The Design of Wideband Current Transformer Burden and Its Calibration Method

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Abstract

In the instrument current transformer calibration, the need for transformer burden to provide simulated secondary load, in order to achieve the measurement with the transformer calibrator. With the increase in low and medium frequency current transformer, the traditional 50Hz current trans-former burden cannot provide the proper error range of the secondary load. Aiming at the problem that the size of inductive impedance in impedance circuits is affected by the frequency of the current, it is proposed here to separate the impedance circuits set at different frequencies and design a wideband current transformer burden. Meanwhile, based on the principle of three-parameter impedance measurement and using a power analyzer, a calibration method of a wideband current transformer burden is obtained, and the calibration case and its uncertainty evaluation of active and reactive components are given.

1. Introduction

With the increase of the need for large current testing in the low and medium frequency bands by aircraft and ships, more and more electrical test equipment such as wideband current comparator, wideband current transformers, etc. need to work in the low and medium frequency bands, mainly involved in the current frequency of the aircraft AC power supply characteristics of the typical system of 400Hz, 360Hz ~ 800Hz inverter system, as well as the secondary power supply system of 50Hz; the ship's 400Hz intermediate-frequency power supply and the need for 400Hz power supply of the navigation system, the accusation system, and so on[1,2].

A calibration and traceability method based on wideband current ratio is proposed for this type of test equipment to improve the accuracy of wide-frequency and high current measurement. When calibrating wideband current transformers, it is usually necessary to use a matching current transformer burden to provide a simulated secondary load[3], therefore a wideband current transformer burden based on impedance is proposed here to cater for providing secondary loads to the current transformers within the error range at frequencies of 50 Hz, 400 Hz, 800 Hz and 1000 Hz.

Current transformer burden as a multi-value metering equipment, it needs to be calibrated periodically[4], the common 50Hz current transformer burden calibration is often used specially designed transformer burden tester, the principle of which has the use of magnetic potential balance and electric potential balance method, the use of the Maxwell bridge principle method and the traditional electrical impedance measurement method and so on[5]. In order to ensure the accuracy of the work of the wideband current transformer burden, with reference to the calibration specification of the transformer burden, a calibration method based on the three-parameter method of the wideband current transformer burden is proposed to realize the calibration of different loads at regular intervals within the specified rated current range, and a method for evaluating the measurement uncertainty of the load calibration results is given.

2. Principle and structure

2.1 Principle of wideband current transformer burden

The rated load of a current transformer can be expressed by the apparent power $S_n = I_n^2 Z$ (VA) at the rated current I_n. In general, the rated current of a current transformer burden is fixed, so the impedance value Z can also be used directly to express the rated load of the burden. When calibrating current transformers, the current transformer burden needs to simulate the rated secondary load of the transformer in addition to the secondary load when the power factor is 0.8. Considering the application scenario of a wideband current transformer burden, when the power factor is 1, it is a pure resistive circuit, with impedance Z equal to resistance R. It does not change due to the frequency, and only a set of series resistors can be used to satisfy different load ratings under wide frequency conditions. When the power factor is 0.8, the circuit consists of an inductive coil and a resistor in series, and the impedance components are divided into the circuit resistance R_1, the coil wire resistance R_x, and the coil inductance jX_L. The impedance is expressed as

$$Z = R_1 + R_x + jX_L \tag{1}$$

where the inductive component is

$$X_L = 2\pi f L \quad (2).$$

f is the current frequency; L is the coil inductance.

Since the frequency is not fixed under wideband, it is necessary to design the impedance unit according to different frequencies, and this constitutes the respective circuit.

2.2 Structure of wideband current transformer burden

As shown in **Figure 1.**, the wideband current transformer burden is composed of resistors and inductors to realize impedance circuit structure. A main knob can realize the selection of 50Hz, 400Hz, 800Hz and 1000Hz under the power factor 1 or 0.8 and the shorting position for the protection of constant current source. Five secondary knobs are used to select simulated secondary load values at different power factors and frequencies, with 8 gears of 2.5VA, 3.75VA, 5VA, 7.5VA, 10VA, 12.5VA, 15VA and 20VA.

