Alternative Testing Technologies for Field Testing of Protection Class Current Transformers

Authors:
Dinesh Chhajer
Lam Nguyen
Megger, North America
Dallas, Texas, USA

Vijay Shanmugasundaram
Power Grid Engineering, LLC
Raleigh, North Carolina, USA

Abstract

Current Transformers (CTs) are an integral part of all protection and control systems. Proper CT operation is critical to the reliability of protection schemes implemented in the system. Test recommendations by IEEE C57.13.1 guide on multi-tap relaying CTs are time intensive, need instrument precision for accuracy, repeatability and require high voltage/current that is intrinsically dangerous. This paper proposes two unique testing techniques that provide a safer working environment and improve the testing efficiency without compromising the accuracy of CT testing in the field.

A unique method based upon IEC 60044-6 recommendation is proposed utilizing DC voltage and conducting reoccurring DC cycles for excitation test. The DC excitation technique allows low voltage operation that promotes safer operating conditions and provides the ability to test transient performance CTs and generator CTs having very high knee point voltages up to 20 kV. This paper will also provide a detailed comparative analysis of different relaying CT excitation results utilizing AC and DC secondary voltage injection techniques to verify the validity and accuracy of the proposed method.

Using the ampere-turns concept of CTs, a concurrent testing technique is recommended that execute the IEEE recommended tests on multiple taps simultaneously. A comparative study to analyze the results from conventional testing of multi-tap CTs to the concurrent mode of testing is shown to highlight the increased efficiency and productivity in field-testing of relaying CTs.

I. Introduction

Relaying CTs serve as one of the critical components in the design of a protection scheme. CT performance under fault conditions should be within its operating characteristics for a true representation of fault magnitudes and reliable operation of the protection system. To ensure proper installation and operation, CTs are often subjected to one or more tests performed in accordance with well-defined standards, such as IEEE C57.13.1, IEC 60044-1, and IEC 60044-6 [1]. IEEE C57.13.1 *"Guide for Field Testing of Relaying Current Transformers"* describe field test methods that assure CTs are connected properly, are of marked ratio and polarity, and are in a condition to perform as designed both initially and after being in service for a period of time [2]. Performing recommended tests such as ratio, polarity, winding resistance and excitation test on each tap of a multiple tap CT can be a labor and time intensive job. This combined with substation assets such as transformers and circuit breakers having multiple CTs per phase make it a complex task to obtain reliable and accurate results.

Excitation test performed using the secondary voltage injection method requires high levels of AC voltage to plot the saturation characteristics and determine the knee point. Special application CTs such as TPY, TPZ or generator CTs may require thousands of volts to perform this test. This requirement not only makes it a challenging situation for the field environment but also poses safety concerns for operating personnel.

Conventional method of testing CTs in the field has been utilized for years with its own limitations and drawbacks. With modern advancement in digital processing and solid-state technology, efforts have been made to perform those same tests quickly, safely, reliably and with a high degree of accuracy.

II. Alternative Testing Techniques

A. DC Excitation Method

Excitation test on protection class CTs utilizing nominal frequency 50/60Hz sinusoidal voltage signal is one of the most challenging test to perform, as it requires high voltage/wattage source to drive the CT into saturation to measure its core characteristics. According to ANSI standard on testing C800 class CT, test voltage can be typically around 800V RMS and in special cases can go as high as 1300V to achieve 1A excitation current for saturation. For some IEC class CTs, test voltage can easily reach 4,000V RMS to achieve 1A saturation. Field portable test instruments to deliver that amount of voltage and watts make it difficult to use for practical applications and involve many safety precautions to be taken before performing the test. DC voltage technique can be employed to achieve the same core saturation and overcome the above mentioned limitations. *IEC 60044-6* Annex B-3 [1] explains the alternate way to perform CT excitation.

