

IEEE Guide for Differential and Polarizing Relay Circuit Testing

IEEE Power and Energy Society

Sponsored by the
Power System Relaying Committee



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IEEE Guide for Differential and Polarizing Relay Circuit Testing

Sponsor

Power System Relaying Committee
of the
IEEE Power and Energy Society

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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, IEEE C37.103™, 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™-2015, 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 for helping to ensure correct differential and polarizing circuit 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™)^{a, b, c}. Electromechanical and solid-state relays usually did not provide direct readout of the currents in the relays.

In contrast, present microprocessor 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.

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1. Overview

1.1 Scope

This guide covers ~~the tests required to~~ [help](#) 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~~ provides [a](#) methodology to establish a systematic series of tests to verify the integrity and accuracy of connections of differential and polarizing circuits.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

~~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 C37.11-~~1996~~TM, IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes.^{1, 2}

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

IEEE Std C57.13.~~1983~~ (~~Reaff 1990~~)TM, IEEE Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases.

IEEE PES Special Report, Publication No. 96TP 115-0, Relay Performance Testing, 1996.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.³

high-impedance scheme: A differential method of bus protection using CTs paralleled on a high-impedance load (a voltage or current relay in series with a stabilizing resistor).

linear coupler (LC): An air-core instrument transformer, that like a current transformer, is intended to have its primary winding connected in series with the conductor carrying the current to be monitored. The secondary excitation characteristic is a straight line, without any point of saturation. Because so much of the primary magneto-motive force is consumed in the magnetizing core, very little current can be drawn from the secondary; for this reason, linear couplers are connected in voltage, instead of current, differential circuits.

³ IEEE Standards Dictionary Online subscription is available at:

http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html

~~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~~ important 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. Primary testing procedures must be performed in compliance with all appropriate safety practices. The protected equipment must not be in service when primary current injection tests are performed. 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.

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

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~~ may be 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 should be 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 injection 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.

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.

It is also important to review the design of current circuit test equipment. Many digital multimeters have internally-fused current measuring circuits. Failure of a fuse while testing a live current circuit could result in an open CT circuit and could cause serious injury. Fused ammeters should never be used for current-circuit testing when the current circuit is energized from a primary source.

4.5 CT short-circuiting devices

Most CTs are connected to their burdens through a short-circuiting device located ~~on~~ [between](#) the CT secondary ~~lead termination point~~ [and the relaying circuit or device under test](#). 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 [\(e.g., failing to short-currents before beginning of work may result in opening a CT circuit or damage to a relay such as a high-impedance differential relay, shorting currents feeding a differential circuit resulting in an unbalance and false trip\)](#).

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 Protective relays](#)

The relays should have been tested in accordance with the manufacturer's instructions and the IEEE PES Special Report No. 96TP1 15-0-1996 prior to the testing of the circuits by primary or secondary injection.

5.2 CTs

It is advisable to ~~test CTs~~ [perform tests such as ratio, polarity, insulation, resistance, and excitation](#) 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~~ [Refer to IEEE Std C57.13.1 for additional information.](#)

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~~

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.~~

⁴~~Information on references can be found in Clause 2.~~

5.3 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~~ Regardless of which verification philosophy is ~~used on~~ adopted for wiring checks, a test should be performed to prove that multiple grounds do not exist (see IEEE Std C57.13.3). 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 ~~being~~ de-energizing the current transformer primary, 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~~ should, therefore, make certain that the secondary circuit ground is not removed until the current transformer primary has been de-energized.

5.4 Test switches

Current switches consisting of a test jack and current shorting elements are typically 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.

