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IEEE Guide for Differential and Polarizing Relay Circuit Testing

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee



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IEEE Guide for Differential and Polarizing Relay Circuit Testing

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Abstract: The issues concerning testing and verification of the correctness of differential and polarizing circuits are described and discussed in this guide. The intention of this guide is to help the reader to detect errors in the wiring of protective relays that might cause erroneous operations of protection systems. It is essential to follow systematic testing procedures and record the observations in a proper organized manner. The records should include documentation of all measurements and a comparison with the desired results.

Keywords: differential protection, generator protection, line protection, polarized ground fault relays, polarized line protection relays, relay testing, transformer protection

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Introduction

(This introduction is not part of IEEE Std C37.103-2004, IEEE Guide for Differential and Polarizing Relay Circuit Testing.)

Errors in the wiring of connections to protective relays have caused erroneous operations of the associated protective schemes resulting in many serious power interruptions. In most cases, thorough testing would have discovered those incorrect connections. Ground relay polarizing and differential relay connections are the most troublesome and difficult to locate; therefore, this guide describes and discusses the issues concerning testing and verification of the correctness of these circuits.

This guide describes tests required for ensuring correct connections. Relay calibration, setting, insulation, instrument transformer tests, etc., are also referred to in this guide, but it is assumed that the individual users have developed these tests, and therefore they are not discussed in detail. Methods for testing differential and polarizing circuits have never really been defined by the manufacturers because a large variety of ways in which differential and polarized circuits are applied in relay systems. Consequently, utilities develop their own testing techniques, which can vary widely depending on factors such as the availability of test switches, test gear, test philosophy, problems discovered in the past, and manpower. Good systematic testing should include systematic documentation of the tests and the test procedures. This should include documentation of all measurements and a comparison with the desired results.

Comments on the advantages and disadvantages of the different techniques are presented, and operating considerations for personnel and equipment are included. Since most of the circuit verification tests include passing current through either the current transformer primaries or secondaries, the voltage source to accomplish these tests varies. For primary testing that may include power transformer windings, the required source voltage will be substantial. For secondary testing, the source voltage may be relatively low. For some of these circuit tests, variable voltages are needed. In each case, the source is identified and noted on the figure involved.

Traditional electromechanical and solid-state differential relays made no provision for phase shifts in the transformers; the connections and wiring had to be arranged so that the normal load currents flowing into the respective primary and secondary “restraint” windings were 180° out of phase. Further, some current transformer (CT) connections were not possible without the use of wye-delta auxiliary CTs or a zero-sequence trap (see IEEE Std C57.13.1™-1981).^a Electromechanical and solid-state relays usually did not provide direct readout of the currents in the relays.

In contrast, present numerical relays compensate for the transformer/CT connections and provide readouts from a front panel human-machine interface (HMI) and/or via the relay communications port. This provision simplifies testing in three ways:

- The installation may be designed such that the CT secondary circuits are all connected in wye, making wiring checkout easier.
- Amplitude and phase of primary/secondary injection and load currents can be checked by interrogation of the relay via the HMI or from a portable computer via the relay communications port. The processing of the signals in the relay automatically takes into account the relationship between the restraint and operating currents that can be ascertained.
- The manufacturer usually provides a worksheet for entry of all the current and phase angle readings, which simplifies interpretation of the results.

^aInformation on references can be found in Clause 2.

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IEEE Guide For Differential and Polarizing Relay Circuit Testing

1. Overview

1.1 Scope

This guide covers the tests required to ensure correct connections of differential relays and polarizing circuits of phase and ground relays. Although other preparatory tests are mentioned in this guide, these tests are not discussed in detail.

1.2 Purpose

This guide is intended to provide methodology to establish a systematic series of tests to verify the integrity and accuracy of connections of differential and polarizing circuits.

2. References

This guide shall be used in conjunction with the following publications. If a publication is superseded by an approved revision, the revision will apply.

IEEE Std C37.110™-1996, IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes.^{1,2}

IEEE Std C57.13.1™-1981 (Reaff 1999), IEEE Guide for Field Testing of Relaying Current Transformers.

IEEE Std C57.13.3™-1983 (Reaff 1990), IEEE Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases.

IEEE PES Special Report, Publication No. 96TP115-0, Relay Performance Testing, 1996.

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3. Definitions

For definitions of terms used in this guide, see IEEE Std C37.100™-1992 [B2]³ and *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B1].

4. Operating considerations for personnel and equipment

A properly trained and equipped relay tester is good insurance for accident prevention. The tester's actions can result in the operation of circuit breakers and motorized switches, which can affect the tester's safety as well as that of others. Therefore, proper communication with all personnel in the area is important.

