.2019.11.091>

This Version is available at:

<https://hdl.handle.net/10419/243905>

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The 6th International Conference on Power and Energy Systems Engineering (CPESE 2019),  
September 20–23, 2019, Okinawa, Japan

# The power frequency voltage divider calibration device and its uncertainty

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Received 6 October 2019; accepted 22 November 2019

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## Abstract

The power frequency high voltage divider is widely used to measure the power frequency high voltage and it is an important measuring instrument for high voltage test. Whether it is accurate or not directly affects the insulation monitoring level of power equipment closely related to the safety of power production, and it is of vital importance for power enterprises to ensure the measurement accuracy of power frequency high-voltage divider. The newly implemented JG496-2016 <Verification procedure for high-voltage power divider> recommended three measurement methods: difference comparison, equal power bridge method and voltage ratio method. At present, only some literatures have introduced the measurement method using voltage ratio method and the measurement uncertainty evaluation procedure. This paper introduces a calibration device and measuring method of power frequency high voltage divider using the difference comparison method, and gives the uncertainty of the ratio difference and phase difference of power frequency high voltage divider obtained under the standard test environment.

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Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

*Keywords:* High voltage divider; Difference comparison method; Uncertainty; Error value; Calibration device

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## 1. Overview

The high voltage measurement system is an important part of the high voltage test [1]. The most widely used high-voltage measurement system in the electric power department and electric power equipment manufacturer is the power frequency voltage divider [2]. The newly implemented JG496-2016 (Verification procedure for high-voltage power divider) recommended three measurement methods: difference comparison, equal power bridge method and voltage ratio method. Ref. [3] describes a calibration method using a standard voltage divider with a digital multimeter. Ref. [4] introduces a method for evaluating the measurement uncertainty of the indication error of AC high voltage divider using a standard capacitor divider as the measurement standard. Both of the above calibration methods belong to the voltage ratio method. At present, there is no measurement method for the difference comparison method and its uncertainty assessment procedure could be used for reference. Therefore, this paper

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<https://doi.org/10.1016/j.egyr.2019.11.091>

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Peer-review under responsibility of the scientific committee of the 6th International Conference on Power and Energy Systems Engineering (CPESE 2019).

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introduces a power frequency high voltage divider calibration device suitable for provincial use and its uncertainty evaluation procedure. The calibration device is composed of a power frequency test transformer, a capacitive voltage proportional device, a voltage distribution device, and a potential difference bridge type error measuring device.

In this paper, the measurement uncertainty of the indication error of the power frequency high voltage divider is evaluated by using the differential voltage comparison method using the capacitive voltage proportional device as the standard device to evaluate the uncertainty of the indication error of the measurement error at 50% of the rated voltage. Wiring as shown in Fig. 1, raised the voltage to each percentage voltage point, At this time, the measurement result of the potential difference bridge type error measuring device is the ratio difference and angular difference of the calibrated power frequency high voltage divider [5].

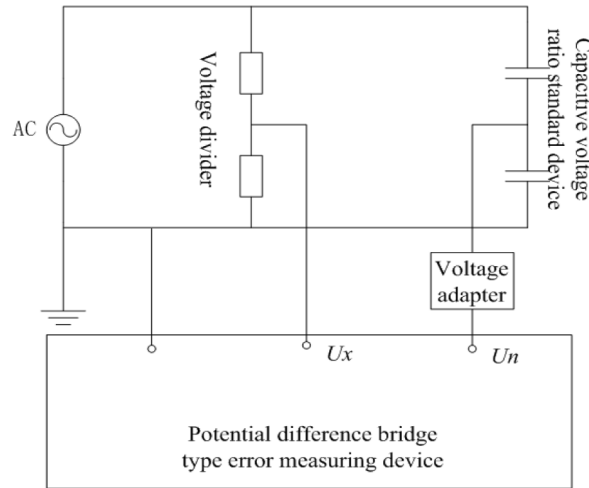


Fig. 1. The circuit of difference comparison method used capacitive voltage proportional device as the standard device.

