A Review On Comparative Study On Two Current Transformers Using Calibration Systems

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ABSTRACT

A study on a comparison of two systems based on different methods for calibration of current transformers at several different transformation ratio and power frequencies of 60 Hz and 50 Hz at the National Research Council (NRC) is described. The obtained discrepancies in ratio and phase errors are within a few µA/A for small test currents and less for larger test currents. Current transformers are precision devices that scale high currents down to a value that can be easily handled by measurement equipment. To support CT application in revenue metering. A calibration service at the National Institute of Standards and Technology (NIST) for laboratory-quality current transformers is described. A service provides measurements of the current ratio andthe phase angle between the secondary and primary currents. Electric energy at current found in utility distribution systems relies on components watthour meter, voltage transformer, and current transformer 50 Hz and 60 Hz transformer can be calibrated at NIST for a range of the primary to secondary current ratios from 0.25A:5A to 12000A:5A.

KEYWORDS: AC measurement, currenttransformer, current comparator, calibration, measurement uncertainty.

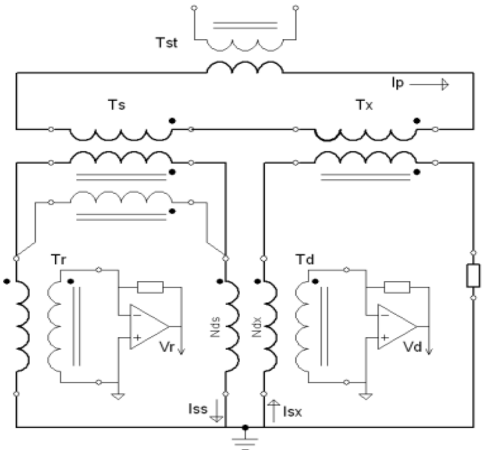
INTRODUCTION

Calibrations of current transformers have a long history with many calibration methods developed over time. They could be grouped into comparisonmethods, in which a CT under test is compared with a standard CT of known and sufficiently lower ratio and phase measurement uncertainties, and methods in which the errors of a CT under test are determined by the use of other means or devices, such as shunts or current comparators. In this paper a comparison of two NRC calibration systems for current transformers at a number of different transformation ratios at power frequencies of 60 Hz and 50 Hz is described. One system uses a standard current transformer-based calibration method recently developed at the Electrical Engineering Institute Nikola Tesla (INT), Serbia. The other system uses the current comparator-based Calibration method developed at NRC Canada. According to the existing standards, instrument transformers are classified into five classes: 0,1; 0,2; 0,5; 1,0, and 3,0. The errors of national and secondary standards must be less than0,005% (50 pap) for amplitude error and ± 0,2 (60 pap) for phase error. Amplitude and phase errors of these standards can be measured with high accuracy about a few ppm but only for the transformation ratio 1:1. This is a so-called autocalibration method thatdoes not require usage of other standard transformers with higher accuracy class. Because of the same current in the secondary and primary winding, measured amplitude and phase errors are inherent errors of standard current transformers under testing.

Experimental measurement of errors for transformation ratio different from the ratio 1:1 can be realised in two ways. The first one is by thecomparison of the tested current transformer with the other standard transformer with the same transformation ratio. Amplitude and phase errors of standard transformer mention above have to be thesame or lower then tested one. The second way isindirectly by comparison with the transfer standard. Mentioned comparison is usually realised as intercomparison between different laboratories. Therefore, in the case of unequal measuringconditions, deviations between results from different laboratories may appear. Using the simultaneous calibration method presented in this paper, this problem can be eliminated. During simultaneous measurement, certain influence can be neglected and as a consequence measurement accuracy and reliabilitycan be increased additionally.

2. INT MEASUREMENT SYSTEM

A simplified block diagram of a CT calibration system based on a differential method is shown in Fig. 1. It consists of a multi-winding multi-ratio standard transformer Ts, a differential transformer Td, a transformer Tr for deriving a replica of the Ts secondary current, and additional electronic circuitry indicated symbolically by two amplifiers and their feedback resistors providing a reference voltage Vr and a differential voltage Vd for further processing (not shown in Fig. 1). Tx is a CT under test, Zb is a T burden impedance, Tst is a supply transformer, Ip is a primary current, and Iss and Isx are Ts and Tx secondary currents.



agram of the differential CT calibrationsystem.