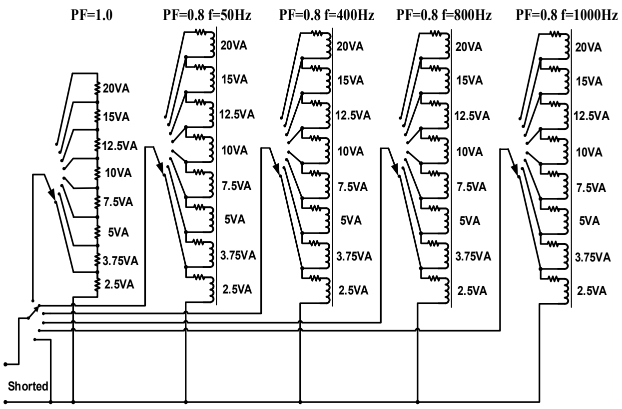

Figure 1. Circuit structure of wideband current transformer burden

When PF=1, the circuit consists of resistive units in series to form a simulated secondary load, wideband current can be realized by a general circuit 2.5VA ~ 20VA simulated load. When PF=0.8, the circuit consists of an inductive unit and a resistive unit connected in series to form a secondary load, in which the inductive component is affected by the frequency, so the wideband current needs to be designed for different frequencies of different inductive units. The 50Hz, 400Hz, 800Hz and 1000Hz are divided into four circuit channels to realize the secondary simulated load for wideband current transformer testing.

3. Calibration device and calibration method

3.1 Composition of wideband current transformer burden calibration device

Referring to JJF 1264-2010 *Specification for Calibration of Transformer Burden*, in addition to the general technical requirements, the main calibration content of the wideband current transformer burden calibration program is to obtain the load value of the transformer burden, i.e., to measure the active and reactive components of the various load stages in the wideband range of the rated current in the range of 20% to 120%. The active and reactive components can be expressed by the active power P, reactive power Q, or by the in-phase resistance R and quadrature inductive reactance X, respectively.

Based on the impedance measurement principle of the three parameters of voltage, current and phase, the wideband current transformer burden calibration device directly measures the voltage value U at both ends of the burden, the current value I through the burden and the phase difference φ between the voltage and the current. The active component R and the reactive component X can be obtained respectively:

$$R = |Z|\cos\varphi = \frac{U}{I}\cos\varphi \quad (3).$$

$$X = |Z|\sin\varphi = \frac{U}{I}\sin\varphi \quad (4).$$

R is the active component (including the specified external conductor resistance) of the simulated secondary load provided by the wideband current transformer burden, Ω; X is the reactive component of the simulated secondary load provided by the wideband current transformer burden, Ω; Z is the total impedance of the burden circuit as measured by the power analyzer, Ω; U is the voltage value as measured by the power analyzer, V; I is the current value as measured by the power analyzer, A; φ is the phase difference between the voltage and current as measured by the power analyzer, rad.

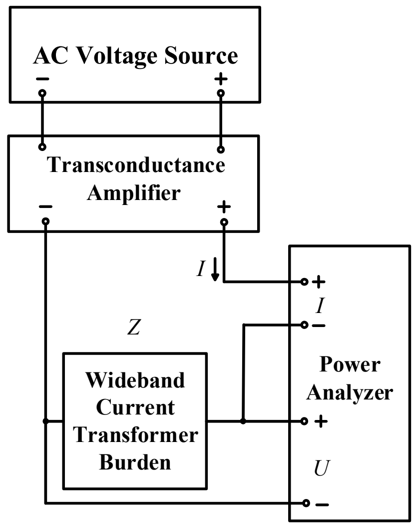

Figure 2. Calibration device for wideband current transformer burden

The wideband current transformer burden calibration device, shown in **Figure 2.**, mainly includes an AC voltage source, a transconductance amplifier and a power analyzer, which can be divided into a power supply part and a measurement part. The power supply part sets the voltage signal and frequency from the AC voltage source, which is converted to the required constant current output by the transconductance amplifier according to different amplification multipliers to realize the function of constant current source. The measurement part connects the current end of the power analyzer in series to the burden circuit, and the voltage end is connected in parallel to the burden to realize the measurement of the three parameters of current I, voltage U and phase difference φ of the wideband current transformer burden.

