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Back to the Basics — Current Transformer Testing

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As test equipment becomes more sophisticated with better features and accuracy, we risk turning our field personnel into test-set operators instead of skilled field service technicians. A test-set operator connects the leads, pushes the buttons, and records the results, hoping the numbers he records are good. A test technician connects the leads, pushes the buttons, and records the results. However, the test technician understands what the test set was doing while all the lights were flashing, and why. The technician can also evaluate the results and determine if a retest is necessary with different connections or substitute external equipment for tests when the test equipment malfunctions. The purpose of this article is to help a test-set operator understand the tests he performs, reinforce a test technique, or add it to his repertoire.

Description of Operation

During normal operation, a current transformer (CT) transforms higher current into a more manageable secondary current. This transformation is made possible by copper coils wrapped around an iron core, with the ratio between primary and secondary currents determined by the ratio between the number of primary and secondary turns. Bar- and window-type CTs do not have a physical primary winding and are considered to have one primary turn. When current flows through the primary winding, the following actions occur:

- The iron core inside the transformer is magnetized.
- The magnetic field in the iron core induces a voltage in the secondary coils.
- If the secondary circuit is closed, a current flows through the secondary circuit in proportion to the CT ratio.

The current transformation requires a small amount of energy to magnetize the iron core that creates small energy losses such as eddy currents, and heat caused by current flowing through the windings. Therefore, the secondary current is not a perfect representation of the primary current. All CTs that are built to ANSI standards have an accuracy class to outline what effect the losses have on the secondary current under normal conditions. The accuracy class is the *minimum* accuracy guaranteed by the manufacturer, although the CT may be built to higher standards.

Like every other transformer, CTs can only transform a finite amount of energy. This is usually the voltampere rating for normal transformers. The CTs energy limitation is included in the accuracy class but is shown as a maximum burden. The CT burden is the amount of impedance (ac resistance) connected to the CT secondaries and is usually rated in ohms or volts. The manufacturer only guarantees CT accuracy up to a maximum burden rating, and CT performance will degrade if the secondary burden is larger than rated.

Visual and Mechanical Inspections

Equipment Specifications

While performing visual and mechanical inspections, always compare equipment nameplate data with drawings and specifications. Every CT test sheet should include the following information:

Serial Number (when possible): The serial number is important to organize test results and allow a reference when comparing test results to manufacturer's specifications. The serial number can also be used when ordering replacement or new CTs from manufacturers.

Model Number (when possible): The model number is important when comparing test results to manufacturer's literature and ordering replacement, new, or spare CTs from manufacturers.

Ratio: The CT ratio is the most important piece of information regarding the CT and must be recorded from the nameplate or the design criteria. The ratio determines the CT's operating characteristics and is used as reference for tests. If the CT has multiple taps (different possible ratio combinations), all taps should be recorded for future reference in case a new ratio is required for the application. This will allow a review of the options without visiting the site beforehand.

Accuracy Class: The CT accuracy class comprises a number-letter-number combination and indicates the CT's ability to perform accurately under different conditions. In other words, the CT accuracy class indicates the CT's performance characteristics and the maximum burden allowable on the CT secondaries. CTs can be separated into two distinct groups: metering and protection or relay. A CT can have ratings for both groups. See Figure 1 for a list of typical accuracy classes.

The CT accuracy class is made up of three parts, which are described in conjuction with Figure 2.

CORRECTION FACTOR LIMITS FOR CTs				
ACCURACY	**100% RATED CURRENT**		**10% RATED CURRENT**	
CLASS	**MIN**	**MAX**	**MIN**	**MAX**
1.2	0.998	1.012	0.976	1.024
0.6	0.994	1.006	0.988	1.012
0.3	0.997	1.003	0.994	1.006
0.5	0.995	1.005	0.995	1.005

Figure 1a — CT Accuracy Classes and Correction Factors

STANDARD BURDENS FOR STANDARD 5-AMP / 60 Hz SECONDARY CURRENT TRANSFORMERS			
BURDEN DESIGNATION	**STANDARD SECONDARY BURDEN RATINGS**		
	IMPEDANCE OHMS	**VOLT AMPS (VA)**	**POWER FACTOR**
B-0.1	0.1	2.5	0.9
B-0.2	0.2	5	0.9
B-0.5	0.5	12.5	0.9
B-1	1	25	0.5
B-2	2	50	0.5
B-4	4	100	0.5
B-8	8	200	0.5

Figure 1b — CT Accuracy Classes and Correction Factors

Accuracy: The first number in the CT accuracy class is the rated ratio accuracy in percent. For example, the ratio of a 0.3B0.1 metering-class CT is accurate within 0.3 percent as long as the CT burden rating is not exceeded. The ratio of a 2.5C100 protection-class CT is accurate within 2.5 percent if the CT burden rating is not exceeded.

