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DEVELOPMENT OF ON-SITE CALIBRATION METHOD FOR CURRENT TRANSFORMER TESTING SYSTEM

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Abstract: Methods for on-site calibration of the components in current transformer (CT) testing systems in industry have been developed, which do not require any component to be detached from the systems. The method utilizes several travelling transfer standards. The on-site calibration method using these travelling transfer standards has been successfully applied to calibration of CT testing systems in industries.

Keywords: Current transformer, CT testing system, CT comparator, calibration.

1. INTRODUCTION

Manufacturers in heavy electrical industry measure the ratio error and phase displacement of current transformers (CTs) by using a CT testing system. The calibration of such systems in factories is strictly required every year for quality control of their products. It is very difficult to carry a CT testing system to a national standards laboratory for calibration, because of its frequent use for product-quality evaluation, its many components, and its great weight. Therefore, an on-site calibration method for CT testing systems in industry is required, using a portable travelling transfer standard.

In this study, we have developed portable travelling transfer standards to calibrate CT testing systems of industry *in situ* without detaching any components from the system. We describe the theoretical principles and the method for on-site calibrations, together with an application example.

2. CONSTITUTION OF CT TESTING SYSTEM

Figure 1 shows a CT testing system for measuring both ratio error and phase displacement of a CT under test. The CT testing system consists of a current source, a standard CT, a CT under test, a CT comparator, and a CT burden (Z_b). An AC current is applied to the primary windings of both the standard CT and the CT under test, and the CT comparator measures the ratio error and the phase displacement by comparing the secondary currents of the CT under test with those of the standard CT, which has negligible error compared with the CT under test. According to the International Electrotechnical Commission (IEC)[1], the ratio error and phase displacement of a CT under test should be measured by connecting the external burden in series to the secondary of the CT under test.

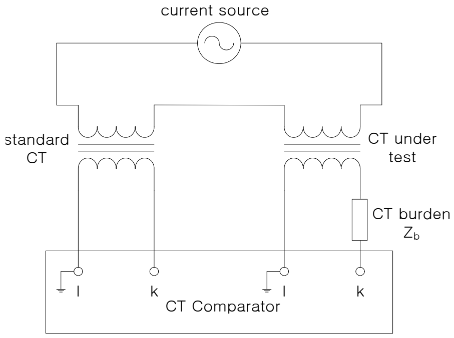

Figure 1. The constitution of the CT testing system of industry

3. ON-SITE CALIBRATION OF CT TESTING SYSTEM OF INDUSTRY

For on-site calibration of a CT testing system in industry, the standard CT, the CT comparator, and the CT burden must be calibrated.

A. On-site calibration of standard CT

Before starting the on-site calibration, both the ratio error and phase displacement of the travelling standard CT at the same current ratios as the standard CTs of industry should be known. After carrying the travelling standard CT to a industry, the ratio error and phase displacement of the travelling standard CT are measured by connecting it to the side of the CT under test in Figure 1. The ratio error (or phase displacement) of the travelling transfer standard CT is obtained by adding the ratio error (or phase displacement) of the standard CT of industry to the ratio error (or phase displacement) reading of the travelling standard CT from the CT comparator, as follows[2, 3]:

$$\alpha_x = \alpha_r + \alpha_s \tag{1}$$

$$\beta_x = \beta_r + \beta_s \qquad (2)$$

where

α_x : ratio error of the travelling standard CT

β_x : phase displacement of the travelling standard CT

α_r : ratio error reading of the travelling standard CT from the CT comparator

β_r : phase displacement reading of the travelling standard CT from the CT comparator

α_s : ratio error of the standard CT of industry

β_s : phase displacement of the standard CT of industry.

The ratio error and phase displacement of the standard CT of industry can be obtained by subtracting the ratio error (α_r) and phase displacement (β_r) readings of the CT comparator measured at the industry from the ratio error (α_x) and phase displacement (β_x) of the travelling standard CT measured at KRISS, respectively, according to equations (1) and (2).

B. On-site calibration of CT comparator

To evaluate the CT comparator of the industrial CT testing system, non-reactive standard resistors were used as travelling transfer standards. When a non-reactive resistor with an AC–DC difference less than 10^{-5}[4], i.e. $(X_b/R_b) < 10^{-5}$, is used as the external burden of the CT under test in Figure 1, then the ratio error (α_b) and phase displacement (β_b) with external burden are as follows[3, 5].

$$\alpha_b = -(G_m R_2 + B_m X_2 + G_m R_b) = \text{constant} - G_m R_b \qquad (3)$$

$$\beta_b = B_m R_2 - G_m X_2 + B_m R_b = \text{constant} + B_m R_b \qquad (4)$$

The parameters in equations (3) and (4) are defined as follows:

$Z_2 = R_2 + jX_2$: secondary leakage impedance of CT

$G_m = \dfrac{R_m}{R_m^{\ 2} + X_m^{\ 2}}$: conductive component of the excitation admittance

$B_m = \dfrac{X_m}{R_m^{\ 2} + X_m^{\ 2}}$: susceptive component of the excitation admittance

$Z_b = R_b + jX_b$: impedance of the external burden.