5.4.1 Test jacks

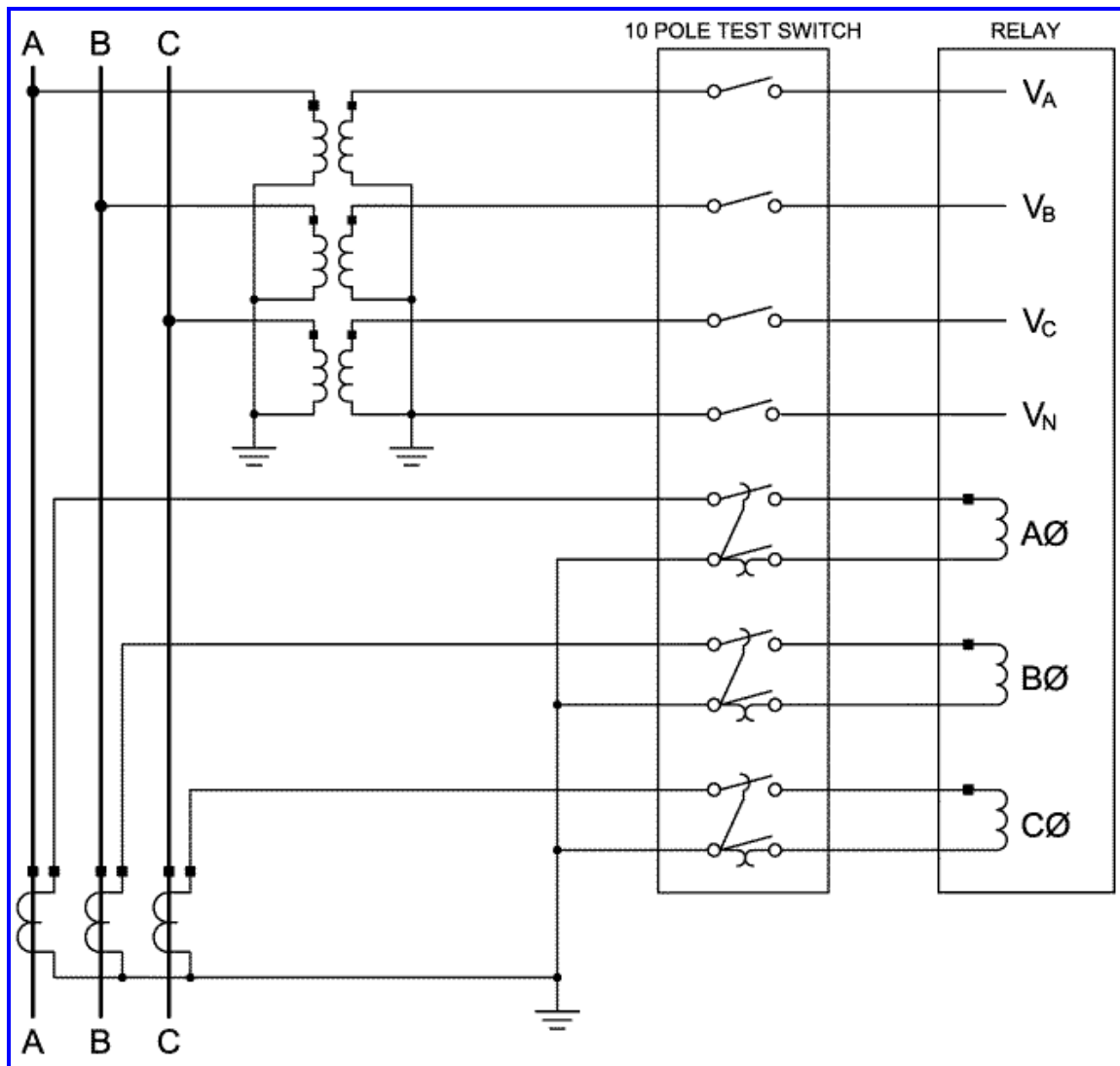
Test jacks are used to allow current measurements to be taken without opening the circuits by inserting a test plug into a test jack. A test plug is a two-wire device connected to a current reading device. Inserting a test plug into a test jack places a current reading device in series with the current 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, [with respect to the relay](#) 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.

5.4.2 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 CT secondary current circuit. 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 [necessarily](#) ground the CT ([see Figure 1](#)).

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. [A test plug designed for this purpose should be used because the use of plastic cable tie-wraps or other such material as these could melt inside the test jack if the CT is inadvertently open-circuited during isolation.](#)

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.