Current-Transformer Class: The second part of the accuracy class is a letter. The letter distinguishes for what application the CT is rated. A CT can have dual ratings and be used in metering or protection applications, if both ratings are listed on the nameplate.

Metering-class CTs have the letter B in the accuracy-class rating. They are designed for maximum accuracy from very low currents to the maximum CT rating. These CTs are often used to record power consumption and are the basis for electrical bills, hence the need for accuracy. A typical metering-class CT has an accuracy class similar to 0.3B0.1

Protection-class CTs have the letters C, H, L, or T to indicate the protection-class rating.

- A C-rating indicates that the CT accuracy can be calculated before construction because there is no appreciable leakage flux in the CT design.
- A T-rating indicates that the CT can have significant leakage flux, and the CT accuracy must be obtained by testing in the factory.
- An H-rating indicates that the CT accuracy rating is applicable within the entire range of secondary currents from five to 20 times the nominal CT rating. These are typically wound CTs.
- An L-rating indicates that the CT accuracy applies at the maximum-rated secondary burden at 20 times rated only. The ratio accuracy can be up to four

times greater than the listed value, depending on the connected burden and fault current. These are typically window, bushing, or bar-type CTs.

Protection-class CTs are not as accurate as metering-class CTs but are designed to operate over a wider range of current. This wider range is necessary to allow the protective relay to operate at different fault levels. Protection-class CTs are typically rated to operate accurately up to 20 times the CT rating. A typical protection-class CT has an accuracy class similar to 2.5C100.

Burden: The third part of the accuracy-class rating follows the letter and indicates the maximum burden allowed. If the CT secondary-burden rating is exceeded, CT accuracy is not guaranteed.

Metering-class CT burdens are displayed as secondary ohms. For example, the ratio of a 0.3B0.1 rated CT is accurate to 0.3 percent if the connected secondary burden impedance does not exceed 0.1 ohms. A 0.6B8 rated metering-class CT will operate within 0.6 percent accuracy if the secondary burden does not exceed 8.0 ohms.

Protection-class CT burdens are displayed as the maximum secondary volts allowable if 20 times (100 amperes with a five-ampere nominal CT secondary) the CT rating were to flow through the secondary circuit. For example, a 2.5C100 protection-class CT is accurate within 2.5 percent if the secondary burden is less than 1.0 ohm (100 volts / 100 amperes).

CT Type: The four typical CT types include window, bushing, bar, and wound.

