TECHNICAL notes

A PUBLICATION OF MULTI-AMP CORPORATION

Instrument Transformer Testing

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Utilities have been faced with the task of testing instrument transformers ever since the current and voltage became too large to apply to the energy meter directly.

Today, utilities use instrument current transformers (CT) that cover a range of 5 amperes to 50,000A and potential transformers (PT) that cover the range of 120V to 765kV. The numbers of instrument transformers are largest in the service and distribution voltage ranges and typically cover currents of 10A to 1200A for CTs and 120V to 15kV for PTs. The numbers of instrument transformers outside of the above range are smaller but are equally or even more important because they are used on very large customers or on interconnections. Small metering errors on such accounts translate into large dollar billing errors, therefore the importance of such installations should not be underestimated.

The following are reasons for routine instrument transformer testing and the various techniques that are available for conducting the tests.

Reasons For Testing

The reasons for testing CTs and PTs may be as varied as the utilities engaged in their testing. Generally speaking, however, the main reasons quoted by utilities for testing CTs and PTs are:

a) Government or regulatory commission requirements.
b) Utility accuracy guidelines.
c) Quality control on purchases.

Government Requirements

In most countries, there are laws that specify the legal units of measurement and the accuracy required in commercial transactions. These laws apply to a full range of goods from agricultural products to energy and specify the performance and characteristics of electrical power and energy measuring devices and auxiliary equipment. The same laws or regulations also specify the testing frequency for meters and auxiliaries. Interestingly electric power and energy meters traditionally have been on a fixed period retesting cycle, where each meter must be retested within a given time period, usually four to eight years. The superior performance of the modern induction meters, with magnetic suspension and Alnico magnets, has made the fixed test period obsolete and has resulted in the almost universal adoption of sample testing for such meters.

Instrument transformers exhibit excellent performance with respect to service time and are typically required to be tested only once, just prior to their installation. With such requirements, many instrument transformers are tested only once during their useful lifetime.

Utility Accuracy Guidelines

Many utilities have adopted guidelines that are more strict than the minimum of the government regulations. Such guidelines may contain higher accuracy specifications or special quality control procedures. Utilities know that instrument transformers are installed at larger customer sites and are responsible for a major portion of their revenue. By paying due attention to instrument transformers and other equipment in the metering installation, the utilities protect their revenue and maintain good customer relations.

Generally speaking, the utility accuracy guidelines are more stringent with larger loads and may even impose special accuracy requirements on large ratio instrument transformers as well as metering equipment used on such loads.

Quality Control Criteria

Some utilities perform accuracy tests on instrument transformers as part of their quality control procedure. Such utilities purchase instrument transformers according to the minimum requirements specified by government or regulatory commissions and wish to ascertain they are receiving goods that satisfy the purchase description.

Testing Techniques

The accuracy testing techniques for instrument transformers can be divided into the absolute methods and relative methods.

Absolute Methods

The original absolute method for calibrating current transformers consisted of two shunts and a comparator circuit. One of the shunts was placed in the primary circuit, while the other was placed in the secondary circuit of the current transformer under test. From a knowledge of the shunts and constants in the comparator circuit, the operator could readily determine the errors of the test transformer. This method had several shortcomings, which include:

- self-heating errors of primary shunts
- phase errors of high current shunts
- low sensitivity

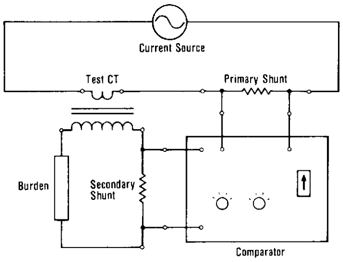

FIGURE 1. *Absolute methods of CT calibration*

The result of these developments is the commercial availability of several automatic instrument transformer comparators. Some of these use watt-metric detectors that measure and digitally indicate the ratio and phase errors; some use sampling techniques to measure the error signals at peak and zero crossing of the reference and then convert these into ratio and phase error indications; still others use self-balancing bridge circuits complete with multiplying (wattmetric) null detectors, all under the control of a microprocessor.