For a fixed secondary current and a constant temperature during a set of measurements, both the ratio error (α_b) and the phase displacement (β_b) of the CT under test in equations (3) and (4) are proportional to the resistance of the external burden, R_b. Consequently, by plotting α_b and β_b as a function of R_b, we can evaluate the linearity of both ratio error and phase displacement measured in the CT comparator.

Figure 2 shows the ratio error measured as a function of the resistance of the burden using the industrial CT comparators at companies A and B. The solid lines in Figure 2 were fitted by equation (3). The ratio error in company A has good linearity in the range of 0.01–2 Ω. The ratio error at 4 Ω and 10 Ω deviates by +0.014 % and +0.052 % from the solid line, respectively. Meanwhile, the ratio error in company B has good linearity in the range of 0.01–2 Ω. The ratio error at 10 Ω deviates by +0.035 % from the solid line. The linearity of the CT comparators in the two companies is good at small ratio errors, but the deviation increases as the ratio error increases. Therefore, the ratio errors at 4 Ω and 10 Ω in the CT comparators were corrected in the direction of the arrows shown in Figure 2. In the similar manner as Figure 2, we evaluate the linearity of phase displacement.

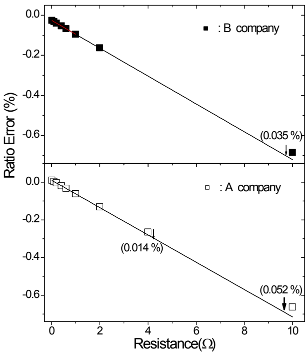

Figure 2. Changes in ratio error as a function of the resistance of the standard resistor burden

C. On-site calibration of CT burden

Figure 3 shows the CT testing system for measuring a CT burden used in industry. The shunt resistor *Z* for measuring the CT burden is connected in parallel with the secondary of the CT, as shown in Figure 3.

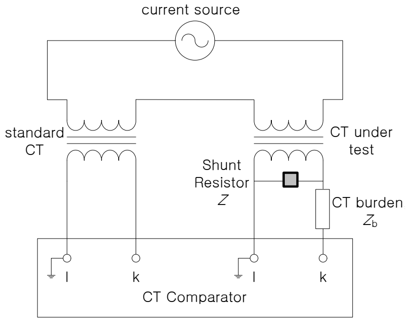

Figure 3. CT burden measurement system using a shunt resistor

The ratio error ($\alpha_b{}'$) and phase displacement ($\beta_b{}'$) with the shunt resistor are as follows[6,7]:

$$\alpha_b'-\alpha_b=-\frac{R_b}{R} \tag{5}$$

$$\beta_b'-\beta_b=-\frac{X_b}{R} \tag{6}$$

where α_b and β_b are the ratio error and phase displacement with an external burden, respectively. In equation (5), the resistance of the leads and the input impedance of the CT comparator (r) connected to the CT burden are included in R_b. In eq. (6), the reactance (x) of the leads connected to the CT burden is also included in X_b. This implies that R_b in eq. (5) and X_b in equation (6) are in practice replaced by ($R_b + r$) and ($X_b + x$), respectively. The impedance of the leads and the input impedance of the CT comparator (~0.04 Ω) connected to the CT burden cannot be neglected compared with that (0.151~1.686 Ω) of the CT burden.

In equation (5), because the value of α_b is constant at a fixed burden and current, the ratio error α_b' caused by the presence of the shunt resistor is proportional to the reciprocal of the resistance, 1/R. When the ratio error is measured as a function of the resistance of the shunt resistor (1/R), the slope of the straight line obtained by fitting the data corresponds to $-R_b$. Thus, we can obtain the value of R_b of the burden under study. Similarly, for the phase displacement of equation (6), the value of β_b is constant at a fixed burden and current. When the phase displacement is measured as a function of the resistance of the shunt resistor (1/R), the slope of the straight line obtained by fitting the data corresponds to $-X_b$. Thus, we can obtain the value of X_b of the burden under study. From the values of the resistance (R_b) and reactance (X_b) obtained by the fitting procedure, the apparent power and the power factor of the burden are given by the following relationships:

$$\text{apparent power(VA)}=I_b^{\ 2}\sqrt{R_b^{\ 2}+X_b^{\ 2}} \tag{7}$$

$$\text{power factor(PF)}=\frac{R_b}{\sqrt{R_b^{\ 2}+X_b^{\ 2}}} \tag{8}$$

where I_b = 5 A is the secondary current of the CT, measured using a digital multimeter.