4.1 Primary testing

Whenever it becomes necessary to work on primary equipment, it is essential to observe all the necessary switching or locking and tagging procedures and to obey those procedures in a rigid and formalized manner. Operating and testing procedures should be followed to avoid exposure to substation equipment that has not been properly de-energized.

NOTE—The primary testing procedures are included to make this guide historically accurate. The Working Group realizes that some of these procedures may not be possible due to personnel safety considerations, lack of suitable power supplies, and in the case of generators, very large current transformer (CT) ratios.

4.2 Secondary testing

Modern relaying systems are designed around the use of dead-front relay and control panels and flexible drawout relays. Whenever possible, secondary relay circuit testing should be performed from the front face of the relay panel through the use of the relay test switches or test connectors associated with drawout relays. Good engineering design practice should take advantage of these features for keeping the relay tester away from the live-rear side of the relay or control panel as much as possible.

At times, it is necessary for the relay tester to work from the live-rear side of the relay or control panel. When working from that side, the tester should find all components clearly labeled including wiring, terminal strips, and fuse blocks.

When it becomes necessary to test equipment that is in service, care should be taken that the appropriate backup equipment is in operation.

4.3 Alternative to primary and secondary testing

Where primary and/or secondary testing is not a normal practice, a preparatory test should be completed prior to energizing the equipment and completing the in-service testing. These preparatory tests should include as a minimum: verifying CT polarity and connections, ringing out circuits from the equipment to the panels, verifying correct current paths through all the applicable relays, and verifying polarizing circuits and/or voltage connections.

Use the techniques described in Clause 7, Clause 8, Clause 9, and Clause 10; modify the techniques to suit the particular application. Next, conduct the in-service tests, reading all current magnitudes and phase angles to determine correct connections.

³The numbers in brackets correspond to those in the bibliography in Annex B.

4.4 Effect of opening CT circuits

An open-circuited CT secondary whose primary circuit is carrying current is hazardous. The voltage of the secondary winding of the CT attempts to rise to a value sufficient to drive the proper secondary current through the impedance created by the open circuit (air gap). In the absence of secondary load current, the average voltage will rise to the rated excitation voltage, with peak voltages several times this value.

Warning

No attempt should be made to reroute the relay currents by disconnecting current circuit wires from terminal blocks or relay terminals when energized, because extremely high voltages could result from such actions. Because the high voltages could be harmful to the persons performing the tests, adequate precautions must be taken when performing these tests.

4.5 CT short-circuiting devices

Most CTs are connected to their burdens through a short-circuiting device located on the CT secondary lead termination point. By proper use of the CT shorting device, it is possible to work on energized CT secondary wiring circuits without necessarily taking the primary equipment out of service, but there are pitfalls.

Care should be taken beforehand to properly identify the CT to be shorted. An ammeter should be connected in the secondary burden to monitor the circuit before, during, and after the CT is shorted and unshorted. Affected relays such as differential, ground, and polyphase relays should be taken out of service before conducting load tests. After conducting the load tests, the relays should be returned to service.

5. Preparatory tests

Before attempting any specific tests by the manufacturer or user to prove the wiring, the following tests should have been completed.

5.1 CTs

It is advisable to test CTs to confirm that their performance is acceptable. Issues concerning the usually performed tests are briefly outlined in 5.1.1, 5.1.2, 5.1.3, 5.1.4, and 5.1.5.

5.1.1 Ratio test

This test is not intended to prove the accuracy of the ratio, but simply to prove that the ratio, as installed, is as specified, and if taps are available, that they also have the correct ratio and have been wired to the correct terminals.

5.1.2 Polarity test

This test proves that the predicted direction of secondary current flow is correct for a given direction of primary current flow. This is essential where currents are summed, compared in differential mode either electrically or magnetically, or where currents and voltages are compared within the relay.

5.1.3 Insulation test

The CT should be tested to prove that the insulation of the secondary winding-to-ground is satisfactory. The CT secondary ground must be lifted for this test.

NOTE—If high-voltage insulation tests are conducted, care must be taken not to expose solid-state relays/devices to the high voltage.

The techniques for carrying out these tests on the CTs are described in IEEE Std C57.13.1-1981.⁴

⁴Information on references can be found in Clause 2.

5.1.4 Resistance measurement

This test confirms that the CT secondary winding dc resistance is within specified limits and that there are no high-resistance joints in the CT or wiring.

5.1.5 Excitation test

This test confirms that the CT, as supplied, is of the correct accuracy rating, that there are no shorted turns in the CT, and that there are no wiring or physical shorts on the CT after installation, primary or secondary. Manufacturer's design curves for the CT should be available; the actual results should be compared with the design curves.

