Lesson Learned

Verification of AC Quantities during Protection System Design and Commissioning

Primary Interest Groups
Transmission Owners (TOs)
Transmission Operators (TOPs)
Generator Owners (GOs)
Generator Operators (GOPs)

Problem Statement
Failure to employ effective commissioning testing practices or effective quality checks of protection system designs when installing or modifying protection systems can lead to protection system misoperations. These can occur with all components of protection systems, but issues with voltage and current instrument transformer wiring regularly surface when protection system misoperations occur. Protection system misoperations have an immediate negative impact on the reliability of the bulk power system and may cause a significant increase in the magnitude and scope of a disturbance.

It should be noted that this lessons learned document is an expanded version of the NERC lesson learned document titled “Verification of AC Quantities during Protection System Commissioning” that was issued on March 11, 2014. The document has been expanded to provide additional guidance based on events noted since 2014.

Details
Event 1:
Effective commissioning and testing practices were not implemented during the installation of a new transformer. As a result, associated line relays were placed in service with the incorrect CT ratio. The defect remained undetected until the occurrence of a system disturbance when the relaying operated incorrectly, increasing the disturbance’s magnitude and scope.

Event 2:
Effective quality checks of a protection system design and effective commissioning testing practices were not implemented. As a result, associated transformer relays were placed in service with a missing connection in a residual current circuit. This defect remained undetected until the occurrence of a system disturbance when again a misoperation resulted, increasing the disturbance’s impact and resulting in a significant loss of load and impact on BES equipment.

Corrective Actions
Event 1:
The entity re-wired the affected relays to the correct CT ratio, and an in-service test was performed to verify current magnitudes and phase angles were correct.

Event 2:
The entity re-wired the affected relays to the correct the missing connection in the residual current circuit and performed primary injection current testing to verify connections.

Lesson Learned

- **Design Accountability**

  The goal of engineering groups must be to issue error free protection system designs. Protection system designs should include appropriate independent reviews and quality checks to detect errors before releasing to the field. Quality checks should be performed for both schematic diagrams and wiring diagrams. An effective quality program will include clear direction on whether engineering, design, or testing personnel are responsible for verification of the accuracy of wiring diagrams. The IEEE working group documents, I12 ”Quality Assurance for Protection and Control Design” and I25 “Commissioning Testing of Protection Systems,” both provide additional discussion on practices to help prevent errors in protection system designs.

  Commissioning testing must include installation tests and effective in-service tests. In-service tests provide an overall check of current and potential circuits to verify these circuits are properly connected and that measured levels of voltage and current are as expected. In-service tests can uncover errors not discovered during installation tests.

  The System Protection and Control Subcommittee put together some guidance for commissioning testing in **Attachment 1**.

NERC’s goal with publishing lessons learned is to provide industry with technical and understandable information that assists them with maintaining the reliability of the bulk power system. NERC is asking entities who have taken action on this lesson learned to respond to the short survey provided in the link below.

Click here for: Lesson Learned Comment Form

For more Information please contact:

NERC – Lessons Learned (via email)

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Attachment 1

Commissioning Testing

Cautions: An open circuit on an in-service CT can produce a high voltage up to 1000 volts or more depending on CT characteristics. Testing personnel performing in-service CT checks should have training and awareness of the potential of high voltage, plan work appropriately, and follow all applicable company safety procedures. Additionally, the consequences of a fault occurring on the primary equipment during in-service testing procedures must be considered prior to isolating protective relay systems to facilitate testing.

In-Service Voltage Tests

In-service tests of voltage circuits consist of comparing voltage magnitudes and phase angles of newly installed circuitry with known proper voltage magnitudes and phase angles of an unaffected circuit at the same location. The reference circuit should be connected to the circuit with the newly installed equipment at the same primary voltage level. In-service tests to verify all phase voltages are correct in terms of magnitude and angle should be done by comparing direct measurements of the voltage magnitudes and phase angles, metered quantities, fault recorder records, etc. of newly installed relays with the reference circuit. Loading of a new circuit is not required to perform in-service voltage tests.

Where external zero sequence voltage is used for determining fault direction in a protective relay, this voltage also needs to be verified. When relays calculate zero sequence voltages directly from the phase voltages, only phase voltage in-service testing is necessary. In-service tests for zero sequence voltage quantities (if required) are done by removing one of the phase voltages on either the primary or secondary side and verifying that the zero sequence voltage magnitude and phase angle is as expected per calculation.