Needless to say, the modern comparators can perform many tasks, such as automatic zeroing and calibration; testing both CTs and PTs; comparing test results with accuracy parallelograms to determine accuracy class. In addition, the burden presented by the electronic comparator to both the reference standard and the test transformers has been reduced dramatically. A modern comparator will present a burden of less than 0.5VA to the standard transformer, in contrast to the 15VA of some older comparators. This reduction in burden has made it easier to design and build reference standard transformers of high accuracy.

Reference Standard Current Transformers

To perform accuracy tests of CTs using the relative method, a calibrated reference standard CT (RSCT) of nominally the same ratio is needed. In order to avoid the application of corrections, it is desirable that the RSCT have errors small enough to be neglected. For this application, special CTs exhibiting errors of only a few hundredths of one percent are typically used. The task of designing and building such CTs for the high burdens of the older comparators was rather difficult. The availability of modern high-permeability nickel alloys and the low burdens of modern comparators have made this much easier. The use of two-stage current transformers [6] makes it possible to build reference CTs with errors of only a few parts per million over a very wide current range.

Reference Standard Voltage Transformers

The availability of accurate reference standard voltage transformers (RSVT) has never been as good as that of the RSCTs. The difficulty lies in the non-linearities of electrical steels and the associated shifts in ratio and phase errors. Such transformers exhibit good accuracy over a very limited voltage range and only a particular burden. The errors of RSVTs become larger at higher voltages where cascade construction has to be employed to control the physical size of the transformers.

The advent of modern electronics has made an electronic voltage transformer (EVT) possible. This device consists of a capacitive divider followed by a high gain amplifier to supply power to the load. Two configurations of EVTs are available. One uses a passive capacitive divider with a non-inverting amplifier to supply output power (Figure 8). This configuration does not provide an isolated output. The output and input have a common ground connection and the passive divider is sensitive to strays and must be completely shielded. The other configuration uses an active divider. It provides an isolated output and its configuration is inherently insensitive to stray ground capacitances.

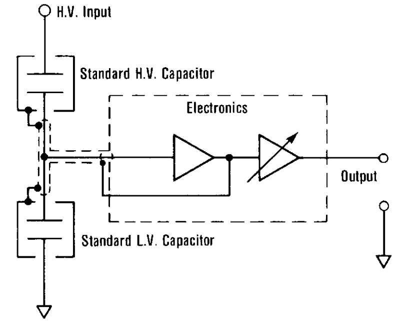

FIGURE 8. *EVT with passive capacitive divider*

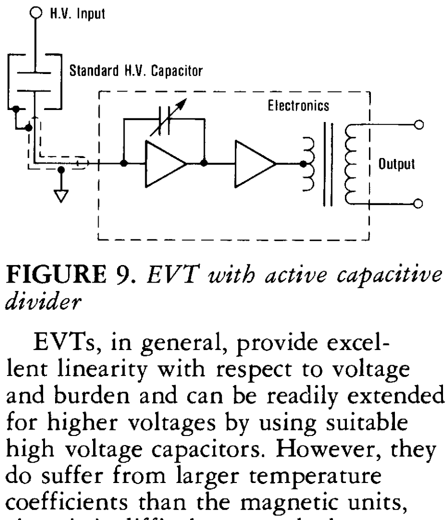

FIGURE 9. *EVT with active capacitive divider*

EVTs, in general, provide excellent linearity with respect to voltage and burden and can be readily extended for higher voltages by using suitable high voltage capacitors. However, they do suffer from larger temperature coefficients than the magnetic units, since it is difficult to match the coefficients of the high and low voltage capacitors.

Another advantage of the EVTs is that they can be adjusted to have small ratio and phase angle errors. Plus, they provide switch-settable ratios that are very accurate over a wide range of voltage.

Auxiliary Equipment

In addition to a reference standard transformer and comparator, a current or voltage supply and a set of burdens are required to test instrument transformers.

The power requirements are small for low current (<1200A) and low voltage (15kV) testing. For higher currents, the power requirements increase dramatically, especially if high voltage CTs are to be tested.

Test Sets

Many users find it convenient to purchase complete test sets or test systems for their instrument transformer test needs. Such systems come completely assembled and pre-tested and do not require high competence on the part of the operator.

A CT test system includes a current supply, a reference standard CT with a number of ratios, a CT comparator, a set of CT burdens and provisions for demagnetizing the test CT.