## 2. Measurement model

The estimated value of the voltage division ratio error of the power frequency high voltage divider is the value of the transformer calibrator. The measurement model is:

a. Ratio error:

$$f_x = f_s + \Delta f_0 \tag{1}$$

In the formula,  $f_x$  is the estimation of ratio error of inspected power frequency high voltage divider,  $f_s$  is the average value of the voltage rise and fall ratio error measured by the transformer calibrator,  $\Delta f_0$  is the correction of ratio error from capacitive voltage proportion standard device.

b. Phase error:

$$\delta_x = \delta_s + \Delta \delta_0 \tag{2}$$

In the formula,  $\delta_x$  is the estimation of phase error of checked power frequency high voltage divider,  $\delta_s$  is the mean value of phase error indicating voltage rise and decline measured by transformer calibrator,  $\Delta \delta_0$  is the correction of phase error from capacitive voltage proportion standard device.

## 3. Evaluation of the standard uncertainty component of input quantity

### 3.1. The source of standard uncertainty for input

There are four main sources of standard uncertainty  $u(f)$  and  $u(\delta)$ :

a. The uncertainty components  $u_A(f_s)$  and  $u_A(\delta_s)$  introduced by the measurement repeatability of the calibration system of the frequency high voltage divider and the power frequency high voltage divider under repetitive measurement conditions, uses the type A assessment method;

b. The standard uncertainty components  $u_B(f_s)$  and  $u_B(\delta_s)$  introduced by the accuracy of transformer calibrator, uses the type B assessment method;

c. The standard uncertainty components  $u_B(\Delta f_0)$  and  $u_B(\Delta \delta_0)$  introduced by the accuracy of the correction value of the capacitive voltage ratio standard device, uses the type B assessment method;

d. The standard uncertainty components  $u_B(f_{x1})$  and  $u_B(\delta_{x1})$  introduced by the refinement of the measurement results, uses the type B assessment method;

In addition, the influence of the phase error contrast value error measured by the power frequency high voltage divider calibration system and the uncertainty component introduced by the influence of environmental condition fluctuation, power supply voltage stability and frequency stability, external electromagnetic field, etc. specified in JJG 496 are actually small. This is negligible in the measurement uncertainty assessment.

### 3.2. The calculation of each standard uncertainty component

#### 3.2.1. The evaluation of standard uncertainty components $u_A(f_s)$ and $u_A(\delta_s)$

The uncertainty component can be measured by continuous measurement and evaluated by the type A assessment method. At 50% of the rated voltage, Ten times independent measurements were carried out on the tested voltage divider under repetitive measurement conditions. As shown in Tables 1 and 2, a set of measurement columns of the ratio error and the phase error at voltage rise and fall are obtained respectively.

**Table 1.** The average value  $f_{si}$  of the ratio measured by the power frequency high voltage divider.

SN.	1	2	3	4	5	6	7	8	9	10
Rise (%)	1.06	1.06	1.05	1.05	1.06	1.05	1.06	1.06	1.06	1.06
Fall (%)	1.07	1.07	1.05	1.06	1.06	1.06	1.06	1.06	1.07	1.06
Mean (%)	1.065	1.065	1.05	1.055	1.06	1.055	1.06	1.065	1.06	1.065

**Table 2.** The phase error  $\delta_{si}$  measured by the power frequency high voltage divider.

SN.	1	2	3	4	5	6	7	8	9	10
Rise ( $10^{-3}$ rad)	25.3	25.2	25.3	25.2	25.3	25.3	25.3	25.3	25.2	25.4
Fall ( $10^{-3}$ rad)	25.2	25.1	25.3	25.2	25.2	25.3	25.2	25.3	25.1	25.3
Mean ( $10^{-3}$ rad)	25.25	25.15	25.30	25.20	25.25	25.30	25.25	25.30	25.15	25.35

The arithmetic mean of the measured results of the ratio error  $\overline{f_s} = 1.06\%$ , and the single test standard deviation  $s(f_s) = 0.0053\%$ .