In-Service Current Tests

General Considerations for In-Service Current Tests

In-service tests of current circuits consist of comparing current magnitudes and phase angles of newly installed circuitry with known, proper current magnitudes and phase angles of an unaffected circuit or circuits. The reference circuit or circuits may be at the same location or other locations. In-service tests should be done to verify magnitude and angle of all phase currents, residual currents, and zero sequence polarizing currents. When relays calculate residual current directly from phase currents, the residual current circuit still needs to be verified as intact via primary current tests and/or secondary current tests.

Various additional factors may need to be taken into consideration when comparing current circuits. For example, if a relay is changed at one end of a two-terminal 230kV transmission line, currents could be compared with the other end of the transmission line to determine proper connections. However, the current magnitude and phase angle at one end of a line will not be exactly the same as at the other end of the line due to loads tapped off the line, line charging current (especially on long lines), tapped shunt loads, phase shifting transformers, etc. Secondary currents may also be different due to the use of different CT ratios at the ends of the line. Similar considerations may be required in order to test installations with other varying configurations. Testing personnel must be cognizant of these factors and consider them when performing and interpreting in-service current test results.

Phase Current In-Service Current Tests

In-service tests for phase current quantities are done by comparing measurements of newly installed relays with other known, undisturbed relays and circuits by comparing the direct measurements of the current magnitudes and phase angles, metered quantities, fault recorder records, etc. Loading of a new circuit, at a measurable level, is required to perform in-service current tests.

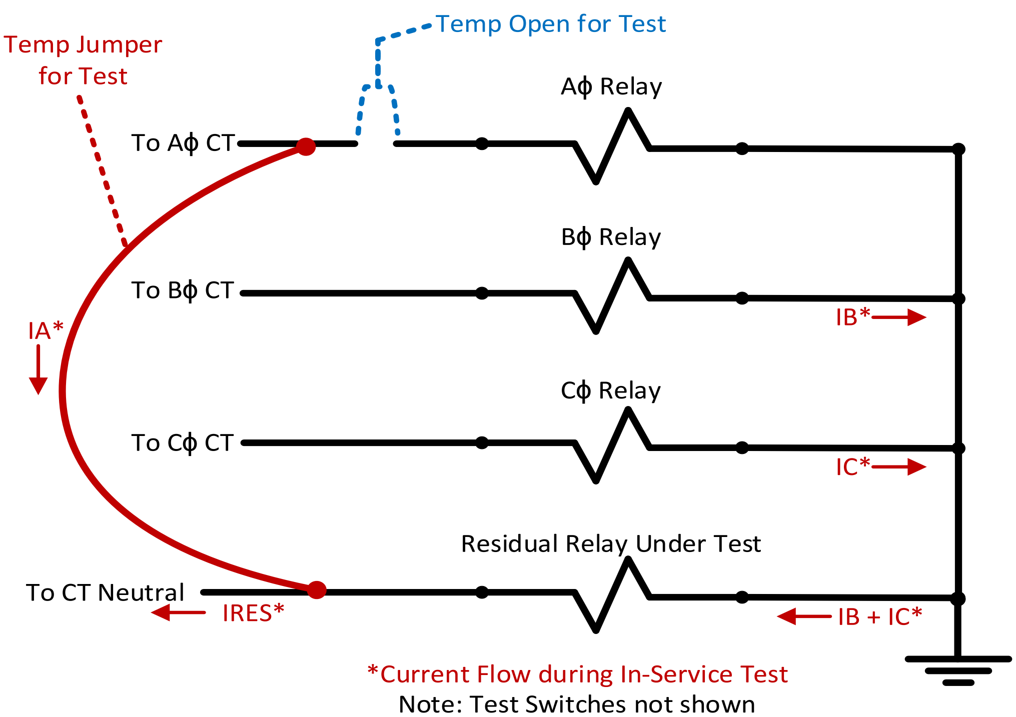
When system conditions are such that loading of the new circuit is too low to accurately verify proper magnitude and phase angle of the new current circuits, system reconfiguration will be temporarily required to attain a sufficient level of load to attain a measurable level of current.

Residual Current In-Service Current Tests

Testing and verifying residual currents are correct can be more challenging than testing and verifying phase currents are correct.

