

Development and application of an on-site calibration method for voltage transformer testing systems

Jae Kap Jung, Sang Hwa Lee, Jeon Hong Kang, Sung Won Kwon,
and Young Tae Park

*Korea Research Institute of Standards and Science
P. O. Box 102, Yuseong, Daejeon 305-340, Republic of Korea,
Phone : +82 42 8685759, Fax : +82 42 8685018, Email : jkjung@kriss.re.kr*

Abstract- The ratio error and phase displacement of a voltage transformer (VT) under test are measured by using a VT testing system that consists of a voltage source, a standard VT, a VT under test, a VT comparator, and a VT burden. Methods for on-site calibration of the components in industrial VT testing systems that do not require the removal of the components from the systems have been developed. Our method utilizes several portable travelling transfer standards: standard VTs, a calculable wide-ratio-error VT and a decade resistor. The travelling standard VT is used for the evaluation of an industrial standard VT and a voltage source. The calculable wide-ratio-error VT are used to evaluate the linearity of the errors in the industrial VT comparator. The decade resistor is used to evaluate the industrial VT burden. The on-site calibration method using these travelling transfer standards has been applied to the calibration of industrial VT testing systems.

I. Introduction

A voltage transformer (VT) has a ratio error and a phase displacement because of the magnetizing current of the core and the primary leakage impedance [1, 2]. Heavy electric factories producing VTs measure the ratio error and phase displacement of a VT under test using a VT testing system (VTTS). Meanwhile, the calibration of industrial VTTSs is strictly required every year for quality control of the products. However, it is very difficult to carry a VTTS 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 industrial VTTSs is required, using some kind of portable travelling transfer standard.

In this study, we have developed portable travelling transfer standards to calibrate VTTSs *in situ* without removing the components from the system. We describe the theoretical principles and the methods for on-site calibration, together with an industrial application example.

II. Constitution of VTTS

Figure 1 shows the VTTS for measuring both ratio error and phase displacement of an industrial VT under test. The VTTS consists of an AC high-voltage source, a standard VT, the VT under test, a VT comparator and a VT burden. The AC high voltage is applied to the primary of both the standard VT and the VT under test, and the VT comparator measures the ratio error and the phase displacement by comparing the secondary voltage of the VT under test with that of the standard VT, which has negligible errors compared with the VT under test. According to the International Electrotechnical Commission (IEC) [3], the ratio error and phase displacement of a VT under test should be measured by connecting the external burden in parallel to the secondary terminal of the VT under test.

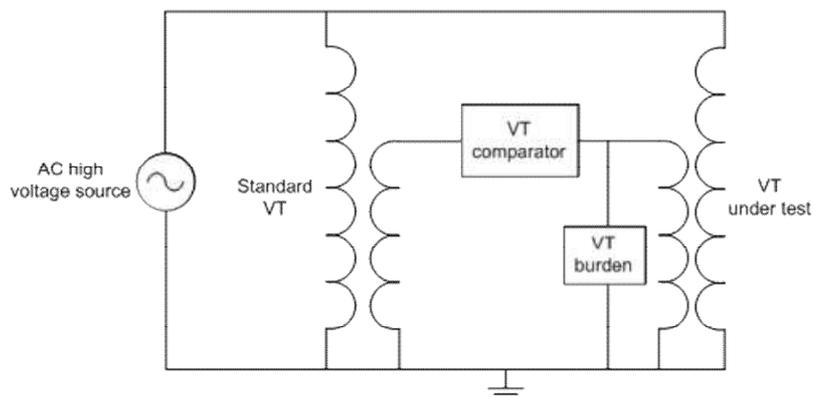


Figure 1. The VT testing system

III. On-site calibration of VTTS

For on-site calibration of an industrial VTTS, the standard VT, the voltage source, the VT comparator and the VT burden are calibrated without removing the components from the system.