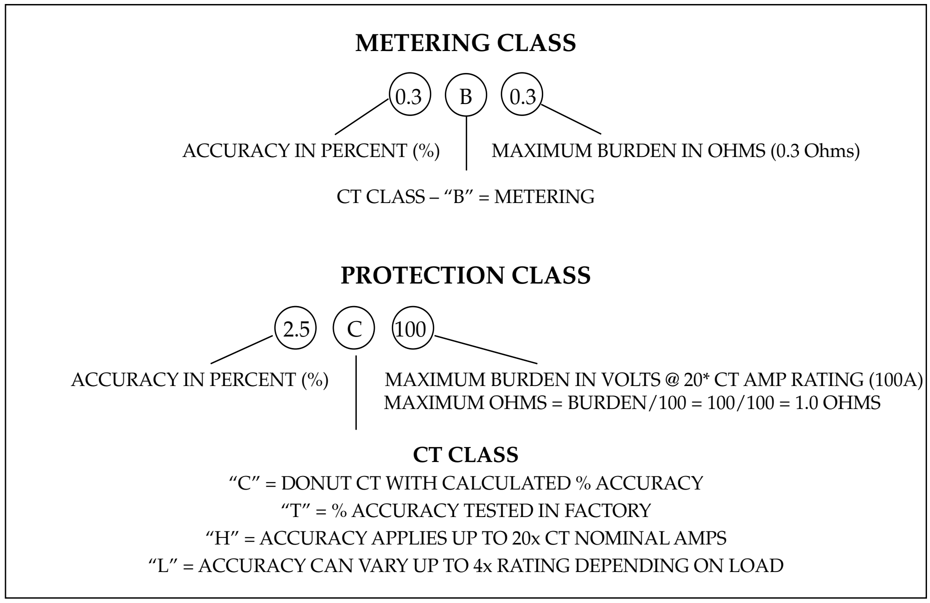

Figure 2 — Understanding CT Ratings

- Window CTs are the most common. They are constructed with no primary winding and are installed around the primary conductor. The electric field created by current flowing through the conductor interacts with the CT core to transform the current to the appropriate secondary output. Window CTs can be of solid or split core construction. The primary conductor must be disconnected when installing solid window CTs. However, *split core* CTs can be installed around the primary conductor without disconnecting the primary conductor.
- Bushing CTs are window CTs specially constructed to fit around a bushing. Usually they cannot be accessed, and their nameplates are found on the transformer or circuit-breaker control cabinets.
- Bar-type CTs operate on the same principle of window CTs but have a permanent bar installed as a primary conductor.
- Wound CTs have a primary and secondary winding like a normal transformer. These CTs are rare and are usually used at very low ratios and currents, typically in CT secondary circuits to compensate for low currents, to match different CT ratios in summing applications, or to isolate different CT circuits. Wound CTs have very high burdens, and special attention to the source CT burden should be applied when wound CTs are used.

Voltage Class: The CT voltage class determines the maximum voltage with which a CT can be in direct contact. For example, a 600-volt window CT cannot be installed on or around a bare 2400-volt conductor. However, a 600-volt window CT can be installed around a 2400-volt cable if the CT is installed around the insulated portion of the cable and the insulation is rated correctly.

Physical and Mechanical Condition

Verify the physical and mechanical condition of the CT. When possible, the CT should be inspected for shipping damage, incorrect bracing, cracks, and general overall condition. The CT should be permanently mounted and not supported by the primary conductor.

Correct Connection of Transformers

Verify the correct connection of transformers with system requirements. This step is often the most critical step performed. Incorrect CT connections can cause significant problems on any polarity-sensitive metering or protection scheme such as generator protection (IEEE 32, 40, 67), line protection (IEEE 21, 67, 78), or differential elements (IEEE 87). In many instances, the connection is as important as the CT polarity. If the primary polarity of a CT is reversed, the secondary wiring can also be reversed to achieve the desired overall polarity. Two wrongs *often* make a right when working with CT connections.

Adequate Clearances

Verify that adequate clearances exist between primary and secondary circuit wiring. Inspect the space between the CT phases, ground, and secondary conductor to ensure adequate clearance. (Quick rule-of-thumb: one inch per kilovolt plus one inch.) Remember that line-to-line voltages apply between phases. Also check that the secondary wiring is not run parallel and/or close to the primary conductor to prevent any current from being induced into the secondary path. All wiring above the primary conductor should be permanently affixed to the structure to prevent the wiring from falling onto the primary conductors in the future. (Sticky backs are *not* considered permanent.)

Grounding and Shorting Connection

Verify that all required grounding and shorting connections provide contact. CTs are always shipped with shorting devices installed if the burden circuit cannot be completed at the factory. Measure the resistance between both sides of the terminal block to ground before removing the shorting device to ensure the device is operating correctly. The measured resistance should be negligible. The CTs should remain shorted until the secondary wiring is complete and loop-tested. Always check to ensure that the shorting devices are removed on in-service CTs just prior to energization.

CT Electrical Tests

Insulation-Resistance Test

In accordance with NETA specifications, "Perform insulation-resistance tests to ground of the CT and wiring at 1000 volts dc. For units with solid-state components, follow manufacturer's recommendations.

When applicable, perform insulation-resistance and dielectric-withstand tests on the primary winding with the secondary grounded. Use test voltages in accordance with Tables 100.5 and 100.9 respectively in the NETA specifications."

When electromechanical relays were king, insulation-resistance tests of CTs and wiring were an acceptable method of testing the entire circuit including the internal relay wiring. In the age of microprocessor relays, the risk of damage to the new, more sensitive, relays must be weighed against the benefit of the test. I recommend isolating the CTs from the external wiring at the first terminal block or test point and applying the test voltage between the CT and ground. All three CTs can be tested simultaneously. Investigate any measurement below 100 megohms.