Where the relays being checked are connected in the residual current circuit, the method employed to verify that residual current is proper will depend on the type of relay and the presence of residual current on the primary circuit while performing the test. Verification of magnitude and phase angle in the residual current circuit of an electromechanical relay requires direct measurement in the circuit.

To verify residual current in an electromechanical relay, one method is to force residual current to flow in the relay by bypassing a phase current around the relay. In order to minimize the chance of an open circuit during this type of testing, it is recommended that secondary current testing of the CT circuit be done prior to performing this test. A generic illustration of this is shown in the figure below.



If circuit loading is high enough and enough imbalance between phase currents is present, a measurable level of residual current may exist. In this case a second method of verifying residual current is to compare the directly measured residual current with the calculated residual current based on the verified phase currents. This comparison should be done in a relatively short time period where circuit loading is stable. The residual current input to a modern relay can be verified by comparing the relay's phase currents versus its residual current using the relays metering capability or fault recorder records.

When relays calculate residual current directly from phase currents, the residual current circuit still needs to be verified as intact via primary current tests and/or secondary current tests.

Some types of equipment (e.g. generators, generator step-up transformers, transformers with delta windings) have very low levels of residual current or no residual current under load conditions. Thus, in-service measurement of residual current is not an effective method of verifying proper residual current in relays in these circuits. In these cases, the only secondary current method to verify residual current is to force residual current to flow in the relay by bypassing a phase current around the relay.

Zero Sequence Current Polarizing In-Service Current Tests

Zero sequence current polarizing quantities generally come from current transformers in transformer neutrals or delta windings. Similar to the discussion on residual current verification above, some transformers may have adequate zero sequence current to make in-service measurements. Some transformers may have very low or no zero sequence current under loading conditions. In these cases, secondary circuit installation tests may be solely relied on to verify proper connection of zero sequence currents.

Transformer Neutral Differential (87TN) In-Service Current Tests

Transformer neutral differential relay schemes, also called restricted earth fault schemes, may be used on transformers to provide sensitive detection of ground faults on transformer low side windings or leads. A generic illustration of this scheme is shown in the figure below.

Testing and verifying residual and neutral currents are correct for electro-mechanical implementations of these schemes can be more challenging than testing and verifying phase currents are correct.