A. On-site calibration of an industrial standard VT

To calibrate the industrial standard VT of the VTTS in industry, the travelling transfer standard VT is used. Before starting the on-site calibration, both the ratio error and the phase displacement of the travelling standard VT should be known. After carrying the travelling standard VT to the factory, the ratio error and phase displacement of the travelling standard VT are measured by connecting it to the side of the VT under test as shown in figure 1. The ratio error (or phase displacement) of the travelling standard VT is obtained by adding the ratio error (or phase displacement) of the industrial standard VT to the ratio error (or phase displacement) reading of the travelling standard VT from the VT comparator, as follows [4]:

$$\alpha_x = \alpha_r + \alpha_s, \quad (1)$$

$$\beta_x = \beta_r + \beta_s, \quad (2)$$

where:

α_x is the ratio error of the travelling standard VT,

β_x is the phase displacement of the travelling standard VT,

α_r is the ratio error reading of the travelling standard VT from the VT comparator,

β_r is the phase displacement reading of the travelling standard VT from the VT comparator,

α_s is the ratio error of the industrial standard VT, and

β_s is the phase displacement of the industrial standard VT.

The ratio error (α_s) and phase displacement (β_s) of the industrial standard VT can be obtained by subtracting the ratio error (α_r) and phase displacement (β_r) readings of the VT comparator measured in an

industry from the ratio error (α_x) and phase displacement (β_x) of the travelling standard VT measured at the Korea Research Institute of Standards and Science (KRISS), respectively, according to Eqs. (1) and (2).

B. On-site calibration of an industrial high-voltage source

To calibrate the industrial high-voltage source of the VTTS at an industry, the same travelling standard VTs as in Section A are used. The ratio error of the travelling standard VT is measured by connecting it to the side of the VT under test as shown in figure 1. The RMS voltage (V) of the industrial voltage source is expressed as [5–6]

$$V = NV_s(1 - \alpha_x), \quad (3)$$

where:

N is the rated transformation ratio of the travelling standard VT,

V_s is the actual secondary voltage of the travelling standard VT,

α_x is the ratio error of the travelling standard VT.

Therefore, the RMS voltage (V) of the industrial voltage source is calibrated by measuring the secondary voltage (V_s) using a calibrated voltmeter according to Eq. (3). Here, the ratio error of the travelling standard VT is already known.

C. On-site calibration of an industrial VT comparator

The ratio error (α) of the calculable wide-ratio-error VT is written as [3] ;

$$\alpha \equiv \alpha_t + \alpha_s \quad (4)$$

where:

$$\alpha_t = 100 \cdot \left(N \left(\frac{n_2}{n_1} \right) - 1 \right) [\%], \quad (5)$$

$$\alpha_s = 100 \cdot \left(-N \delta \left(\frac{n_2^2}{n_1^2} \right) \right) [\%]. \quad (6)$$

N : the rated transformation ratio of the VT.

n_1 : primary turn number in the core of the VT

n_2 : secondary turn number in the core of the VT

δ : intrinsic error of the VT

The first term (α_l) in Eq. (4) is the turn-ratio error, which depends linearly on the turn ratio, $\frac{n_2}{n_1}$. The turn-ratio error of the VT with turn ratio of wide range can be calculated according to Eq. (5). Thus the calculable wide-ratio-error VT is used to evaluate the linearity of the ratio error of the VT comparator.

D. On-site calibration of an industrial VT burden

Figure 2 shows the VTTS for measuring industrial VT burdens. The series resistor R_s for measuring the VT burden is connected in series with the secondary of the VT under test. The ratio error and phase displacement with the series resistor are expressed as follows [5, 7].

$$\alpha_b \{R_s\} = \alpha_b + [(\alpha_0 - 1)G_b - \beta_0 B_b] R_s \quad (7)$$

$$\beta_b \{R_s\} = \beta_b + [(\alpha_0 - 1)B_b + \beta_0 G_b] R_s \quad (8)$$

In Eq. (7), because the values of α_b , α_0 , β_0 , G_b and B_b are constant for a fixed burden and voltage, $\alpha_b \{R_s\}$ is proportional to R_s . When the ratio error is measured as a function of the resistance of the series resistor, the slope of the straight line of best fit for the data corresponds to $[(\alpha_0 - 1)G_b - \beta_0 B_b]$.