In the actual calibration process, except for the upper limit calibration point, the errors of other calibration points are measured once at the voltage rises and falls, and the average value is used as the measurement result.

$$u(f_s) = s(\overline{f_s}) = s(f_s) / \sqrt{2} = 0.0037\% \quad (3)$$

The arithmetic mean of the measured results of phase error  $\overline{\delta_s} = 25.25 \times 10^{-3}$  rad, and the single test standard deviation  $s(\delta_s) = 6.67 \times 10^{-5}$  rad.

In the actual calibration process, except for the upper limit calibration point, the errors of other calibration points are measured once at the voltage rises and falls, and the average value is used as the measurement result.

$$u(\delta_s) = s(\overline{\delta_s}) = s(\delta_s) / \sqrt{2} = 4.72 \times 10^{-5} \text{ rad} \quad (4)$$

#### 3.2.2. The evaluation of standard uncertainty components $u_B(f_s)$ and $u_B(\delta_s)$

The uncertainty component is mainly derived from the maximum allowable error of the transformer calibrator (pressure difference measuring device). The device can be used as a level 2 measuring instrument after passing the higher level test. Its relative error of indication does not exceed 2%.

The Interval half width of uncertainty of ratio error:

$$a_{f_s} = \overline{f_s} \times 2\% = 0.0212\% \quad (5)$$

The Interval half width of uncertainty of phase error:

$$a_{\delta_s} = \overline{\delta_s} \times 2\% = 5.05 \times 10^{-4} \text{ rad} \quad (6)$$

This interval can be considered to be uniformly distribution and containing factor  $k = \sqrt{3}$ , standard uncertainty component:

$$u_B(f_s) = a_{f_s}/\sqrt{3} = 0.0122\% \quad (7)$$

$$u_B(\delta_s) = a_{\delta_s}/\sqrt{3} = 2.92 \times 10^{-4} \text{ rad} \quad (8)$$

### 3.2.3. The evaluation of standard uncertainty components $u_B(\Delta f_0)$ and $u_B(\Delta\delta_0)$

Usually the correction values of input quantities  $\Delta f_0$  and  $\Delta\delta_0$  are zero. Then the uncertainty component is mainly derived from the maximum allowable error of the capacitive voltage proportional standard device and the uncertainty assessment is based on the B-class assessment method [5]. The capacitive voltage proportional standard device is qualified by the upper level calibration, and the maximum allowable error of the ratio difference is  $\pm 0.2\%$ . The maximum allowable error of the phase error is  $\pm 0.5$  mrad. The Interval half width of uncertainty of ratio error:  $a_{\Delta f_0} = 0.2\%$ . The Interval half width of uncertainty of phase error:  $a_{\Delta\delta_0} = 0.5$  mrad. This interval can be considered to be uniformly distribution and containing factor  $k = \sqrt{3}$ , standard uncertainty component:

$$u_B(\Delta f_0) = a_{\Delta f_0}/\sqrt{3} = 0.1155\% \quad (9)$$

$$u_B(\Delta\delta_0) = a_{\Delta\delta_0}/\sqrt{3} = 2.89 \times 10^{-4} \text{ rad} \quad (10)$$

### 3.2.4. The evaluation of standard uncertainty components $u_B(f_{x1})$ and $u_B(\delta_{x1})$

According to JJG496, the obtained data are revised according to 1/10 of the maximum allowable error of the detected partial voltage ratio (including phase shift). The Interval half width of uncertainty of ratio error:  $a_{f_{x1}} = 2\%/10/2 = 0.1\%$ , The Interval half width of uncertainty of phase error:

$$a_{\delta_{x1}} = 0.03 \cdot 2/10/2 \text{ rad} = 0.003 \text{ rad} \quad (11)$$

This interval can be considered to be uniformly distribution and containing factor  $k = \sqrt{3}$ , standard uncertainty component:

$$u_B(f_{x1}) = a_{f_{x1}}/\sqrt{3} = 0.058\% \quad (12)$$

$$u_B(\delta_{x1}) = a_{\delta_{x1}}/\sqrt{3} = 1.73 \times 10^{-3} \text{ rad} \quad (13)$$

## 4. The combined standard uncertainty

### 4.1. Sensitivity coefficient

$$c_1 = \partial f_x / \partial f_s = 1 \quad c_2 = \partial f_x / \partial \Delta f_0 = 1$$

$$c_3 = \partial \delta_x / \partial \delta_s = 1 \quad c_4 = \partial \delta_x / \partial \Delta\delta_0 = 1$$

### 4.2. The summary and calculation table of each uncertainty component

The summary of the uncertainty components of the ratio error measurement results is shown in [Table 3](#).