The flux generated in the core can be represented by

$$\Phi = \int dv * dt \tag{1}$$

Integral of voltage over a period of time would be a measure the flux ($\boldsymbol{\Phi}$) produced as shown in *equation (1)*. It can be generated by using an AC or DC excitation voltage. The area under the curve reflects the flux produced as shown in Figure 1.

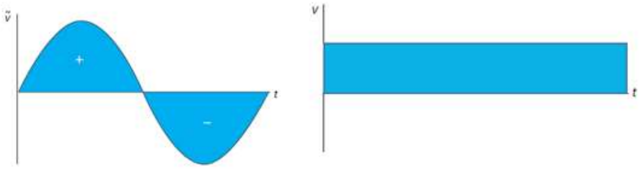


Figure 1: Flux generated using AC or DC method is the area under the curve

Flux can be increased by utilizing either of the two methods. Either the time period can be kept constant as the voltage is increased, or the voltage can be kept constant with increase in time. The conventional method used by the industry over the years has been to keep the time period constant (or fixed frequency at 50/60Hz) as the voltage is increased. Alternatively, the voltage can be kept the same; thus DC voltage, and the time can be prolonged until the core is saturated. By integrating the constant DC voltage over time the core saturation can be determined. This saturation can then be mathematically converted back to an equivalent 50 Hz / 60 Hz saturation. This will achieve the same result as the conventional AC excitation test technique.

The advantage of this method is eliminating the need for higher levels of AC voltage and achieving the same results by utilizing a DC voltage at or below the available line voltage. The technique allows testing CTs with higher knee point voltages utilizing the same concept with a slightly longer test duration. Additionally, lower levels of DC test voltage allows safer operating conditions and a portable lightweight instrument ideal for field conditions.

CT demagnetization is an important step to ensure that the core has no residual magnetism. This can be achieved by reducing the hysteresis loops starting from saturation, through a series of similar DC excitation reoccurring cycles in opposite directions with progressively reduced magnitudes.

B. Concurrent Testing Technique

The conventional testing method works on the concept of keeping the primary circuit open, applying an AC voltage to the secondary winding and measuring secondary voltage/current along with primary voltage values to obtain the test parameters such as ratio, polarity, winding resistance and excitation characteristics curve. For a multi-tap CT these tests are repeated for each tap either through a manual operation or utilizing automatic switching technique [3].

The concurrent testing technique uses the transformers ampere-turn principle to obtain the recommended test results for all the taps and any inter-tap combination simultaneously.

$$\frac{V1}{V2} = \frac{N1}{N2} = \frac{I2}{I1} \tag{2}$$

The turns ratio of a CT is a ratio of the applied voltage on the secondary side to the measured voltage on the primary side as shown in *equation (2)*. The concurrent technique applies the test voltage across the complete secondary winding and measures the voltage across each secondary tap position in addition to the primary winding induced voltage. Concurrent testing test connections to a multi-tap CT can be made as per Figure 2.

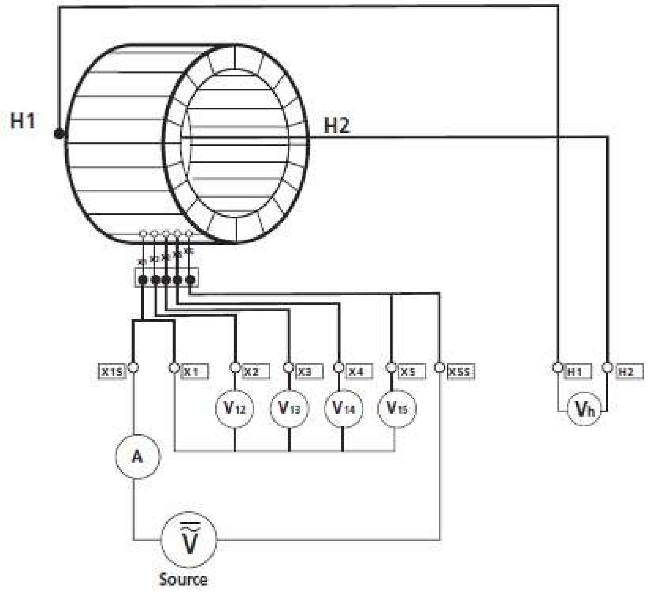


Figure 2: Multi-tap CT Concurrent testing technique connection setup

With those measurement values, the ratio for each tap position can be calculated simultaneously as shown in equation 3.