Never perform this test on bushing CTs while the power transformer is under vacuum. Although a perfect vacuum is a perfect insulator, the transformer vacuum is not perfect, and there is a strong possibility of causing a flashover inside the transformer.

Polarity Test

Perform a polarity test of each current transformer. There are two generally accepted methods of testing a CT's polarity using simple meters and connections:

- **DC Kick/Flick Test:** This is the tried and true method for testing CT polarity, used before electricity was discovered by some accounts. For this test, a dc battery, a dc voltmeter or ammeter (preferably analog), and test leads are required. This method is a quick and easy test for polarity, but there is a possibility that it may leave remnant flux in the CT. Remnant flux may cause saturation when the CT is next energized. (See C57.13.1, paragraph 4.3.) Always perform an excitation/saturation test after performing this test. The steps of the dc kick/flick test are as follows:

1. Connect the positive of the voltmeter to the H_1 (marked) terminal of the high-voltage side of the CT and the negative lead to the H_2 as shown in Figure 3.

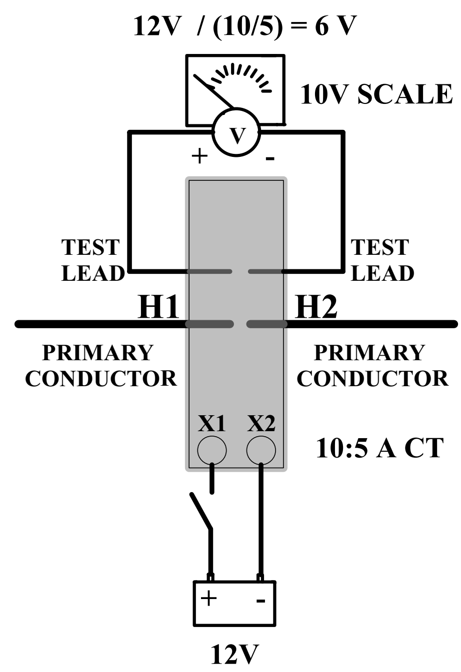

Figure 3 — DC Polarity Test Circuit Window Type CT

- If testing a window-type CT, run a wire through the CT and connect your meter across the wire. Make note of the wire and meter polarity.
- If the CT is enclosed within a breaker, close the breaker and connect your voltmeter across the breaker poles. Review the CT drawing carefully and note the CT polarity and meter polarity.
- If the CT is enclosed within a generator, connect the voltmeter across the generator windings. Review the CT drawing carefully and note the CT polarity and meter polarity. If the star point is not accessible, connect the voltmeter across two generator leads and short the remaining generator lead to one of the generator leads under test.
- If the CT is enclosed within a transformer, connect the voltmeter across the transformer bushings associated with the CT and short the remaining bushing to the nonpolarity bushing under test. Review the CT drawing carefully and note the CT polarity and meter polarity. (See Figure 4.)