The summary of the uncertainty components of the phase error measurement results is shown in [Table 4](#).

The above standard uncertainty components are not related to each other. Therefore, the synthetic standard uncertainty is calculated according to formula:

$$u_c(y) = \sqrt{\sum_{i=1}^N u^2(y_i)} \quad (14)$$

Then bring the data into the formula.

$$u_c(f_x) = \sqrt{u_A^2(f_s) + u_B^2(f_s) + u_B^2(\Delta f_0) + u_B^2(f_{x1})} = 0.12987\% \quad (15)$$

$$u_c(\delta_x) = \sqrt{u_A^2(\delta_s) + u_B^2(\delta_s) + u_B^2(\Delta\delta_0) + u_B^2(\delta_{x1})} = 1.7787 \times 10^{-3} \text{ rad} \quad (16)$$

**Table 3.** The summary of each uncertainty component of the ratio difference measurement result.

Uncertainty component	Source of uncertainty	$u(f_i)$	Sensitivity coefficient $c_i$	$ c_i  u(f_i)$
$u_A(f_s)$	Repeatability of measurement results	0.0037%	1	0.0037%
$u_B(f_s)$	The accuracy of the transformer calibrator	0.0122%	1	0.0122%
$u_B(\Delta f_0)$	The accuracy of the correction value of the capacitive voltage ratio standard device	0.1155%	1	0.1155%
$u_B(f_{x1})$	The adjustment of measurement results	0.0580%	1	0.0580%

**Table 4.** The summary of each uncertainty component of the phase difference measurement result.

Uncertainty component	Source of uncertainty	$u(\delta_i)/\text{rad}$	Sensitivity coefficient $c_i$	$ c_i  u(\delta_i)/\text{rad}$
$u_A(\delta_s)$	Repeatability of measurement results	$4.72 \times 10^{-5}$	1	$4.72 \times 10^{-5}$
$u_B(\delta_s)$	The accuracy of the transformer calibrator	$2.92 \times 10^{-4}$	1	$2.92 \times 10^{-4}$
$u_B(\Delta \delta_0)$	The accuracy of the correction value of the capacitive voltage phase standard device	$2.89 \times 10^{-4}$	1	$2.89 \times 10^{-4}$
$u_B(\delta_{x1})$	The adjustment of measurement results	$1.73 \times 10^{-3}$	1	$1.73 \times 10^{-3}$

## 5. The evaluation of expanded uncertainty

The value of the measured value falling within the inclusion interval depends on the value of the inclusion factor  $k$  taken, and the value of  $k$  is generally 2 or 3. In the usual measurement,  $k = 2$  is generally taken, and the inclusion probability at this time is about 95%. Then the extended uncertainty is:

$$U(f_x) = k \cdot u_c(f_x) = 0.25974\% \quad (17)$$

$$U(\delta_x) = k \cdot u_c(\delta_x) = 3.557 \times 10^{-3} \text{ rad} \quad (18)$$

## 6. The uncertainty report

At 50% of rated voltage, the extended uncertainty of the ratio error measurement is:  $U(f_x) = 0.26\%$ ,  $k = 2$ ; and the extended uncertainty of the phase error measurement result is:  $U(\delta_x) = 3.6 \times 10^{-3} \text{ rad}$ ,  $k = 2$ .

## 7. Conclusion

According to JJG496, this paper introduces a power frequency high voltage divider calibration device and measurement method suitable for field use. Taking the 800 kV power frequency high voltage divider as an example, the uncertainty of the indication error measurement at 50% rated voltage is evaluated. It also provides a reference scheme for the calibration of power frequency high voltage dividers.

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