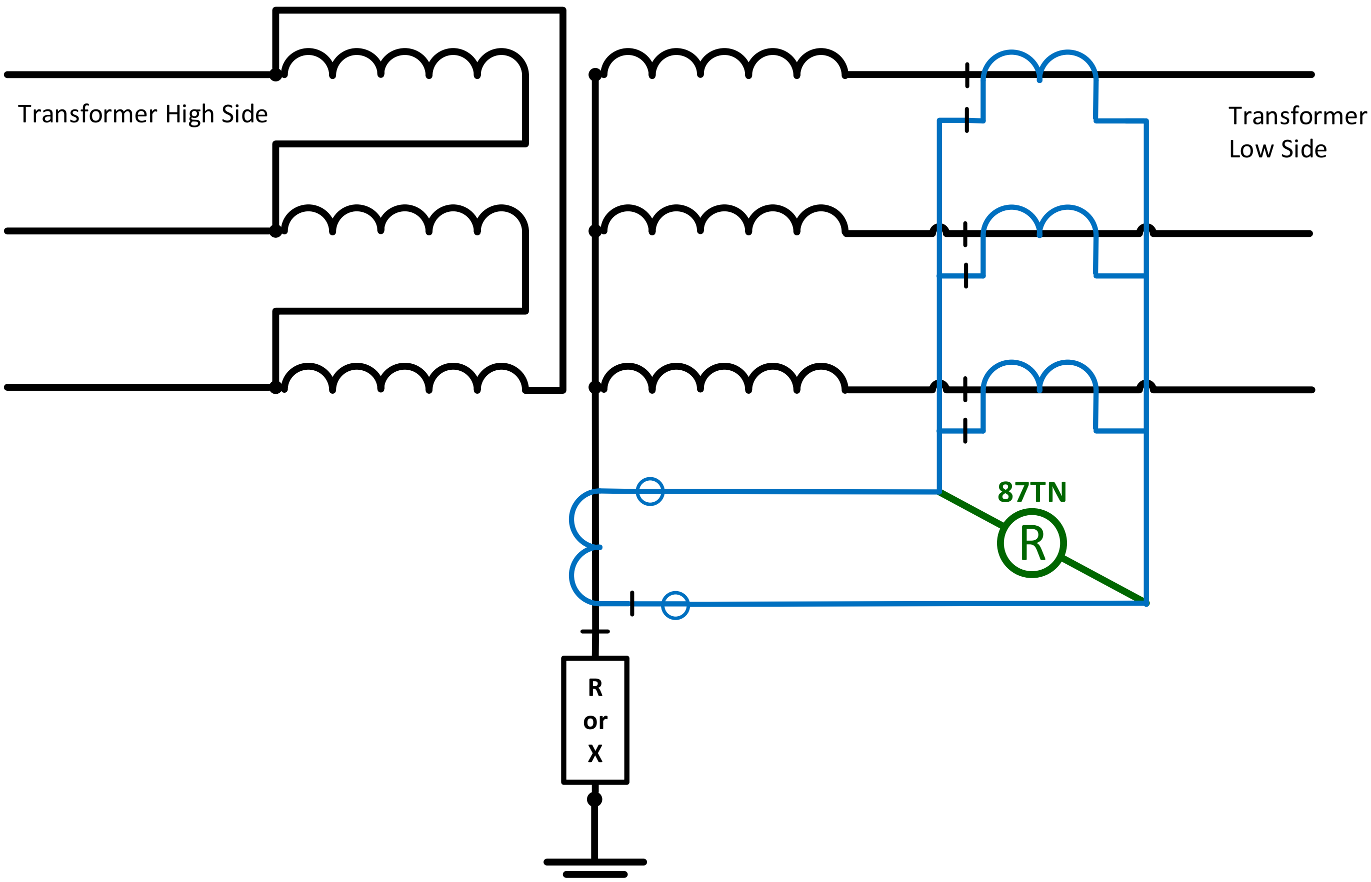
In-service testing of the residual, neutral, and operating current circuit portions of an electro-mechanical 87TN relay scheme depends on the presence of zero sequence load current. If circuit loading is high enough and enough imbalance between phase currents is present, a measurable level of neutral and residual current may exist. In this case, residual and neutral currents can be measured and compared to the calculated residual current based on the verified phase currents. In addition, the residual and neutral currents should be 180 degrees out of phase and the operating current can be verified to be zero. These comparisons should be done in a relatively short time period where circuit loading is stable.

If no measurable residual current exists, testing the residual circuit portion of an electro-mechanical 87TN relay can be accomplished in the same manner as described in the discussion above titled "Residual Current In-Service Current Tests".

If no measurable neutral current exists, the neutral and operating current circuits cannot be verified via in-service tests. Therefore secondary current continuity checks or primary current tests (see section below) must be completed to verify circuit integrity.

In a microprocessor-based relay, the residual current is generally derived from the phase currents and the neutral current is a direct input to the relay. In this case, the residual current circuit still needs to be verified as intact.