5.2 Wiring checks

Some verification procedures assume that a detailed check of the wiring for agreement with the elementary diagrams should be carried out prior to injection testing. Other verification procedures assume that any wiring errors will be disclosed by the actual injection tests. It is true that injection tests will disclose some wiring errors, but it should be realized that this procedure can damage the equipment because the wiring error may result in accidental injection of test quantities that exceed the rating of the inadvertently connected equipment. Also, errors may not be detected until incorrect operation occurs in service. Selector switches in current circuits, such as ammeter switches, should be checked for proper contact development and operation.

When performing single-phase injection, three-phase and neutral current circuits should be monitored to verify the presence of current where it should be and the absence of current where it should not be. The three-line, elementary, or schematic diagrams should be used for the purpose of checking the connections.

Whichever verification philosophy is used on wiring checks, a test should be performed to prove that multiple grounds do not exist. This test is best performed by removing the known or desired ground and checking insulation to ground at the same location.

Warning

If the current transformer secondary circuit ground is removed without the current transformer primary being de-energized, dangerous voltages may result in the secondary circuit. This is due to electrostatic coupling even with no primary current flowing in the current transformer. The effect of the voltage experienced on the secondary circuit could be harmful to the persons who may come in contact with the secondary circuit. Persons performing the tests must, therefore, make certain that the secondary circuit ground is not removed until the current transformer primary has been de-energized.

5.3 Test switches

Current switches consisting of a test jack and current shorting elements are placed in current circuits to facilitate checkout, troubleshooting, calibration, and periodic testing of relays, meters, transducers, and other instruments. These switches enable the tests to be performed without de-energizing the primary circuit; a switch may be a separate unit or may be built into a protective relay case.

5.3.1 Test jacks

Test jacks are used to allow current measurements to be taken without opening the circuits by inserting a test plug into a test jack. A test plug is a two-wire device connected to a current reading device. Inserting a test plug into a test jack places a current reading device in series with the current circuit. Before the test plug is inserted in the jack, extreme care should be taken to ascertain that a complete low-impedance circuit exists through the current reading device. This can readily be accomplished by using an ohmmeter. A low resistance from the polarity blade to non-polarity blade of the test plug indicates a complete current path. A minimal amount of time is required to perform this test, and its usefulness in preventing the inadvertent opening of a CT secondary makes its frequent use worthwhile.

5.3.2 Current shorting switch

The current shorting switch is usually found mounted on the test jack. The purpose of this switch is to disconnect the current coil of the device to be tested from the current circuit or CT secondary. As its name implies, it does this by first shorting the source-side circuit and then disconnecting the load-side circuit by means of make-before-break contacts. This operation bypasses and open-circuits the device to be tested. An important point to remember is that this switch does not ground the CT. Also, depending upon the switch configuration, total isolation of the load-side circuit may require insertion of a “dummy” test plug in the test jack. With the switch in the shorted position, a closed current circuit still exists. When a test plug is inserted into the test jack without the shorting switch operated, the circuit from the test plug must be completed in order to keep the CT circuit closed.

5.4 Test equipment

The relays should have been tested in accordance with the manufacturer’s instructions and the IEEE PES Special Report No. 96TP115-0-1996 prior to the testing of the circuits by primary or secondary injection.

5.4.1 Transformer load box

This type of test set derives its test voltages and/or currents from a variable autotransformer and loading transformers. The technique is especially useful in high-current testing since the test currents are developed with a lower test voltage, thus reducing the input power requirements for the test source. The output is relatively constant at a low voltage, and therefore, may be subject to some current wave-shape error. This is minimized by using the lowest current output tap (highest source voltage) that will deliver the required test current for the required time duration.

5.4.2 Resistance load box

The resistance box consists of switched resistance units and a variable resistor. It is connected in series with a suitable test current source and the relay under test. The test source must be capable of supplying the required current. The current wave shape is good since the resistance is usually more than the nonlinear impedance of the load.

5.4.3 Electronic techniques

This principle uses electronic circuitry to accurately control and maintain the magnitude, wave shape, and phase-angle relationship of the various test quantities using active feedback of the analog signal. Errors are generally less than 1%.

6. Power supplies for tests

6.1 AC sources for primary current injection tests

The philosophy of primary current injection tests is directly related to the desire for simulating the working of the protective equipment as closely as is physically possible outside a test laboratory. The primary concern usually is the availability and portability of the power supply to be used for conducting these tests. Several good quality power supplies are being marketed today. They provide high currents at low voltages, and their output ranges from 1 to 15 kVA.