3.2 Calibration method of wideband current transformer burden

Wideband current transformer burden calibration is based on three-parameter impedance measurement principle. Connect the calibration device and carry out calibration at the ambient temperature of (20±5) ℃. The operation process is as follows:

(1)First select the current test point as the actual output current, generally select 20%, 100% and 120% of the rated current as the calibration point for calibration.
(2)Select the output current frequency. Select a gear from 50Hz, 400Hz, 800Hz and 1000Hz for calibration and set the output frequency from the AC voltage source.
(3) Set the burden gear. Select the simulated secondary load at any power factor at the frequency in step (2) as the load to be measured.
(4) Turn on the power supply, and read the measured values of three parameters of current I, voltage U and phase difference φ of the wideband current transformer burden on the power analyzer. Repeat the measurement for ten times and take the average value, and then calculate the active component R and reactive component X by the formula (3) and (4).
(5) Judgment of load value error. For the measured active and reactive components of the actual value of the error analysis, the relative error of active component can be expressed as follows:

$$\varepsilon_R = \frac{R_0 - R_x}{R_x} \times 100\% \tag{5}$$

R_0 is the nominal value of the active component of the load, $R_0 = Z_0 \cos\varphi_0$ (Z_0 is the nominal value of the load being calibrated, $\cos\varphi_0$ is the nominal power factor); for the load active component of the actual value of the display value. R_x is the measured value of the active component of the load.

When the power factor is not 1, the relative error of the load reactive component of the wideband current transformer burden can be expressed as:

$$\varepsilon_X = \frac{X_0 - X_x}{X_x} \times 100\% \tag{6}$$

X_0 is the nominal value of the load reactive power component, $X_0 = Z_0 \cos\varphi_0$; X_x is the measured value of the load reactive power component.

When the power factor is 1, the relative error of the residual reactive power component is expressed as:

$$\varepsilon_X = -\frac{-X_x}{R_x} \times 100\% \tag{7}$$

According to the calibration of the relative error of the burden as a reference index of burden performance, the requirement of power factor is not 1, the maximum relative error of active and reactive components does not exceed ± 3%; power factor of 1, the residual reactive component does not exceed ± 3% of the rated load. Taking the calibration data of active and reactive components of burden at 100% rated current, frequency 400Hz, PF=0.8 under 7.5VA gear as an example, the relative error of active component is $\varepsilon_R = -0.95\%$, and the relative error of reactive component is $\varepsilon_X = 2.21\%$, which are all within the error range of ±3%.

4. Uncertainty assessment

4.1 measurement model

An example of measurement uncertainty assessment is given by the active and reactive components of the burden at 100% rated current, frequency 400 Hz, and PF=0.8 at 7.5 VA. The measurement model for the calibration of the wideband current transformer burden has been given by formula (3)(4) of 3.1.The inputs are uncorrelated, and the uncertainty of the active component R can be expressed as:

$$u_c(R) = \sqrt{c_1^2 u^2(U) + c_2^2 u^2(I) + c_3^2 u^2(\varphi)} \tag{8}$$

The sensitivity factor are $c_1 = 0.162$, $c_2 = -0.242$, $c_3 = -0.176$.

The uncertainty of the reactive component X can be expressed as:

$$u_c(X) = \sqrt{c_4^2 u^2(U) + c_5^2 u^2(I) + c_6^2 u^2(\varphi)} \tag{9}$$

The sensitivity factor are $c_4 = 0.118$, $c_5 = -0.0352$, $c_6 = 0.242$.