$$\text{Ratio}_{\text{X1-X2}} = V_{12}/V_h \tag{3}$$

The excitation characteristics can also be obtained for all the taps by performing an excitation test across the complete secondary winding and measuring voltages across all the taps throughout the test duration. Measured tap voltages along with calculated turns ratios and secondary current can be utilized to plot the excitation curves for all the tap combinations concurrently.

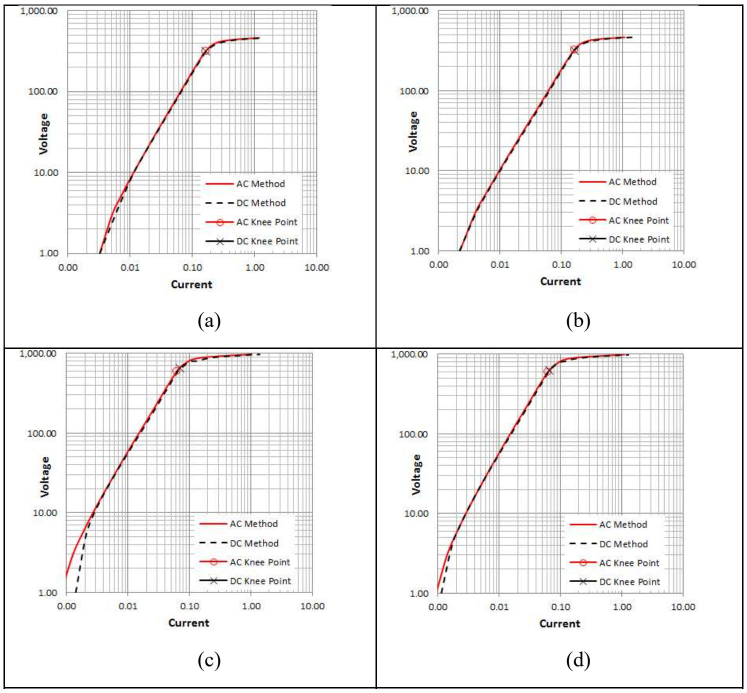
A DC winding resistance test for CT secondary winding is performed to detect any shorted turns or high resistance connection point in the CT secondary circuit. The same concurrent technique can be employed to measure the winding resistance of each tap combination by applying a DC current through the entire secondary winding and measuring the voltage drop across each tap position.

III. Comparative Analysis

This section focuses on the performance characteristics of a CT using the two techniques discussed in the previous section; the DC excitation method and the concurrent test technique. The accuracy of testing a multi-tap CT in concurrent DC method is explained by comparing the test results obtained from testing the same CT on a tap-by-tap basis.

A. AC vs DC excitation test

Four different types of protection CTs (C400 and C800) with varying saturation characteristics were tested in the field using AC and DC methods explained in the previous section. The excitation test was conducted between the X1-X5 taps of the CT and their characteristics are shown in Figure 3 a,b,c,and d.



(a) (b) (c) (d)

Figure 3: Comparison of AC and DC testing methods

From Figure 3, the saturation curves for two C400 and two C800 CTs obtained from AC and DC excitation methods provided a similar excitation characteristics and knee point value. The difference in knee point measured using ANSI 45 method (tangent at 45° angle) for the two methods (AC and DC) was found to be negligible.

B. Concurrent vs Non-concurrent Test

i. Excitation Tests:

Performing excitation test using non-concurrent method involves measuring voltage/current across individual taps. Whereas, the concurrent method measures the voltage drop across all the taps simultaneously and calculates the secondary current using ampere-turns principle as given in equation (2). The field results from the AC excitation test across different taps using concurrent and non-concurrent measurement are provided in Figure 4.