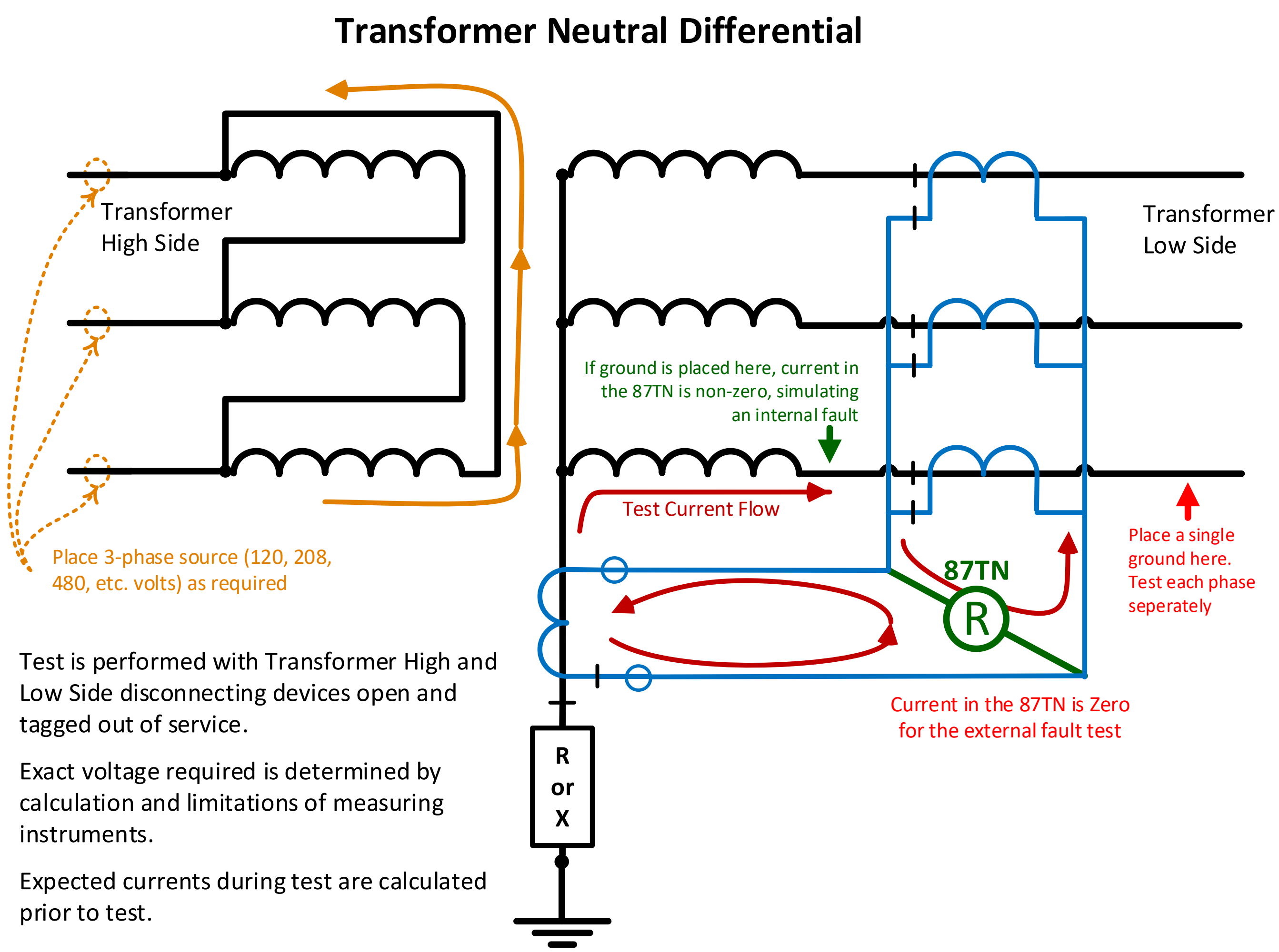
Transformer Neutral Differential



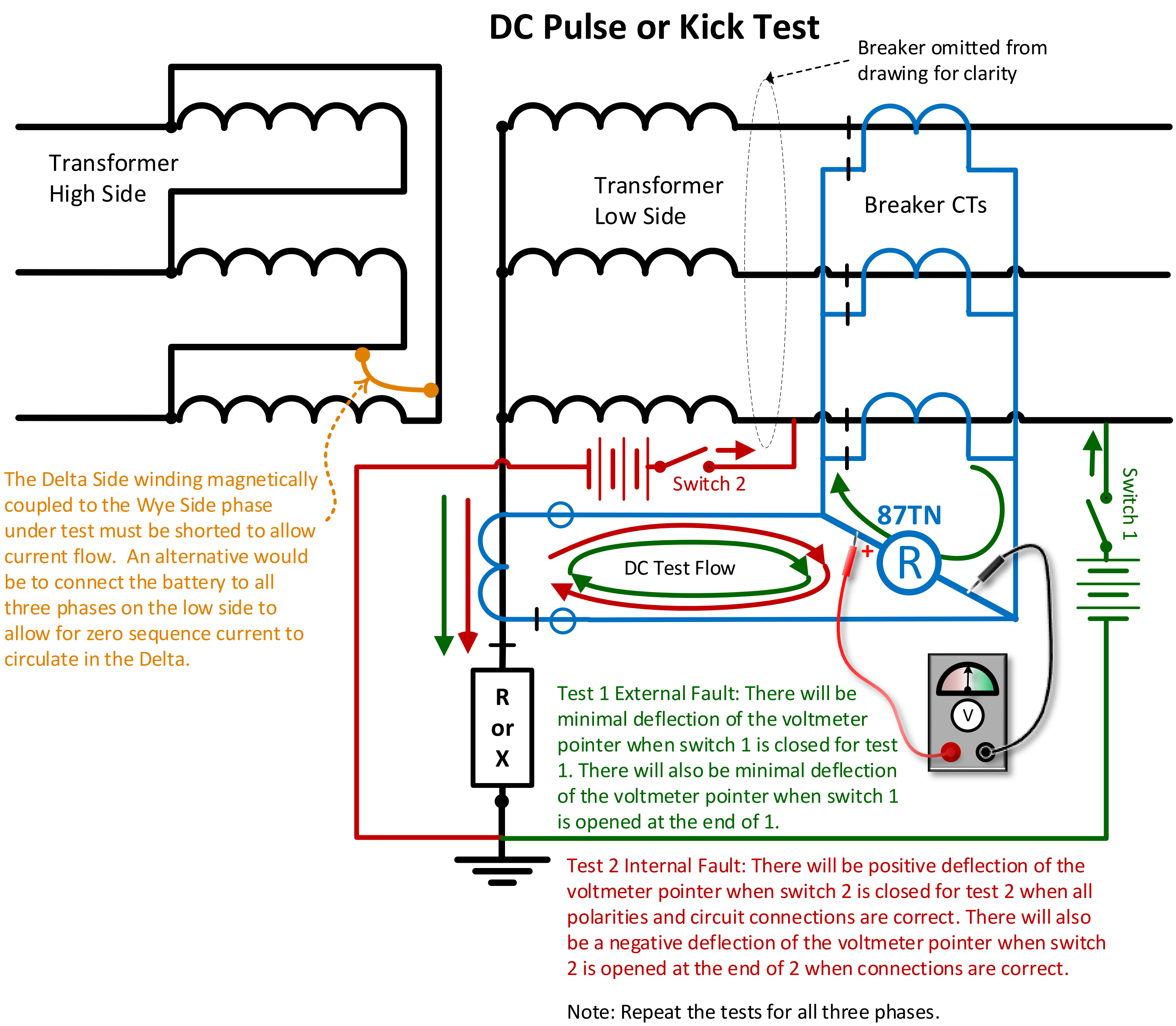
Primary Current Tests

Some entities employ the practice of performing a primary current test (sometimes also called a through-fault test) prior to placing equipment in service. This type of test is typically done on bus or transformer relays and consists of injecting primary current from a test source through the primary equipment and associated current transformers under test. Expected current magnitudes and phase angles are calculated prior to testing and verified during testing. Primary current tests can be three-phase or single-phase. Single-phase tests on transformers can be used to verify proper magnitudes and directions of residual currents, transformer neutral currents, and polarizing currents (if used). Single-phase tests will verify these circuits when in-service tests may not be accomplished (?). These types of tests can be costly and lengthen the time for equipment to return to service. Each entity should determine whether the extra effort to perform these types of tests is justified based on its own circumstances.

A high-level illustration of a single-phase primary injection test for a transformer neutral overcurrent is illustrated below for reference.