A PT test system will include a voltage supply, a reference standard PT with a number of ratios, a PT comparator and a set of PT burdens. Some suppliers provide CT and PT systems. There are certain economies to be gained in CT/PT test systems, since only one metered supply source and one comparator (CT and PT) is required.

When considering a test system, the user should ask the following:

1. Does the equipment have all the required ratios? Does it have additional ratios that may be required in the future? Will it accommodate /3 ratios?
2. Can the equipment test 5- and 1-ampere CTs?
3. Is the range of the comparator wide enough to compare accurate standard transformers and provide ppm resolution? Can it also measure transforms that may be out 10 percent or more in ratio?
4. Is the equipment easy to set up for various ratios?
5. Does the equipment demagnetize the test CT?
6. Is the equipment easy and simple to operate?

References

[1] H. S. Baker, "Current Transformer Ratio and Phase Error by Test Ring Method." AIEE Proceedings, 1917, pp. 1172-83.

[2] P. N. Miljanic, N. L. Custers and W. J. M. Moore, "The Development of the Current Comparator, a High-Accuracy A-C Ratio Measuring Device." AIEE Proceedings, 1962, pp. 359-68.

[3] E. Zinn, "An Electronic Self-Balancing Instrument Transformer Testing Device." IEEE Trans. Vol. I, M-21, December 1971, pp. 291-6.

These limitations were recognized very early and led to the development of the "Test Ring Method" [1], which in turn led to the development of the "Current Comparator" [2]. The current comparator is the modern method of determining current ratios and is capable of accuracies of better than one part per million. See figures below:

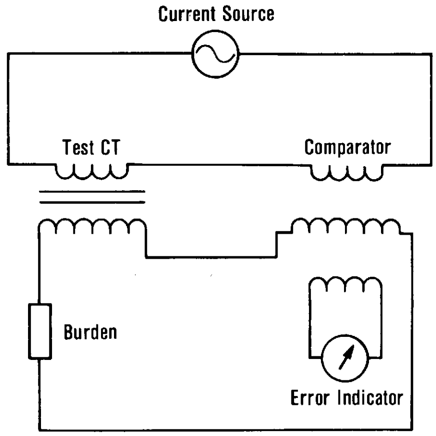

FIGURE 2. *Baker's current comparator*

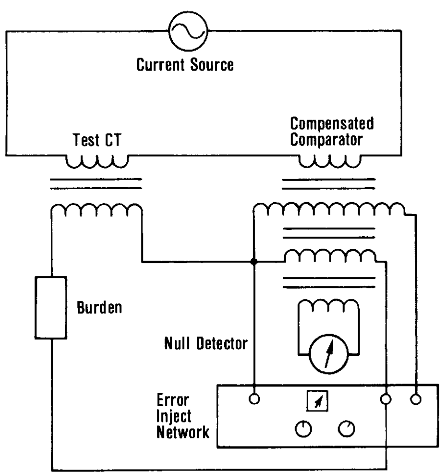

FIGURE 3. *Compensated current comparator*

The absolute method for voltage transformer measurements used a resistive divider (Figure 4). A suitably constructed test set compared the output voltage of the test voltage transformer with that of a precision resistive voltage divider. This method functioned well for lower voltages, where the heating of the resistors is moderate and the phase shift, due to stray capacitance, could be controlled by means of an auxiliary guard circuit. This method could not be used for voltages above 50kV due to excessive heating and phase angle problems.

For higher voltages, the capacitive divider was developed (Figure 5). In this circuit, a gas dielectric, loss-free capacitor was used as the high voltage element in a divider. As with the resistive divider, a comparator was used to compare the output voltage of the test voltage transformer with that of the capacitive divider.

The modern method of calibrating voltage transformers uses two capacitors and a current comparator. The current comparator is used to determine the ratio between the capacitors and to read the ratio and phase errors of the test voltage transformer. When using this method, the ratio of voltage transformers can be determined with reference to one current comparator.

Relative Test Methods

Relative test methods rely on a calibrated reference standard transformer nominally of the same ratio as the transformer to be tested. A suitable comparator is used to compare the output of the test transformer with that of the reference transformer.

To use this method, one is required to have a number of calibrated voltage transformers covering the range of interest and a comparator. The following is a discussion of comparators and reference standard transformers suitable for use in the relative method of instrument transformer testing.