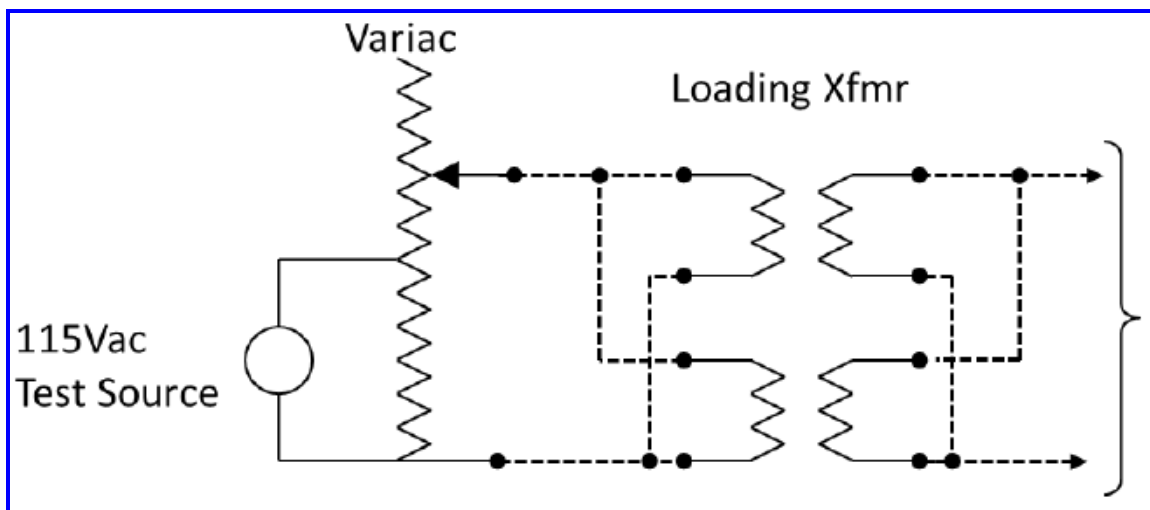
(New)

Figure 1—Current test switch

5.5 Test equipment

5.5.1 Transformer load box

This type of test set derives its test voltages and/or currents from a variable autotransformer and loading transformers (see Figure 2). 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.



[\(New\)](#)

Figure 2 – Variac with loading transformers

5.5.2 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~~ should 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~~ sources 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 kVA to 15 kVA.

6.2 AC sources for secondary current injection tests

A flow of about 1 A current in the relays ~~of~~ having 5 A nominal rating should be sufficient to obtain acceptable readings on measuring instruments.

In the early days, the 120 V station service ~~is usually~~ was used as a ~~convenient~~ source, which ~~can~~ could overcome the impedance of the circuit under test. A variable resistor (resistance load box) or a 120 V lamp bulb ~~can be used to control the level of current that is injected~~ was used to control the level of current that was injected. With the increasing prevalence of ground-fault interrupting outlets in substations, it may be necessary to find a voltage source that is not protected by a GFI for circuit testing with resistive load boxes, unless the current return is referenced only to the outlet (i.e., circuit ground is lifted).

Modern relay test equipment can be used for secondary injection tests instead of discrete components such as phase shifters, load boxes and variable autotransformers. Many test sets can provide three or even six phase currents and voltages. The magnitude, phase angle, frequency, and application interval of the currents and voltages are under the complete control of the user. The test set may be operated with manual controls, or with a portable computer using the appropriate interface and software. This is ideal to test the circuits as they would be in service and they can be used as a tool to reduce wiring errors during commissioning. These test sets can also be used to simulate various faults and abnormal conditions that may be experienced by the protective relay during service.

The secondary injection test set can simulate faults that are inside and outside the zone of protection. Faults within the zone of protection and above the expected pickup can be tested for a trip. Faults outside the zone of protection can be tested to the settings of the protection scheme. The effects of CT saturation on the protection scheme can also be determined with the assistance of software.

6.3 DC current sources for primary and secondary injection tests

~~The dc primary injection tests are used for checking that the polarities of CTs used in a protection scheme are appropriate. The current flow through the primary winding of a CT causes the flux to build up in its core. The flux links with the secondary winding of the CT, and when the current in the primary winding is constant, the flux is constant and the secondary current is zero. When the current flow in the primary winding is interrupted, the current decays rapidly and so does the flux. This in turn causes a flow of current in the secondary winding of the CT, which can be observed on a milliammeter connected in the secondary circuit. The positive or negative deflection of the needle indicates the polarity of the CT.~~ A readily available source of power to perform these tests on CTs is a ~~6-V~~ dc battery. It is suggested that the station battery not be used.

CAUTION

Any time dc is applied to a CT, it may be necessary to perform a demagnetization procedure as described in IEEE Std C57.13.1.

6.4 Test set capacity considerations

If the test involves passing current through low-impedance components such as buswork, closed circuit breaker contacts, secondary cables, and the station ground mat, a low-capacity (VA) or low-voltage test set can generally be used. These are labeled “LV” in the figures below.

