Lesson Learned

Verification of Alternating Current Quantities during Protection System Commissioning

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

Problem Statement
Failure to employ effective commissioning testing practices can lead to protection system misoperations. Protection system misoperations impact the reliability of the bulk power system and can cause a significant increase in the magnitude and scope of a disturbance.

Details
Effective commissioning and testing practices were not implemented during the installation of a new transformer. As a result, associated line relays were placed into service with the incorrect Current Transformer (CT) ratio. The defect remained undetected until a system disturbance occurred when the relaying operated incorrectly, increasing the disturbance's magnitude and scope.

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

Lesson Learned
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 measured levels of voltage and current are as expected. In-service tests can uncover errors that were not discovered during installation tests.

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 currents and zero-sequence polarizing currents directly from the phase currents, only phase current in-service testing is necessary.

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 230 kV 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

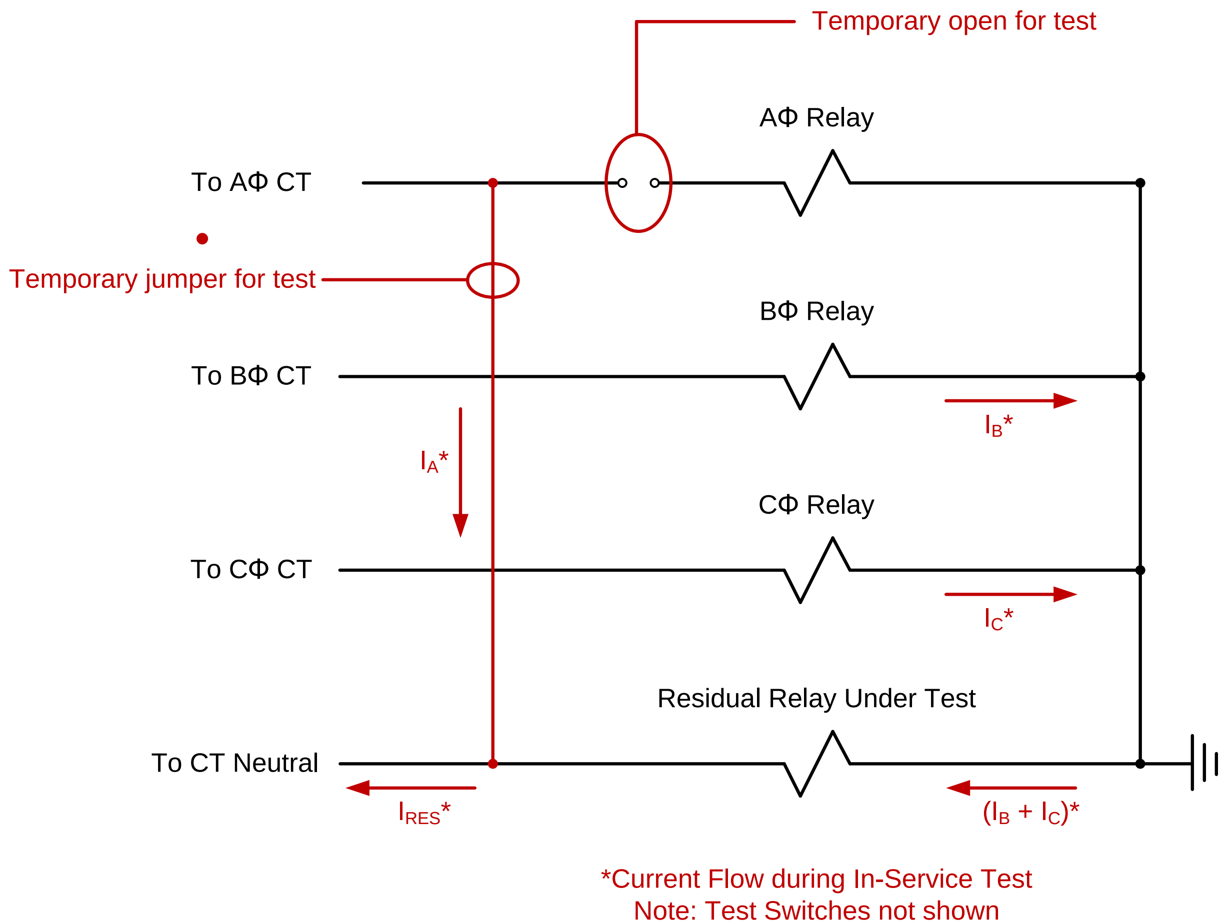
In-service tests for phase current quantities are done by comparing measurements of newly installed relays with other known, undisturbed relays and circuits by comparing the direct measurements of the current magnitudes and phase angles, metered quantities, fault recorder records, etc. Loading of a new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

When 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 that the residual currents are correct can be more challenging than testing and verifying that 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. A generic illustration of this is shown in the figure below.



If circuit loading is high enough and there is enough imbalance between phase currents, 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 phase currents and the residual current using the relay metering capability or fault recorder records.

When relays calculate residual current directly from phase currents, only phase current in-service testing is necessary.

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.

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 into 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 possible. 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.

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