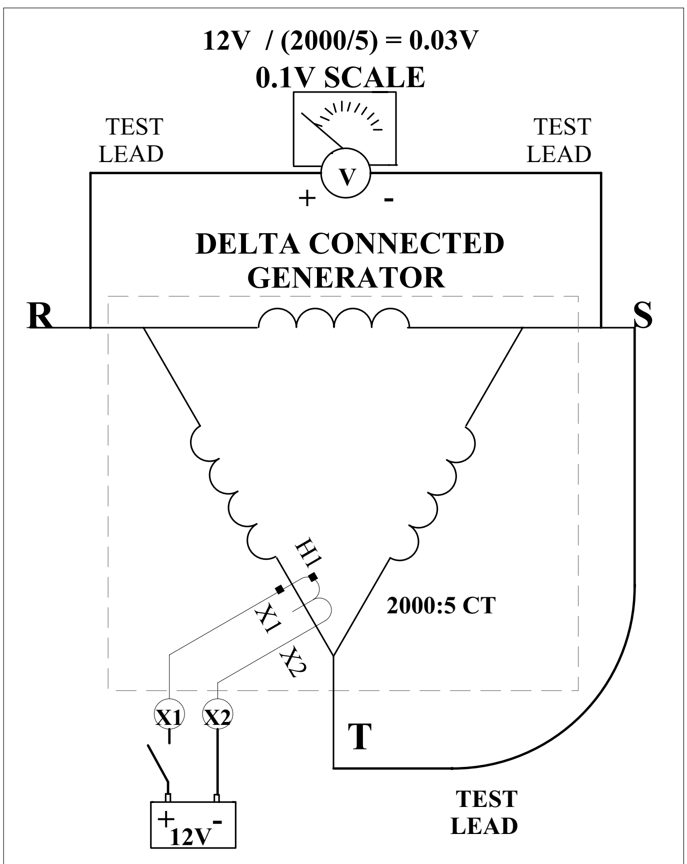

Figure 4 — DC Polarity Test Circuit Delta Connected Generator

2. Calculate the expected voltage using the battery voltage and the CT ratio. (Battery voltage/CT ratio.)
3. Connect the negative terminal of the battery to the nonpolarity of the CT winding under test. *Momentarily* touch or connect the battery's positive terminal to the polarity terminal of the CT winding under test.
4. Closely watch the needle or analog scale of the voltmeter. It should jump in the positive direction. This happens in a fraction of a second, so the meter must be monitored very closely. If the voltmeter kicks in the positive direction, the polarity marks are correct. If it kicks in the negative direction, the polarity marks are incorrect.

AC Voltage Method: This method digs deep into transformer theory and can be used with any kind of transformer. Most transformer polarities are marked with additive polarity that allows creation of an autotransformer by connecting X1 and H2 or H1 and X2 together.

This method is limited by the accuracy of the meters and may not be reliable with unstable source voltages (such as construction power or generator) and high ratio CTs due to the low H side voltages induced.

To test polarity using ac voltage, a variable transformer and voltmeter (preferably two) are required. Use the following steps to test for CT polarity using the ac method, as shown in Figure 5.

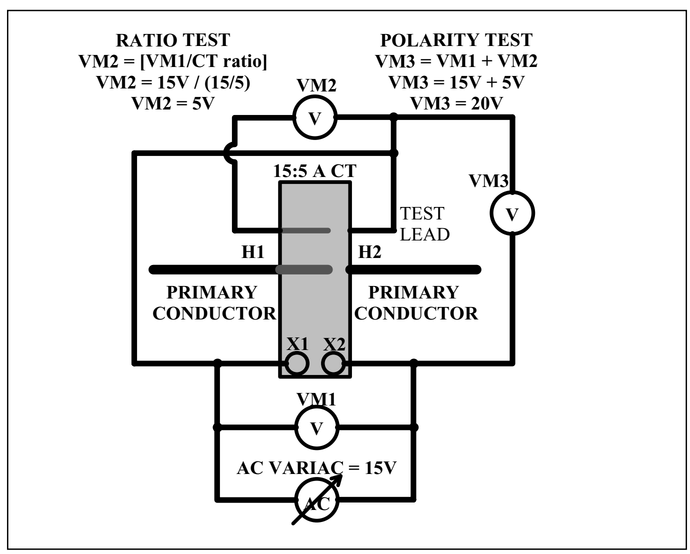

Figure 5 — AC Voltage Ratio Test Circuit

1. Connect a variable transformer (such as a Variac) across the secondary winding of the CT.
2. Connect a voltmeter (VM1) across the secondary CT winding and variable transformer.
3. Connect a jumper between the nonpolarity of the H winding and the polarity of the X winding.
4. Connect a voltmeter (VM3) from the polarity mark of the H winding to the nonpolarity mark of the X winding.

5. Increase the variable-transformer test voltage to a predetermined value. Calculate the expected value. ([VM1 / CT ratio] + [VM1]). If VM3 displays the expected result, the CT polarity markings are correct. If VM3 is less than VM1, the test connection or the CT polarity markings are incorrect. (Note: VM1 and VM3 can be one voltmeter switching between positions if the test voltage remains stable.)

Ratio-Verification Test

The NETA specifications state, "Perform a ratio-verification test using the voltage or current method in accordance with ANSI C57.13.1 (*IEEE Guide for Field-Testing of Relaying Current Transformers*)." The CT ratio test determines the CT accuracy, and the results should be compared to the accuracy class. The easiest and most accurate CT ratio test method for most applications is the voltage method and is the method we will discuss here.