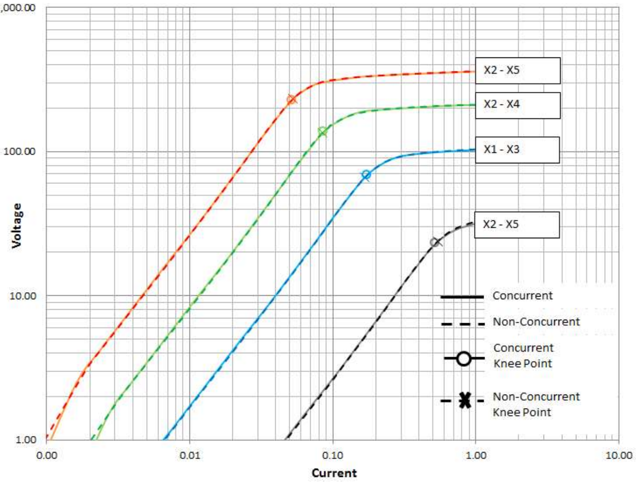


Figure 4: Comparison of non-concurrent and concurrent testing methods

The field results show that the excitation curves using concurrent measurement technique follows the non-concurrent measurements. The results also confirm that concurrent method could improve the testing efficiency by reducing the testing time considerably without compromising the accuracy of test results.

ii. Ratio Tests:

For Concurrent tests, equation (3) could be used to calculate the ratio of each tap by simultaneously measuring the voltage drop across each tap (V12, V23, V34, V45) and the voltage induced on the primary (Vh). Table 1 provides the field results of a non-concurrent and concurrent test across the same tap of a CT.

Table I: Ratio Test Comparison

Tap	Name Plate	Non-Concurrent		Concurrent	
		Measured	Error (%)	Measured	Error (%)
X1-X2	200 : 5	200.021 : 5	0.01	200.095 : 5	0.048
X1-X4	800 : 5	799.892 : 5	-0.013	800.386 : 5	0.048
X2-X5	1000 : 5	999.99 : 5	0.00	1000.246 : 5	0.025
X3-X4	500 : 5	499.904 : 5	-0.012	500.156 : 5	0.031

From Table I, it can be observed that the differences between the two methods are negligible.

iii. Winding Resistance Tests:

A DC current is applied to the secondary windings of a CT and the voltage drop across each tap is measured individually. The winding resistance of different tap positions measured using non-concurrent and concurrent methods are provided in Table II. The field results show that the resistance value does not differ much between the two methods.

Table II: Winding Resistance Test Comparison

Tap	Measured Resistance(mΩ)	
	Non-Concurrent	Concurrent
X2-X3	53	50
X1-X4	406	405
X2-X5	504	504
X3-X5	456	454

C. Concurrent DC vs Concurrent AC Test

The concurrent DC method follows the same connection and working procedures of a concurrent AC method. It applies DC voltage across the CT secondary and measures the voltage across individual taps simultaneously. The excitation characteristics of a C800 type CT using AC and DC concurrent method is shown in Figure 5.