Several differential methods for CT calibrationshave been developed over the years. Two of thesedeveloped previously by INT and based on standard CTs and electronic data acquisition systems are described. In the new calibration system, the improvement is achieved by the use of a high-accuracymulti-winding multi-ratio differential transformer Td. As it is known, the accuracy of the measurement of CTmagnitude and phase errors in the differential method depends on the standard transformer, Ts, accuracy. In the method presented here, the emphasis is put on the accuracy of the differential transformer, Td, while the accuracy of the standard transformer Ts is not compromised. This way, the high accuracy of the whole system is ensured. The standard transformer Ts is of a two-stage design, with a fixed number of turns of its secondary and compensation windings. The calibration system provides Tx secondary current ranges of 5 A, 1A, 2.5 A, 0.1 A, and 0.08 A.

One part of the calibration system's electronic circuitry is based on the modular virtual instrument concept. The analysis and processing of the measurement signals Vr and Vd, which are necessary to determine the magnitude and phase errors, is performed by a Lock-in Amplifier module of the virtual instrument. It decomposes the differential voltage Vd into two orthogonal components concerning Vr and provides a significant reduction of noise and electromagnetic disturbances. This represents an advantage of the presented approach. The other part of the electronic circuitry calibration system is a custom-made device developed at INT. It automatically selects the differential transformer windings and their number of turns according to the primary currents set andconnects them to the Ts and Tx secondary windings. Italso allows a self-calibration of the system. The software controlling the operation of the calibrationsystem has been developed in MATLAB and C#. The selection of MATLAB as a programming language provided a powerful numerical computing environment for processing the measurement signals, and C# provided a user-friendly interface for the calibration system operator. The software-aidedself-calibration of the electronic device provides an additional increase in the accuracy of measurements, which is of particular importance at low test currents.

The Institute Nikola Tesla (INT) calibration system for differential current transformers (DCTs) is a highlyaccurate and reliable system used to calibrate DCTs in power systems, industrial applications, and instrumentation. The calibration system is based on theuse of a current injection transformer to generate a known current that is injected into the CT under test. The output voltage of the CT is then measured and compared to the known current to determine the ratio error and phase error. The ratio error and phase error should be within the specified limits for the CT to be considered calibrated. The INT calibration system is designed to meet the highest standards of accuracy andreliability. The system is used by a variety of customers, including national metrology institutes, power utilities, and industrial companies.

NRC CALIBRATION SYSTEM

The NRC calibration system for current transformers is based on the use of compensated current comparators as the current ratio devices of the highest accuracy. In the calibration, the current comparator is connected to the current transformer Tx being calibrated. A ratio error set injects a currentopposite to the Tx error current into the joint point between the Tx secondary winding and the current comparator secondary ratio winding to balance the current comparator. The other end of the TX secondary is connected to a phantom burden. This calibration is accredited under IEC/ISO Standard 17025, and its expanded measurement uncertainties (k=2) are withina few μA/A, or smaller, depending on the ratio errorsof the CT under test.

BENEFITS OF NRC CALIBRATION SYSTEM

The National Research Council (NRC) calibration system provides several benefits to its users, including

1 ACCURACY:

NRC calibrations are performed using the highest quality standards and equipment, ensuring that measurements are as accurate as possible. This is especially important for industries where precise measurements are critical, such as manufacturing, healthcare, and research. The accuracy of the NRC calibration system is very high. The NRC requires that dose calibrators used in nuclear medicine have an accuracy of ±5%. This means that the measured activity of a radioactive source should be within 5% ofits true activity. The NRC calibration system is designed to meet this requirement and is very reliable in practice.

In a study by the IAEA, NRC calibrators were found to have an average accuracy of ±2.8%. Thismeans that the measured activity of a radioactive source was on average within 2.8% of its true activity. This is a very high level of accuracy, and it demonstrates the reliability of the NRC calibration system. The NRC calibration system is also regularly audited by independent organizations. These audits have confirmed that the NRC calibration system is accurate and reliable. The NRC calibration system is very accurate and reliable. It is designed to ensure that dose calibrators used in nuclear medicine meet the NRC's accuracy requirements. This helps to ensure that patients receive the correct dose of radioactive material during diagnostic and therapeutic procedures.

4.2 RELIABILITY:

NRC calibrations are performed by experienced and qualified technicians, and the results are carefully documented. This helps to ensure that measurements are reliable and consistent over time. e NRC calibration system is regularly audited by independent organizations to ensure that it meets the NRC's standards for accuracy and reliability. In addition to these measures, the NRC also participates in international comparison programs to ensure that its calibration system is aligned with calibration systems in other countries. This helps to ensure that the NRC calibration system is reliable and accurate on a global scale. The NRC calibration system is very reliable.The NRC takes some steps to ensure that the system is accurate and reliable, including the use of traceable reference standards, regular calibration of reference standards, use of qualified personnel, use of controlled environmental conditions, and regular audits.