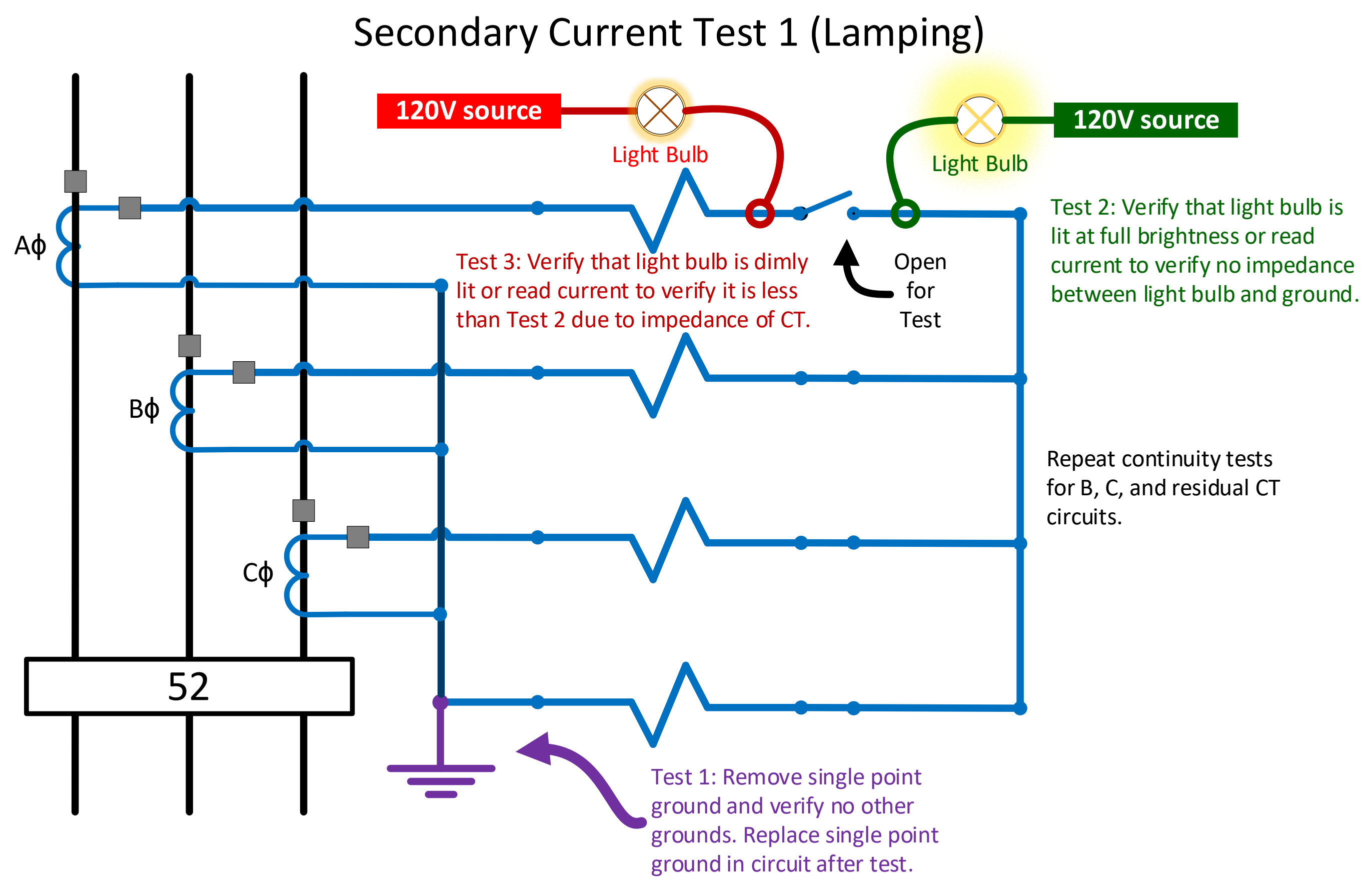


Another type of primary test that verifies overall circuit continuity and proper polarity connections is a “DC pulse test” or “kick test”. In this test, the primary side equipment is taken out of service and isolated. Then, a low voltage DC battery (e.g. 15 volts) is applied on the primary side of the circuit under test so a DC current will flow through the primary side of the circuit CT or CTs. When the battery is applied, the primary side DC current results in a short pulse of current on the secondary side of the CT. This pulse of secondary side current can be measured. The direction of the secondary side current and associated voltages are dependent on the polarity of the primary battery connections. The short pulse of secondary side current can be seen, for example, by the movement of a DC analog voltmeter’s pointer. If the DC voltmeter is connected to verify a positive voltage pulse and the meter’s pointer deflects in the negative direction, it is an indication of incorrect wiring of polarity connections in the CT circuit somewhere. This type of test can be done for a wide variety of circuit types and CT connections. A high-level illustration of a DC pulse test for a transformer neutral overcurrent is below for reference.