It may seem strange to use voltage to test a CT ratio, but basic transformer theory applies to all transformers, including CTs. One of the first transformer fundamentals is that the transformer ratio applies inversely to current and voltage. A 400:5 CT ratio will convert 400 primary amperes to five secondary amperes and convert 80 secondary volts to one primary volt. We apply this principle to CT testing because it is easier to locate, carry, and apply an 80-volt voltage source than a 400-ampere current supply. The voltage method is also more accurate because measurements can be made directly instead of applying CTs and clip-on ammeters that add error based on their accuracy. The applied voltage must be well below the saturation voltage or there will be a significant error reported. The steps for a ratio-verification test are as follows:

1. Connect a voltage source (variable transformer) and voltmeter (VM1) across the CT secondary, as shown in Figure 5.
2. Connect a voltmeter (VM2) across the CT primary.
3. Apply a voltage to the CT secondary and measure the secondary (VM1) and primary voltages (VM2) simultaneously. Calculate the ratio between the two voltages (VM1 / VM2).

This voltage should match the CT ratio (primary / secondary). You can repeat the procedure above for each tap of a multitap CT, but I prefer to treat the CT taps as I would an autotransformer. I apply a voltage across the maximum ratio tap and measure all remaining taps to a common point, as shown in Figure 6. Prove all tap combinations by using the information recorded from this test.

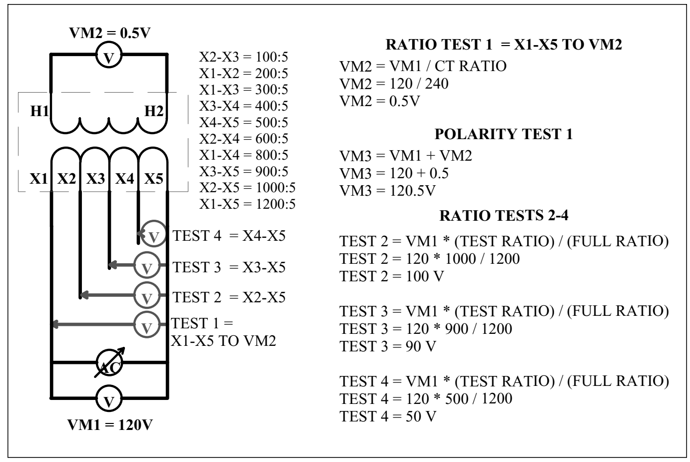

Figure 6 — Multi Ratio CT AC Ratio CT Test Connections

Excitation Test

In accordance with NETA specifications, "Perform an excitation test on transformers used for relaying applications in accordance with ANSI C57.13.1. (*IEEE Guide for Field Testing of Relaying Current Transformers*)." During normal operation, the CT operates as a nearly perfect machine with very small energy losses necessary for CT operation. The magnetic theory involved in transformer operation is too complex to address in this article, but the magnetic circuit can be compared to a normal electrical circuit: the primary winding (generator), iron core (transmission line), and secondary winding (load). During normal CT operation the high-side winding (generator) supplies energy through the iron core (transmission line) to the low-side winding (load) with small losses in the transmission line.

When a CT is saturated, the magnetic path inside the CT operates like a short circuit on the transmission line. Almost all of the energy supplied by the primary winding is shunted away from the secondary winding and is used to create a magnetic field inside the CT. Saturated CTs can be very deceiving when used to supply protective relays as they may operate normally at low current levels and not operate at all during fault currents.

Some of the following conditions can cause CT saturation:

- CT secondary burden greater than rated.
- Extremely high current flowing through the CT (fault current).
- Current flowing through CT primaries with open-circuit secondaries.
- DC current flowing through either winding.

The excitation test is used to prove that the CT is not saturated and will operate within specifications at the rated burden. It is important to remember when comparing test results to the burden rating that the burden rating is a *minimum* value. The CT could actually have a higher rating. This happens often in transformer bushing applications.