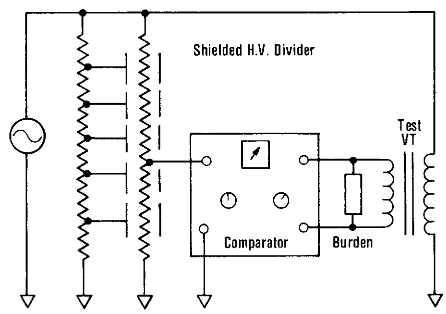

FIGURE 4. *Absolute method of PT calibration with resistive divider*

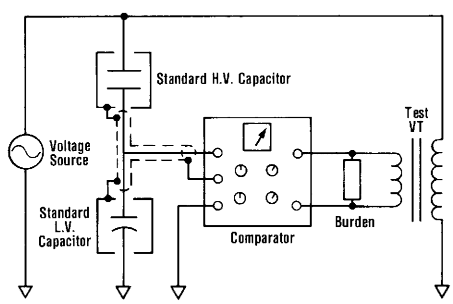

FIGURE 5. *Absolute method of PT calibration with capacitive divider*

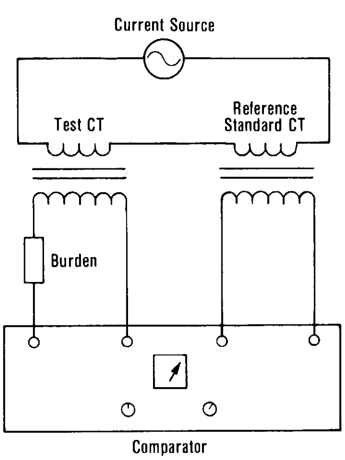

FIGURE 6. *Relative method of CT calibration*

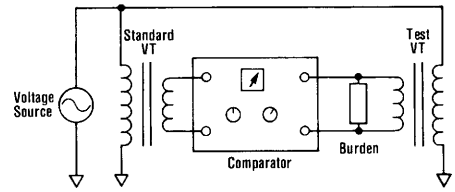

FIGURE 7. *Relative method of PT calibration*

Comparators

The traditional practice in North America was to use two comparators, one for comparing current transformers and one for comparing potential transformers (see Figures 6 and 7). A different tradition was followed in Europe, where typically one universal comparator was used for both potential and current transformers. This universal comparator, often referred to as an AC potentiometer, would be used with different input networks to operate correctly for both potential and current inputs.

Most of these comparators used a resistive network for balancing the ratio error component and a mutual inductor for balancing the phase error component. One serious shortcoming of this arrangement was the comparator's sensitivity to stray magnetic fields that would couple into the measuring circuit through the mutual inductor. For this reason, some test sets abandoned the mutual inductor and incorporated a capacitive-type phase shift network.

One of the most important components of the comparator is the null detector. It has to be sensitive only to the fundamental frequency. To facilitate the balancing of the ratio and phase error components, it also is desirable to have it phase-sensitive. The original vibration galvonometers, which were mechanically tuned to the fundamental, did not have phase sensitivity. They gave way to wattmeter-type detectors and oscilloscopic null detectors.

The wattmeter-type detector is inherently sensitive only to the frequency applied to the reference input. Its sensitivity to phase can be changed by changing the phase of the reference input. The wattmeter-type, or multiplying null detector, has many advantages and is often used in modern test equipment.

The oscilloscopic null detector uses electronic filters to tune out the harmonic components of the fundamental test frequency. By means of a Lisajous figure, an operator can obtain an appreciation of the phase as well as magnitude of the residual signal.

Until quite recently only manual comparators were available. The first automatic comparator was described by E. Zinn [3], while other versions were described by A. Braun and H. J. Koehler [4] and by O. W. Iwanusiw [5].

[4] A. Braun and H. J. Koehler, "Automatic Error Measuring Test Set for Current and Voltage Transformers." ETZ-Z Vol. 99, No. 1, 1978.

[5] O. Iwanusiw, "Microprocessor Based Automatic Instrument Transformer Comparator." IEEE Trans. IM-32, No. 1, March 1983.

[6] H. B. Brooks and C. F. Holtz, "The Two Stage Current Transformer." AIEE Trans. Vol. 41, 1922, p. 382.