4.3 TRACEABILITY:

NRC calibrations are traceable to the International System of Units (SI), which is the worldwide standard for measurement. This means that NRC calibrations can be used to compare measurements made in different countries or using different instruments. The traceability of the NRC calibration system to the International System of Units (SI) is established through a chain of calibrations. The NRC usesreference standards that are traceable to NIST. These reference standards are calibrated by NIST using primary standards, which are the highest level of standards in the SI traceability chain. The NRC calibration system is also traceable to the SI through its participation in international comparison programs. These programs allow the NRC to compare its calibration results with those of other national metrology institutes. This helps to ensure that the NRCcalibration system is aligned with the SI.

4 RECOGNITION:

NRC calibrations are recognized by accredited laboratories and organizations around the world. This can be beneficial for businesses that need to demonstrate compliance with industry standards or government. The recognition of the NRC calibration system is important for some reasons. First, it allows NRC licensees to use the NRC calibration system to calibrate their dose calibrators without having to have them calibrated by an accredited laboratory. Second, it allows NRC licensees to import and export dose calibrators that have been calibrated by the NRC without having to have them calibrated again. Third, it allows NRC licensees to participate in international research and development projects that require the use of calibrated dose calibrators. The recognition of the NRC calibration system is a testament to the high quality of the system and the commitment of the NRC to ensuring the safety of patients undergoing nuclear medicine procedures.

MEASURING METHODS

The Differential method and current comparator method are usually used for the calibration of standard current transformers.

1 DIFFERENTIAL METHOD

The differential method assumes that there is a reference standard current transformer TN with transformer ratio nN equal to the rated ratio nX of the current transformer TX being verified. It measures the differential voltage Ud, i.e., the differential current ΔI. This current is compared to the secondary current IR (or secondary voltage) to determine the complex error G of the tested transformer TX. Complex error i.e., thevalue of amplitude and phase error is measured by a complex compensator.

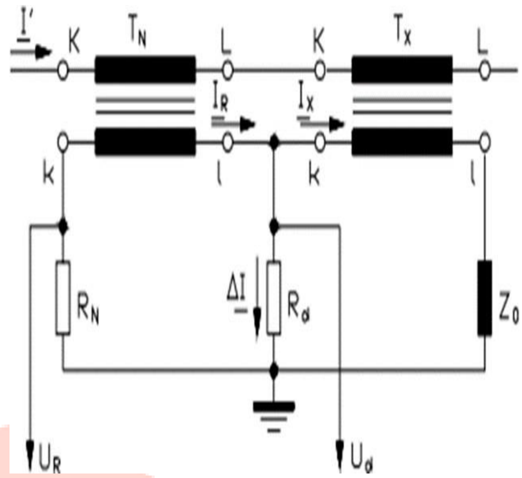


Fig.2. Differential method for calibration of currenttransformers

The principle of the differential method is to measure the difference in current between the reference standard current transformer and the transformer under test. This difference in current iscalled the differential current. The differential currentis then compared to the secondary current of the transformer under test to determine the error of the transformer under test. The differential method can be used to measure both the amplitude error and the phase error of a current transformer. The amplitude error is the difference between the actual current ratio and the rated current ratio of the transformer. The phase error is the difference between the actual phase angle of the secondary current and the ideal phase angle of the secondary current.

To calibrate a current transformer using the differential method, the following steps are typically followed:

i. Connect the primary windings of the reference standard current transformer and the transformer under test in series.
ii. Connect the secondary windings of the reference standard current transformer and the

transformer under test to a differential current comparator.

iii. Apply a known current to the primary windingsof the transformers.

iv. Measure the differential current using the differential current comparator.

Calculate the amplitude error and the phase error of the transformer under test using the following equations:

Amplitude error:

Amplitude error (%) = (Differential current / Secondary current) * 100

Phase error:

Phase error (degrees) = Differential current phase angle - Secondary current phase angle

The reference standard current transformer and the transformer under test are connected in series on the primary side. The secondary windings of the transformers are connected to the differential current comparator. The AC source is used to apply a known current to the primary windings of the transformers. The AC meter and the phase meter are used to measurethe secondary current and the phase angle of the secondary current of the transformer under test.