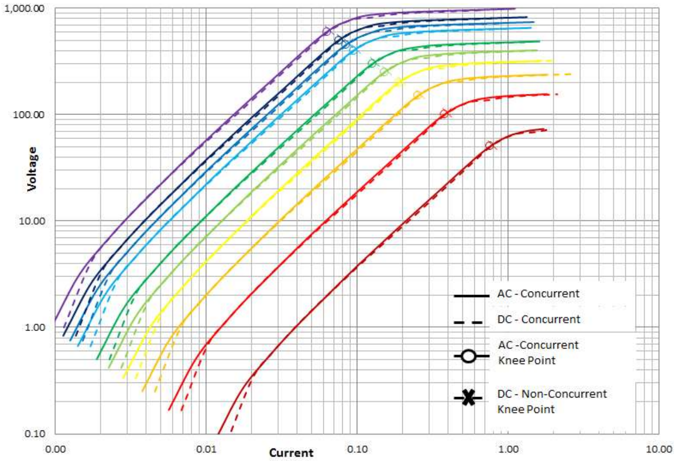


Figure 5: Comparison of concurrent AC and DC testing methods

The linear portion of the AC and DC method excitation curves are observed to be following each other closely. The knee point for CT saturation for the DC method is approximately similar to the AC method. The difference in the curves for lower voltage value is primarily due to the range selection (< 5V) of the instrument during measurement.

The DC method can test CTs with high saturation point, such as TPY and TPZ that are used in locations with high transient and sub-transient currents are expected. Figure 6 shows the result of a CT with high knee point value of close to 14,000 V.

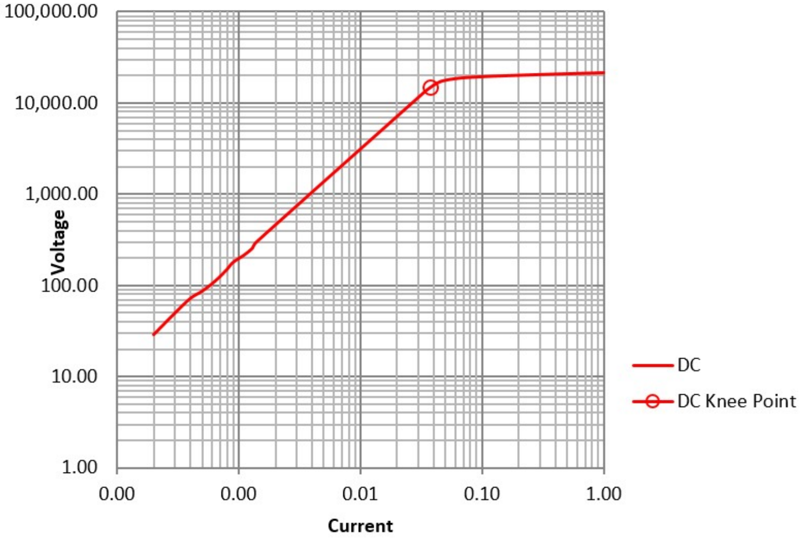


Figure 6: Testing CT with high knee point using the DC method

Testing CTs such as TPY and TPZ is practically difficult when only AC method is employed, as the voltage required to saturate the core is high. On the other hands, the DC method only requires a voltage below line power value to achieve core saturation characteristics for these type of CTs.

IV. Discussion and Conclusions

It is imperative to test protection class CTs during installation and thereafter periodically to ensure that they will work as intended for power system protection application. The tests recommended in the industry standards are well established, however methods used to perform those tests are evolving and effort is being made to create safer operating conditions, ability to test special application CTs, and improve the efficiency and productivity of the test system through automation, intelligent data processing and developing smart algorithms utilizing basic principles of transformer operation and electromagnetics.

New measurement techniques proposed in this paper are although unique but utilizes the concepts well described in electrical textbooks. DC excitation and concurrent method of testing offer an alternative approach for testing CTs that provide same measurements and results as conventional techniques recommended in various international standards. The comparative analysis between different methods indicate that DC excitation and concurrent method of testing can be utilized in place of AC excitation and individual tap by tap testing techniques without compromising the accuracy and reliability of the results. Demagnetization is highly recommended after DC excitation to minimize any residual magnetism in the core of the CT.

V. References

[1] *IEC 60044-6 Instrument Transformers Part 6: Requirements for Protective Current Transformers for Transient Performance.*

[2] *IEEE C57.13.1-2006: Guide for Field Testing of Relaying Current Transformers.*

[3] *United States Patent: Concurrent Transformer Test System and Method. Patent No.: US 9,128,134 B2, Date of Patent: Sep. 8, 2015*