A saturation test is performed by applying ac voltage to the CT secondary and increasing the voltage in steps until the CT is in saturation. The test voltage is slowly decreased to zero to demagnetize the CT. The test results are plotted on a logarithmic graph and evaluated based on the transition period between normal operation and saturation. This transition is called the knee of the curve and is directly related to the voltage burden rating of the CT. Use the following steps to perform an excitation test:

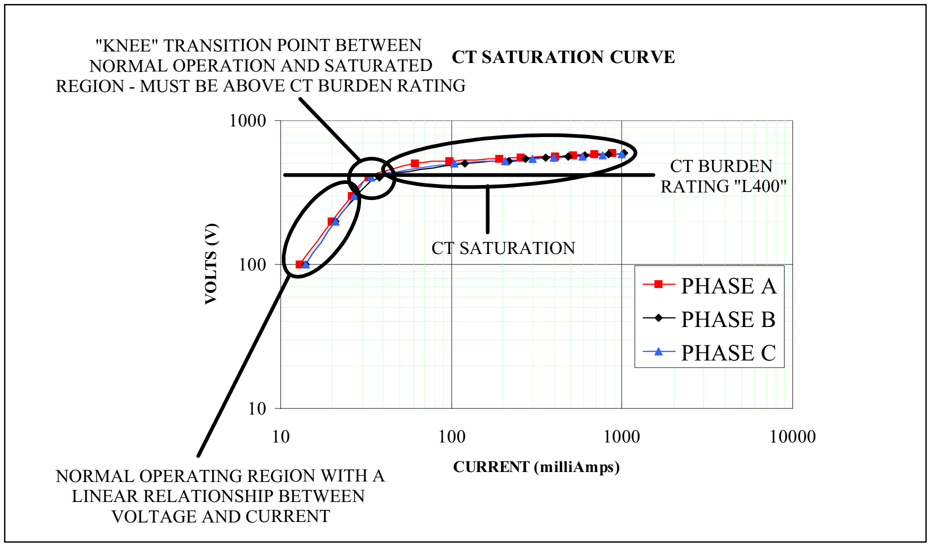

Figure 8 — Example Excitation Test Results

1. Obtain the CT accuracy class.
2. Convert the accuracy class to a voltage burden rating. (See Part I of this article Fall 2004 issue of *NETA World*.)
3. Connect the test equipment per Figure 7 to the first CT scheduled for test.
4. Slowly increase the voltage until saturation. (We will use 1000 milliamperes for this article, but saturation could be higher or lower depending on CT construction.) Watch the current and note the voltage where the current increase *begins* to increase dramatically. Note the voltage where the current reaches 1000 milliampere.

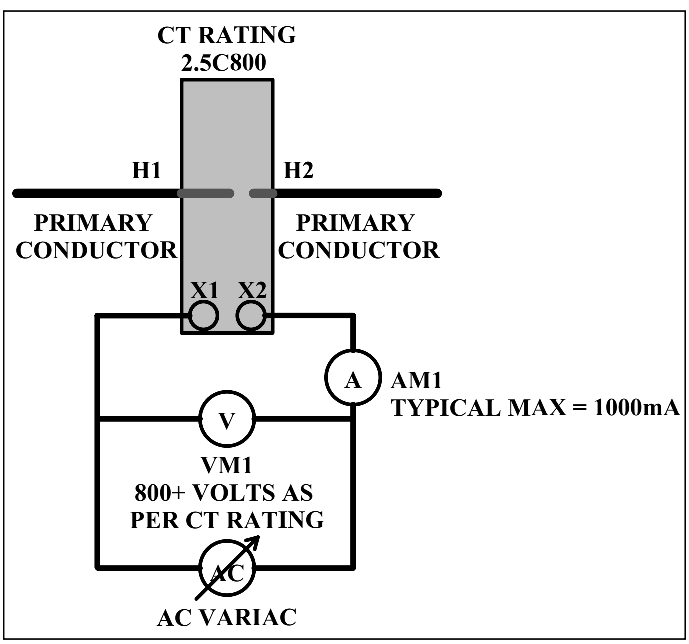

Figure 7 — Excitation Test Connection

5. Slowly decrease the voltage to zero.
6. Determine your test voltages using four equal steps to the first-noted voltage and six equal steps between the first-noted voltage and the second-noted voltage at 1.0 amperes.
7. Repeat the test using the voltage points determined in Steps 4 and 6 and record the milliamperes at each step. *Never* decrease the voltage until the maximum test voltage is reached. You must either skip the voltage step or restart the test from 0 volts if the voltage must be decreased to record a result.
8. Slowly decrease the voltage to zero volts. If the voltage is turned off for any reason before the test is complete, the CT may remain saturated. To desaturate the CT, increase the voltage to 1000 milliamperes (saturation) and slowly decrease the voltage to zero.
9. Graph the results on a log-log graph and compare to the manufacturer's supplied results. See Figure 8 to help evaluate the results.