CURRENT COMPARATORMETHOD

The method of the compensated current comparator (CCC) permits the current comparator to replace the reference transformer and primary current source. As shown in Fig. 2, the current comparator is supplied from a controlled current source I2N on the secondary winding side N2. In the primary winding of the comparator, N1, and the primary winding of the current transformer under test, TX, a current I1 is flowing which induces current I2X in the secondary of the tested transformer. To secure the transfer of energyfrom the secondary to the primary, the current transformer must have a corresponding magnetic circuit. This role is played by the magnetic shield,which has a dimension sufficient to transfer the rated power (order of 2 kW). The magnetic shield, therefore, has a double function. Thus, this current transformer transforms the secondary current into the primary with a given, non-negligible error. The basic idea behind this device is that the compensation winding, Nk, with its current, Ik, almost completely compensates for this error. The compensation winding of large cross-sectioncopper wire has low impedance and presents a nearly ideal current loop through which flows the error current of

the current comparator, but also the error current of thetransformer under test. The detection winding voltage reflects only the current error IG of the testedtransformer. This is nullified by the feedback loop current IG', placing the measurement core into a state of zero magnetic flux. This current is in correspondence with the complex error of the tested transformer, which is measured by the complex compensator.

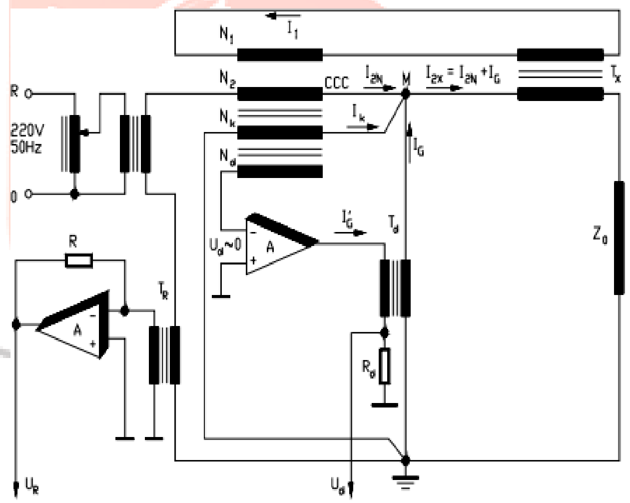


Fig. 3. Compensated current comparator method for calibration of current transformers.

The current comparator method is based on the principle of comparing the secondary current of the transformer under test to the secondary current of a reference standard current transformer. The current comparator is used to measure the difference in currentbetween the two transformers. This difference in current is then compared to the rated current of the transformer under test to determine the error of the transformer under test. This comparator method can beused to measure both the amplitude error and the phaseerror of a current transformer. The amplitude error is the difference between the actual current ratio and the rated current ratio of the transformer. The phase error is the difference between the actual phase angle of the secondary current and the ideal phase angle of thesecondary current.

To calibrate a current transformer using the currentcomparator method, the following steps are typically followed:

i. Connect the secondary windings of the reference standard current transformer and the transformer under test to the current comparator.
ii. Apply a known current to the primary windingsof the transformers.
iii. Measure the difference in current between the two transformers using the current comparator.

Calculate the amplitude error and the phase error ofthe transformer under test using the following equations:

<u>Amplitude error</u>:

Amplitude error (%) = (Difference in current / Rated current) * 100

<u>Phase error</u>:

Phase error (degrees) = Secondary current phase angle
- Reference standard current phase angle

The current comparator method is a very accurate method for calibrating current transformers. However, it is also a relatively complex and expensive method. Itis typically used for calibrating high-accuracy current transformers, such as those used in metrology and power system protection.

SIMULTANEOUS CALIBRATION METHOD

Calibration of standard current transformers is usually performed using two independent methods in different time intervals. This way of comparison does not provide completely equal conditions of measurement in the sense of outdoor influences. The simultaneous calibration method, fig. 3, solves the problems of external influences. A compensated current comparator is a current supply for elements in both methods (differential and current comparator). A

common element of both methods is the current transformer under test TX. The secondary circuit of transformer TX is connected with both devices for transformer accuracy testing “2767” (differential method) and “INST-2A” (compensated current comparator method). Both devices are based on microprocessor, and data processing of signals measured by different methods is performed within them. Device type “INST-2A” connects with the PC by serial connection RS232, and device type “2767” by

parallel connection IEEE488. For this simultaneous measurement, special software is developed for the conduction of measurement, result representation, and final data processing.

