Development of an On-site Calibration Method for a Current Transformer Testing System

Jae Kap Jung, Sang Hwa Lee, Jeon Hong Kang and Kyu Tae Kim
Division of Physical Metrology,
Korea Research Institute of Standards and Science
Daejeon 305-340, Republic of Korea
jkjung@kriss.re.kr

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

I. 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.

II. CONSTITUTION OF CT TESTING SYSTEM

Figure 1 shows a CT testing system for measuring both 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.

III. 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]:

\[
\alpha_\text{t} = \alpha_\text{r} + \alpha_\text{c},
\]

(1)
\[ \beta_s = \beta_r + \beta_a \]  

(2)

where

- \( \alpha_r \): ratio error of the travelling standard CT
- \( \beta_r \): phase displacement of the travelling standard CT
- \( \alpha_s \): ratio error reading of the travelling standard CT from the CT comparator
- \( \beta_s \): phase displacement reading of the travelling standard CT from the CT comparator
- \( \alpha_s \): ratio error of the standard CT of industry
- \( \beta_s \): 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 (\( \alpha_r \)) and phase displacement (\( \beta_r \)) readings of the CT comparator measured at the industry from the ratio error (\( \alpha_s \)) and phase displacement (\( \beta_s \)) of the travelling standard CT measured at KRISS, respectively, according to eqs. (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\(^{-5}\), i.e. (\( X_0/R_0 \)) < 10 \(^{-5}\), is used as the external burden of the CT under test in Figure 1, then the ratio error (\( \alpha_b \)) and phase displacement (\( \beta_b \)) with external burden are as follows\(^6, 5\).

\[
\alpha_b = (G_a R_2 + B_a X_2 + G_a R_b) = \text{constant} - G_a R_b.
\]  

(3)

\[
\beta_b = B_a R_2 - G_a X_2 + B_a R_b = \text{constant} + B_a R_b.
\]  

(4)

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

- \( Z_a = R_a + jX_a \): secondary leakage impedance of CT
- \( G_a = \frac{R_a}{R_a^2 + X_a^2} \): conductive component of the excitation admittance
- \( B_a = \frac{X_a}{R_a^2 + X_a^2} \): 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 (\( \alpha_b \)) and the phase displacement (\( \beta_b \)) of the CT under test in eqs. (3) and (4) are proportional to the resistance of the external burden, \( R_b \). Consequently, by plotting \( \alpha_b \) and \( \beta_b \) 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 eq. (3). The ratio error in company A has good linearity in the range of 0.01–2 \( \Omega \). The ratio error at 4 \( \Omega \) and 10 \( \Omega \) 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 \( \Omega \). The ratio error at 10 \( \Omega \) 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 \( \Omega \) and 10 \( \Omega \) 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.

\[ \text{Figure 2. Changes in ratio error as a function of the resistance of the standard resistor burden} \]

C. On-site evaluation 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.

\[ \text{Figure 3. CT burden measurement system using a shunt resistor} \]
The ratio error ($\alpha$) and phase displacement ($\beta$) with the shunt resistor are as follows:[6,7]

$$\alpha = -\frac{R}{r}$$ \hspace{1cm} (5)

$$\beta = -\frac{X}{r}$$ \hspace{1cm} (6)

where $\alpha$ and $\beta$ are the ratio error and phase displacement with an external burden, respectively. In eq. (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 eq. (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 ($\sim 0.04 \Omega$) connected to the CT burden cannot be neglected compared with that ($0.151 \sim 1.686 \Omega$) of the CT burden.

In eq. (5), because the value of $\alpha$ is constant at a fixed burden and current, the ratio error $\alpha$ 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 eq. (6), the value of $\beta$ 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:

$$\text{apparent power (VA)} = I_b^2 \sqrt{R_b^2 + X_b^2}$$ \hspace{1cm} (7)

$$\text{power factor (PF)} = \frac{R_b}{\sqrt{R_b^2 + X_b^2}}$$ \hspace{1cm} (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 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 $-0.252 \Omega$ and this value corresponds to $-X_b$. Therefore, the reactance of the CT burden alone is $X_b = 0.248 \Omega$.

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 $-0.4162 \Omega$ and this value corresponds to $-R_b$. Therefore, the lead reactance $x = 0.004 \Omega$. Therefore, the reactance of the CT burden alone is $X_b = 0.248 \Omega$.

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 eqs. (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

<table>
<thead>
<tr>
<th>Rated apparent power/</th>
<th>Resistance (Rb)</th>
<th>Reactance (Xb)</th>
<th>Apparent power (VA)</th>
<th>Power factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 VA/0.8</td>
<td>0.139</td>
<td>0.056</td>
<td>3.759</td>
<td>0.927</td>
</tr>
<tr>
<td>3.75 VA/0.8</td>
<td>0.180</td>
<td>0.092</td>
<td>5.045</td>
<td>0.891</td>
</tr>
<tr>
<td>5 VA/0.8</td>
<td>0.221</td>
<td>0.117</td>
<td>6.251</td>
<td>0.884</td>
</tr>
<tr>
<td>10 VA/0.8</td>
<td>0.377</td>
<td>0.248</td>
<td>11.276</td>
<td>0.835</td>
</tr>
<tr>
<td>15 VA/0.8</td>
<td>0.536</td>
<td>0.360</td>
<td>16.144</td>
<td>0.830</td>
</tr>
<tr>
<td>40 VA/0.8</td>
<td>1.358</td>
<td>0.999</td>
<td>42.140</td>
<td>0.805</td>
</tr>
</tbody>
</table>

IV. 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.

REFERENCES