$u_c(R)$ is the synthetic standard uncertainty of the active component, Ω; $u_c(X)$ is the synthetic standard uncertainty of the reactive component, Ω; $u(U)$ is the standard uncertainty introduced by the power analyzer's voltmeter, V; $u(I)$ is the standard uncertainty introduced by the power analyzer's ammeter, A; and $u(\varphi)$ is the standard uncertainty introduced by the power analyzer's phase-difference measurement, (rad).

4.2 Individual standard uncertainty components

(1) The standard uncertainty introduced by the power analyzer voltmeter $u(U)$ is mainly due to the repeatability of the power analyzer voltage measurements $u_1(U)$ and the standard uncertainty introduced by the maximum allowable error of the voltage measurements $u_2(U)$.
(2)The standard uncertainty introduced by the power analyzer ammeter $u(I)$ is mainly due to the repeatability of the power analyzer's current measurement $u_1(I)$ and the standard uncertainty introduced by the maximum allowable error of the current measurement $u_2(I)$.
(3)The main sources of standard uncertainty introduced by the power analyzer phase difference measurement $u(\varphi)$ are the repeatability of the power analyzer voltage and current phase difference measurement $u_1(\varphi)$ and the standard uncertainty introduced by the maximum allowable error of the phase difference measurement $u_2(\varphi)$.

The standard uncertainty components for the active component R and the reactive component X are shown in **Table 1.**

Table 1. Standard uncertainty components

Standard uncertainty components	Sources of uncertainty	standardized uncertainty
$u_1(U)$	Repeatability of burden voltage measurements	0.00243V
$u_2(U)$	Power analyzer voltage measurement maximum allowable error	0.00130V
$u_1(I)$	Repeatability of measurement of circuit current	0.00209A
$u_2(I)$	Power analyzer current measurement maximum allowable error	0.00433A
$u_1(\varphi)$	Repeatability of voltage and current phase difference measurements	0.00038rad
$u_2(\varphi)$	Maximum Allowable Error of Power Analyzer Phase Difference Measurement	7.054×10^{-5} rad

4.3 Analysis of calibration results

From formula (8) (9), the synthetic standard uncertainty of the transmission is obtained as

$$u_c(R) = 0.00125\ \Omega$$

$$u_c(X) = 0.00038\ \Omega$$

Taking the inclusion factor k=2, the extended uncertainty is:

$$U(R) = ku_c(R) = 0.0025\ \Omega$$

$$U(X) = ku_c(X) = 0.0008\ \Omega$$

The measurement results of the wideband current transformer burden calibration device are

$$R = 0.2423 \pm 0.0025\ \Omega$$

$$X = 0.1761 \pm 0.0008\ \Omega$$

According to the maximum allowable error requirements of the wideband current transformer burden, the active and reactive component error should be within ±3%, then the active component error range of this gear is $0.2400 \pm 0.0072\ \Omega$ (including the external wire resistance of 0.06Ω), the reactive component error range is $0.1800 \pm 0.0054\ \Omega$, and the measurement result is within the allowable error range.

5. Conclusion

The wideband current transformer burden realizes the simulation of multiple loads in multiple frequency gears through series-parallel connection of resistors and inductors. Especially for the sensitivity of the inductive unit to the current frequency, four circuits are set up to realize the simulation of secondary loads of 50Hz, 400Hz, 800Hz and 1kHz at the power factor of 0.8, which provides a reliable simulation of the secondary loads of the wideband current transformers.

Based on the three-parameter impedance measurement method, a calibration method is proposed to measure the secondary load of the wideband current transformer burden by using a constant-current source and a power analyzer, and the measurement results are analyzed in terms of uncertainty. Compared with designing a new-design burden tester for calibration, this method is more flexible, can adapt to multiple current frequencies and multiple rated currents under wideband conditions, and is more time-saving for the early design of wideband current transformer burdens.

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