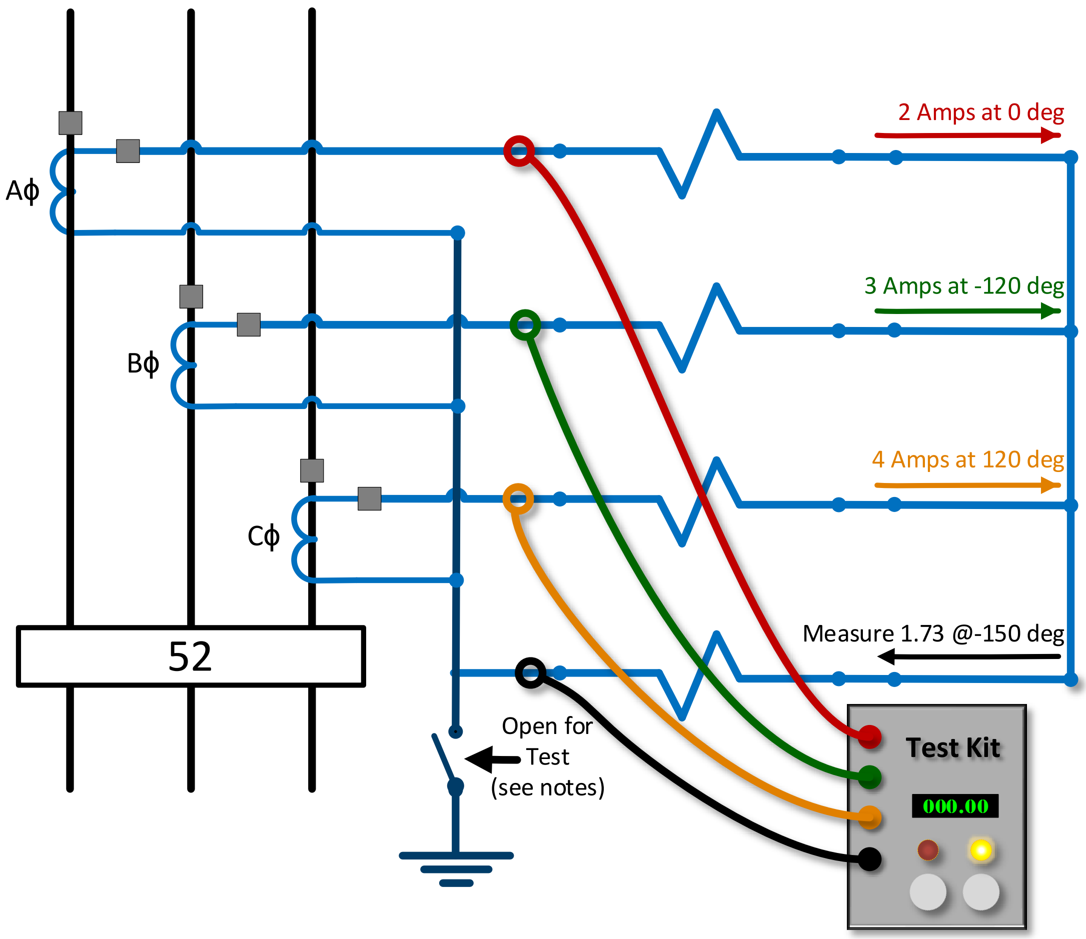


Secondary Current Tests

In-service tests and primary current tests are overall functional tests of current circuits. Secondary current tests are performed earlier in the installation process and include continuity tests and tests to verify a single ground in the CT secondary circuit. Although useful they are not in and of themselves sufficient to preclude the performance of in-service and primary service current tests. These tests do not verify overall circuit function to the level of in-service or primary current tests, but a properly performed secondary current tests will identify secondary circuit wiring issues, secondary grounding issues, etc. so they can be addressed prior to overall functional testing. An example of two methods to perform such tests are below.


Secondary Current Test 1 (Lamping)
120V source
Light Bulb
Light Bulb
120V source
Aϕ
Test 2: Verify that light bulb is lit at full brightness or read current to verify no impedance between light bulb and ground.
Test 3: Verify that light bulb is dimly lit or read current to verify it is less than Test 2 due to impedance of CT.
Open for Test
Bϕ
Repeat continuity tests for B, C, and residual CT circuits.
Cϕ
52
Test 1: Remove single point ground and verify no other grounds. Replace single point ground in circuit after test.

Secondary Current Test 2 (current injection)



Notes:

- Disconnect the CT circuit ground prior to the test as some test kits may have an internal ground that would present a parallel path to test current that could give a false indication of proper circuit flows.
- The CT presents a high impedance compared to the relay side of the secondary circuit. Therefore, there is no need to open the circuit during this test.
- The primary Circuit Breaker is out of service during this test.

CT Tests

CT tests, like secondary current tests are performed earlier in the installation process and do not verify overall circuit function to the level of in-service or primary current tests. CT tests will verify that the CTs installed have the specified ratio/ratios, specified saturation characteristic, and are installed with proper polarity.