Instrument Transformer Test Systems

Description	Catalog No.		Catalog No.
Comparator for CTs and PTs	820120	Standard Current Transformers (5A to 6,000A)	825090
Standard Current Transformers (5A to 2,000A)	825525	Standard Current Transformers (100A to 12,000A)	825060

Standard Current Burdens

Standard Burdens:

ANSI/CSA Current Transformer Metering Burden Set

B-0.1	2.5VA	0.9PF	Current Rating: 5A
B-0.2	5.0VA	0.9PF	Accuracy: 3%
B-0.5	12.5VA	0.9PF	
B-0.9	22.5VA	0.9PF	
B-1.8	45.0VA	0.9PF	Cat. No. 825210

ANSI/CSA Current Transformers Relaying Burden Set

B-0.5	12.5VA	0.5PF	Current Rating: 5A
B-1.0	25.0VA	0.5PF	Accuracy: 3%
B-2.0	50.0VA	0.5PF	
B-4.0	100.0VA	0.5PF	
B-8.0	200.0VA	0.5PF	Cat. No. 825120

IEC Current Transformer Burden Set

2.5 to 77.5VA in steps of 2.5VA 0.8PF — Current Rating: 5A, Accuracy: 3%

Cat. No. 825150

IEC Current Transformer Burden Set

2.5 to 77.5VA in steps of 2.5VA 0.8PF — Current Rating: 1A, Accuracy: 3%

Cat. No. 825152

Standard Potential Burdens

ANSI/CSA PT Burden

			120 Volts 60 Hz
W	12.5VA	0.1PF	Accuracy: 3%
X	25.0VA	0.7PF	
M	35.0VA	0.2PF	
Y	75.0VA	0.85PF	
Z	200.0VA	0.85PF	Cat. No. 825172

ANSI/CSA Potential Transformer Burden Set

W,X,M,Y,Z the same as above plus			120 Volts 60 Hz
ZZ	400VA	0.85PF	Accuracy: 3%
			Cat. No. 825192

ANSI/CSA Potential Transformer Burden Set

W	12.5VA	0.10PF	Voltage Rating: 120V, 69.3V
X	25.0VA	0.70PF	Accuracy: 3%
M	35.0VA	0.20PF	
Y	75.0VA	0.85PF	
Z	200.0VA	0.85PF	Cat. No. 825170

ANSI/CSA Potential Transformer Burden Set

W,X,M,Y,Z the same as above plus			Voltage Rating: 120V, 69.3V
ZZ	400VA	0.85PF	Accuracy: 3%
			Cat. No. 825190

Standard Versions Available

Test Bench Type	Current Transformer		Potential Transformer		Standard Burden Catalog Number		Power Supply			Cat. No.
	Max. A	CT Ratio	Max. KV	PT Ratio	CT	PT	V	HZ	KVA	
CT	2400	2400:5*			825210		240	60	2.4	820260
					825150		240	50	2.4	820260-1
CT	6000	6000:5*			825210		240	60	12.0	820160
					825150		240	50	12.0	820160-1
PT			16	120:1		825172	240	60	2.4	820170
						825350	240	50	2.4	820170-1
PT			36	300:1		825172	240	60	2.4	820360
						825350	240	50	2.4	820360-1
CT & PT	2400	2400:5*	16	120:1	825210	825172	240	60	2.4	820230
					825150	825350	240	50	2.4	820230-1
CT & PT	6000	6000:5*	16	120:1	825210	825172	240	60	12.0	820320
					825150	825350	240	50	12.0	820320-1
CT & PT	2400	2400:5*	36	300:1	825210	825172	240	60	2.4	820240
					825150	825350	240	50	2.4	820240-1
CT & PT	6000	6000:5*	36	300:1	825210	825172	240	60	12.0	820310
					825150	825350	240	50	12.0	820310-1
PT add on			16	120:1		825172				820330
						825350				820330-1
PT add on			36	300:1		825172				820280
						825350				820280-1

We have listed only the most widely used voltage ranges in the above table. The voltage range of the EVT depends only on the standard capacitor (voltage divider) and consequently, this system can be extended to the highest potentials. Ratio modules up to 6,000:1 are available.