   Manufacturer's results are often typical for a class of CT, although each CT may not have been tested. Because every CT has different operating characteristics, the results may not be exactly the same. Look for similarities and glaringly obvious differences when evaluating the results. If manufacturer's results are not available, the knee of the curve must be higher than the rated burden voltage.
10. Repeat the test using the same test voltages for all CTs of the same rating. Start from the beginning for CTs with another rating.

Determining Total Burden

Measure current circuit burdens at transformer terminals and determine the total burden. This test is very important and often missed in today's world of fast track projects where the testing is broken into stages or multiple testing companies are used in different parts of the project. This test is the final-proof test used to ensure that:

- CTs are not energized with shorting devices installed if used for metering or protection.
- CTs are not left open circuit if not used.
- CTs are connected with a single ground point.
- CT burden ratings are not exceeded.
- All connections are tight.

There are many ways of performing this test, each with its own merits and pitfalls, but this article is focused on the basics and will only cover the voltage-drop method. It is time-consuming but only requires a voltage/current source and a voltmeter. The test applies five amperes through the secondary circuit with a known ground reference while measuring the voltage drop at each point of the circuit to ground. Ohm's law plus the measure of the voltage drop at the source will give us the burden impedance. Analyzing the voltage-drop patterns throughout the circuit confirms the wiring is correct.

After all CT testing and secondary circuit wiring is complete, follow the next steps to perform a secondary-loop test via the voltage-drop method.

1. Remove the CT secondary shorting devices and remove the ground from the circuit. Every CT circuit should be grounded at *one* point only and have its own path to ground per IEEE standard C57.13.2. Many manufacturers incorrectly daisy chain all CT grounds together contrary to this standard.
2. Connect an ac source between the CT secondary feeder as close to the CT as possible and ground. Slowly increase the voltage or current dial. A lamping kit may be used as the source. (A lamping kit is a 120 volt ac source with a light bulb in series.) No current should flow and light bulb remains off. If current flows, a second ground exists somewhere in the circuit which must be permanently removed. Investigate possible sources of ground and repeat this step until no current flows.
3. Connect a temporary ground between the neutral of the test source and the CT star point. Increase the source voltage until five amperes flow in the circuit. If no current flows, the ground is incorrectly applied or the circuit is incomplete.
4. Measure the voltage between the first CT circuit terminal and ground. Multiply this number by the measured current to obtain the voltampere burden (VA = Volts * Amperes). Divide the voltage by the current to determine the burden in ohms (Ohms = Volts / Amperes). Check the CT rating to ensure the burden is less than the nameplate value.
5. Measure the voltage between ground and every connection. The voltage should drop incrementally as you work through the circuit. Any increase in voltage should be immediately investigated. The most common problems found are:
   - Unstable source voltages.
   - Reverse polarity connections.
   - Assumptions about what the terminal point should be instead of using drawing references.
   - Assumptions about where the terminal point is instead of reading the designation.
6. Repeat Steps 2 through 5 for the other two CT phases. The measured voltage patterns should be similar to the other two phases in the circuit if they are identical. Drastic deviations from the voltage pattern should be investigated for loose connections or shorts (e.g., single copper strand accidentally connected between terminals). Additional devices in one phase will cause higher voltages, but the difference between devices should be consistent between phases.
7. After all testing has been satisfactorily completed, turn the ac source off and remove all test leads. Reconnect the CT ground and check with an ohmmeter after it is installed. Record the circuit burdens on your test sheet.

Conclusion

Although the sophisticated test equipment of modern test technicians makes all of our lives easier, we often forget that the technicians before us were frequently limited to a lantern battery, variable transformer, multimeter, and their imaginations. We can use their example to complete the job when our test set malfunctions or is damaged.

Reference

NETA 2001 *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*

Chris Werstiuk graduated from the Electrical Engineering Technology program at the Northern Alberta Institute of Technology and is a Registered Engineering Technologist and Journeyman Power System Electrician. He has performed low-, medium-, and high-voltage acceptance testing, commissioning, and maintenance testing at various locations throughout the Americas. His experience is varied, and he is comfortable in mining, utility, generating, distribution, production, institutional, plant, pipeline, and commercial environments. Chris is currently a Project Manager for Valence USA, a full service field service and electrical training organization.