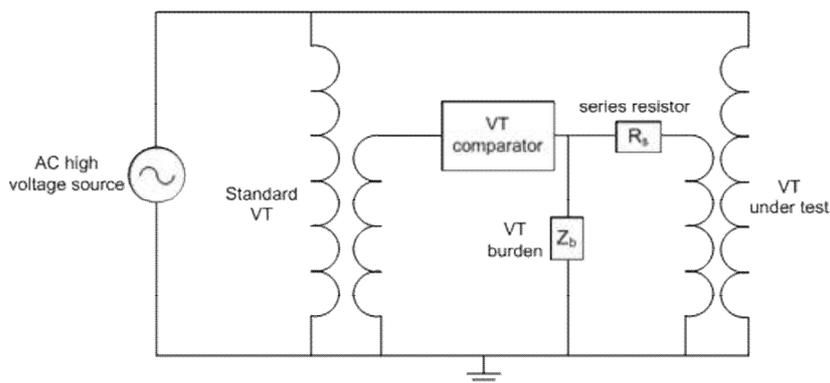


Figure 2. VT burden measurement system using a series resistor, R_s

In Eq. (8), because the value of β_b is constant at a fixed burden and voltage, $\beta_b \{R_s\}$ is proportional to R_s . When the phase displacement is measured as a function of the resistance of the resistor, the slope of the straight line of best fit for the data corresponds to $[(\alpha_0 - 1)B_b + \beta_0 G_b]$. Because α_0 and β_0 for the VT under test were measured earlier in the calibration, the values of the conductance (G_b) and susceptance (B_b) of the VT burden are obtained from the two fitting procedures. Thus, the apparent power (AP) and power factor (PF) of the burden under test are given by the following relationships:

$$AP = V_b^2 \sqrt{G_b^2 + B_b^2}, \quad (9)$$

$$PF = \frac{G_b}{\sqrt{G_b^2 + B_b^2}}, \quad (10)$$

where V_b is the secondary voltage measured using a calibrated digital voltmeter.

IV. Conclusion

We have developed portable travelling transfer standards to calibrate voltage transformer (VT) testing systems consisting of a standard VT, a voltage source, a VT comparator and a VT burden. The developed travelling transfer standards are: standard VTs; a calculable wide-ratio-error VT; and series resistors. Firstly, the industrial standard VT and voltage source are calibrated by using the travelling standard VT, which is traceable to the high-voltage standards of the national standards laboratory. Secondly, the ratio error of the industrial VT comparator is calibrated by using the calculable wide-ratio-error VT with a ratio error range of -10% to $+10\%$. Lastly, the industrial VT burden is calibrated using the series resistor. With these travelling transfer standards, we are conducting on-site calibrations of industrial VT testing systems.

References

- [1] P. J. Betts, "Calculated temperature coefficients of transformers", Australia National Measurement Laboratory *Technical Paper* no 4, 1–13, 1977.
- [2] J. K. Das, "Determination of characteristics of a three-winding potential transformer and predetermination of errors", *I. E. J.*, vol. 51, pp. 51–58, 1970.
- [3] International Electrotechnical Commission *Instrument Transformers: Part 2. Inductive Voltage Transformer IEC 60044-2* (Geneva: International Electrotechnical Commission), 1999.
- [4] I. E. Zinn, "PTB testing instructions instrument transformers", *PTB testing instructions*, vol. 12, pp. 85–86, 1977.
- [5] W. E. Anderson, "A calibration service for voltage transformers and high-voltage capacitors", *NBS Measurement Services Special Publication*, vol. 250–33 (Gaithersburg, MD: National Bureau of Standards) pp. 12–13, 1988.
- [6] F. K. Harris, W. C. Sze, N. L. Kusters, O. Petersons and W. J. M. Moore, "An international comparison of voltage-transformer calibration to 350 kV", *IEEE Trans. Commun. Electron.*, vol. 70, pp. 18–19, 1964.
- [7] J. K. Jung, S. W. Kwon, K. T. Kim and M. Kim, "A study on ratio error and phase angle error caused by an external burden in voltage transformer", *Trans. KIEE.*, vol. 53C, pp. 137–14, 2004.