The simultaneous calibration method ofcalibration of current transformers is a method of calibrating multiple current transformers (CTs) simultaneously using a single reference CT. This method is more accurate than traditional methods of CT calibration, which calibrate each CT individually. This is because the simultaneous calibration method eliminates the errors that can occur when calibrating each CT individually, such as errors due to the different characteristics of the CTs and errors due tothe different environmental conditions in which theCTs are being calibrated. A compensated current comparator is a device that compares the output currents of two CTs. The two CTs are connected to the compensated current comparator in such a way that their output currents are opposed to each other. If the two CTs are perfectly calibrated, then their output currents will be equal and the compensated currentcomparator will output a current of zero. However, if the two CTs are not perfectly calibrated, then their output currents will be unequal and the compensated current comparator will output a current that is proportional to the difference in the output currents of the two CTs. To calibrate multiple CTs simultaneouslyusing a compensated current comparator, the CTs are connected to the compensated current comparator in pairs. The compensated current comparator is then used to compare the output currents of the two CTs in each

output a current that is proportional to the difference inthe output currents of the two CTs in each pair.

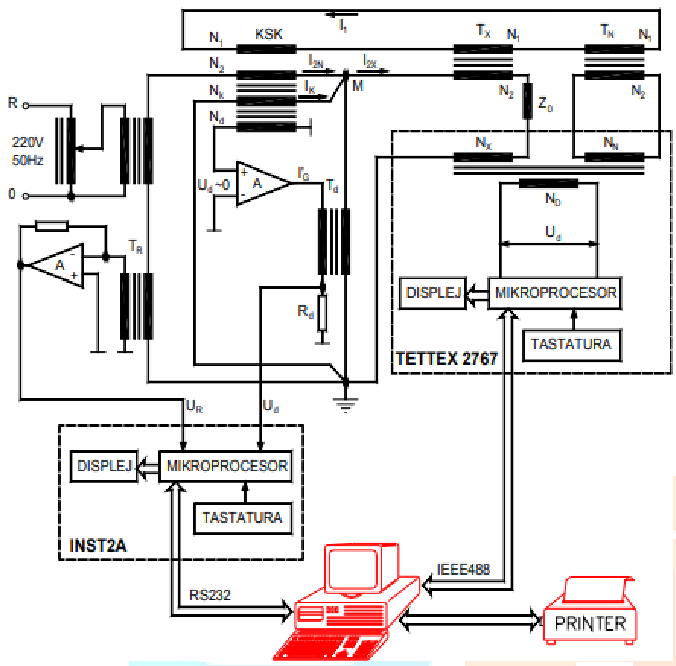


Fig. 4 Simultaneous calibration method

COMPARISON AND EVALUATION

In the comparison of the two calibration systems, a transfer standard and direct comparison were used. A high-accuracy CT designed at NRC as a 1000:1 two-stage CT was used as a transfer standard. Other CT ratios are set by the number of turns of an external primary. The CT's long record of calibrations at various test conditions shows a stable ratio and phase errors on the order of µA/A. This CT was calibrated by the differential calibration system 5 times on different days at currents 1-150 % of the rated

current of 1000 A, with 10 repeated measurements at each test current at 60 Hz and 50 Hz. The difference inratio and phase errors obtained by the two systems at 60 Hz are shown in Fig. 2. The difference in errors at 50 Hz is similar. A direct comparison of the system

based on the differential method with the current comparator-based system while both were calibrating the aforementioned transfer standard was performed at60 Hz and 50 Hz. At test currents

pair. The compensated current comparator will below 5 % of the rated current, the differences in ratio and phase errors were within a few µA/A and

SR NO.	NAME OF QUANTITY	FICATION
1.	Ambient temperature	19oC to 22oC
2.	Atmosphere pressure	95 kPa to 105 kPa
3.	Relative humidity	30 % to 35 %
4.	Frequency	50 Hz ± 1 Hz

fewer test currents.

CONCLUSION

The paper described a comparison of two systems based on different methods for calibration of current transformers at various transformation ratios at 60 Hz and 50 Hz. Two different evaluation approaches used in the comparison were shown. The obtained discrepancies in ratio and phase errors were within a few µA/A, and less for larger test currents.

According to the table, the difference between results is from – 2 ppm to 9 ppm for amplitude error and from

– 9 ppm to 3 ppm for phase error. These differences are calculated for a large extent of referent currents from 5 % To 200 % In and for the applied burden of 2 VA and 5 VA. These differences are lower than the estimated measuring uncertainty of measuring standards and devices used in the simultaneous calibration method. Considered measuring method could be also of great interest for the intercomparison of current transformer system.

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