Figure 4 shows the measurement results for ratio error as a function of the reciprocal of the resistance for a representative burden of an apparent power of 10 VA and a power factor of 0.8. The measurement was performed for the CT under test with the rated current ratio of 100 A:5 A at a secondary current of 5 A.

As shown in Figure 4, the slope of the straight line obtained from the best fit of the data was –0.4162 Ω and this value corresponds to –($R_b + r$), including the lead resistance and input impedance of the CT comparator (r). To obtain the contribution of the r to $R_b + r$, the ratio error was remeasured as a function of the resistance of the shunt resistor after the CT burden was removed and the leads on both sides of this burden were shorted to each other. The slope of the straight line corresponds to the lead resistance and input impedance, r = 0.0396 Ω. Therefore, the resistance of the CT burden alone is R_b = 0.3766 Ω.

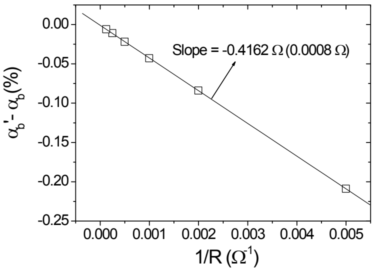

Figure 4. Measurement results for the ratio error of a CT as a function of the resistance of the shunt resistor

Figure 5 shows the measurement results for phase displacement as a function of the reciprocal of the resistance for a representative burden of an apparent power of 10 VA and a power factor of 0.8. The measurement was performed for a CT under test with the same current ratio and secondary current as the previous measurement for ratio error. The slope of the straight line obtained from the best fit for the data was –0.252 Ω and this value corresponds to –(X_b + x), including the lead reactance (x). To obtain the contribution of the lead reactance (x) to the total reactance (X_b + x), the phase displacement was remeasured as a function of the resistance of the shunt resistor after the CT burden was removed and the leads on both sides of this burden were shorted, as in the previous measurement. The slope of the straight line corresponds to the lead reactance, x = 0.004 Ω. Therefore, the reactance of the CT burden alone is X_b= 0.248 Ω.

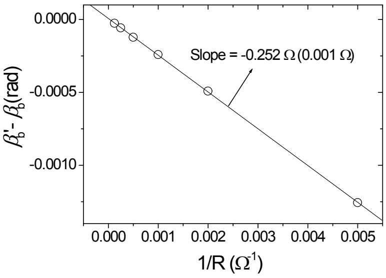

Figure 5. Measurement results for the phase displacement of a CT as a function of the resistance of the shunt resistor

From the values of the resistance and reactance obtained at the rated burden of 10 VA and a power factor of 0.8, the apparent power and the power factor of this burden were obtained using equations (7) and (8), respectively. In the same manner, the values of the resistance, reactance, apparent power, and power factor obtained at the other rated burdens, i.e., 3.75 VA/0.8 to 40 VA/0.8, are summarized in Table 1.

Table 1. Apparent power and power factor calculated from the resistance and reactance values of the CT burden

Rated apparent power/ power factor	Resistance (R_b)	Reactance (X_b)	Apparent power (VA)	Power factor
2.5 VA/0.8	0.139	0.056	3.759	0.927
3.75 VA/0.8	0.180	0.092	5.045	0.891
5 VA/0.8	0.221	0.117	6.251	0.884
10 VA/0.8	0.377	0.248	11.276	0.835
15 VA/0.8	0.536	0.360	16.144	0.830
40 VA/0.8	1.358	0.999	42.140	0.805

4. CONCLUSIONS

We have developed travelling transfer standards to calibrate CT testing systems consisting of a standard CT, a CT comparator, and a CT burden. The travelling transfer standards are: a standard CT; a non-reactive resistor with a negligible AC–DC difference; and a shunt resistor with a negligible AC–DC difference. Firstly, the standard CT in industry is calibrated by using the travelling standard CT, which is traceable to the high-current standards of the national standard laboratory. Secondly, both the ratio error and phase displacement of the CT comparator of industry are calibrated by using a non-reactive resistor with an AC–DC difference less than 10^{-5}. Lastly, the CT burden in industry is calibrated by using the shunt resistor. With these travelling transfer standards, we are successfully conducting on-site calibrations of industrial CT testing systems.

5. REFERENCES

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