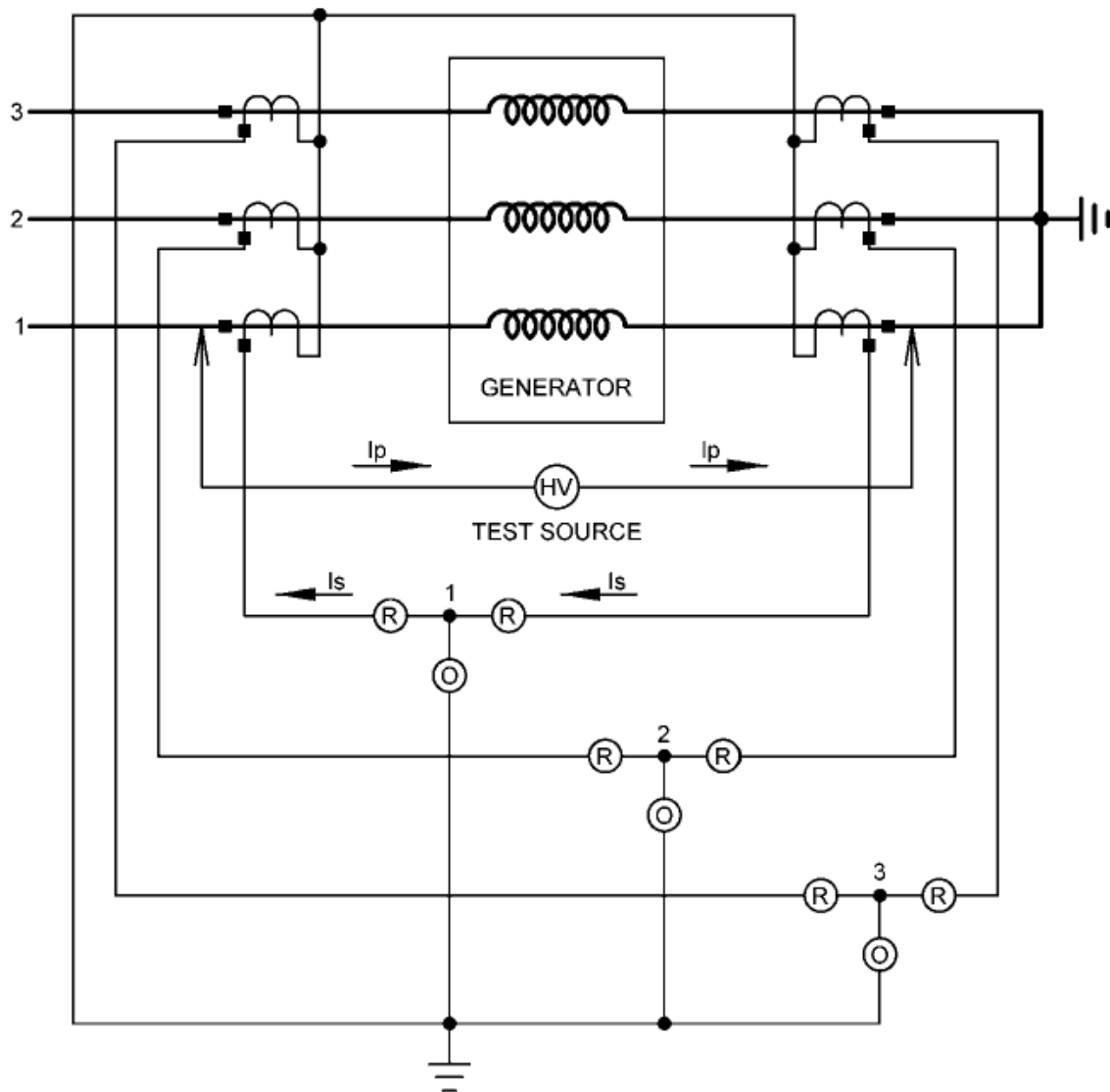
However, if a primary winding is in the circuit, such as a transformer winding or generator winding, a high-capacity (VA) or high-voltage test set will generally be required. These are labeled “HV” in the figures below.

6.4 ~~Demagnetizing the core of a CT~~

~~For information and procedures for demagnetizing the core of a CT, see IEEE Std C57.13.1-1981.~~

7. Generator, motor, and reactor differential relaying

~~The purpose of testing relay circuits is to ensure that relays are properly connected. For example,~~
When the current flowing out of one phase of the generator equals the current flowing into the same phase at the neutral end, then no current should flow in the “operate” winding of the differential relay connected to that phase. Generators, motors, and reactors protected by a differential relay, shown in Figure 3, Figure 4, [Figure 5](#), and Figure 6 for generators, would require identical tests.



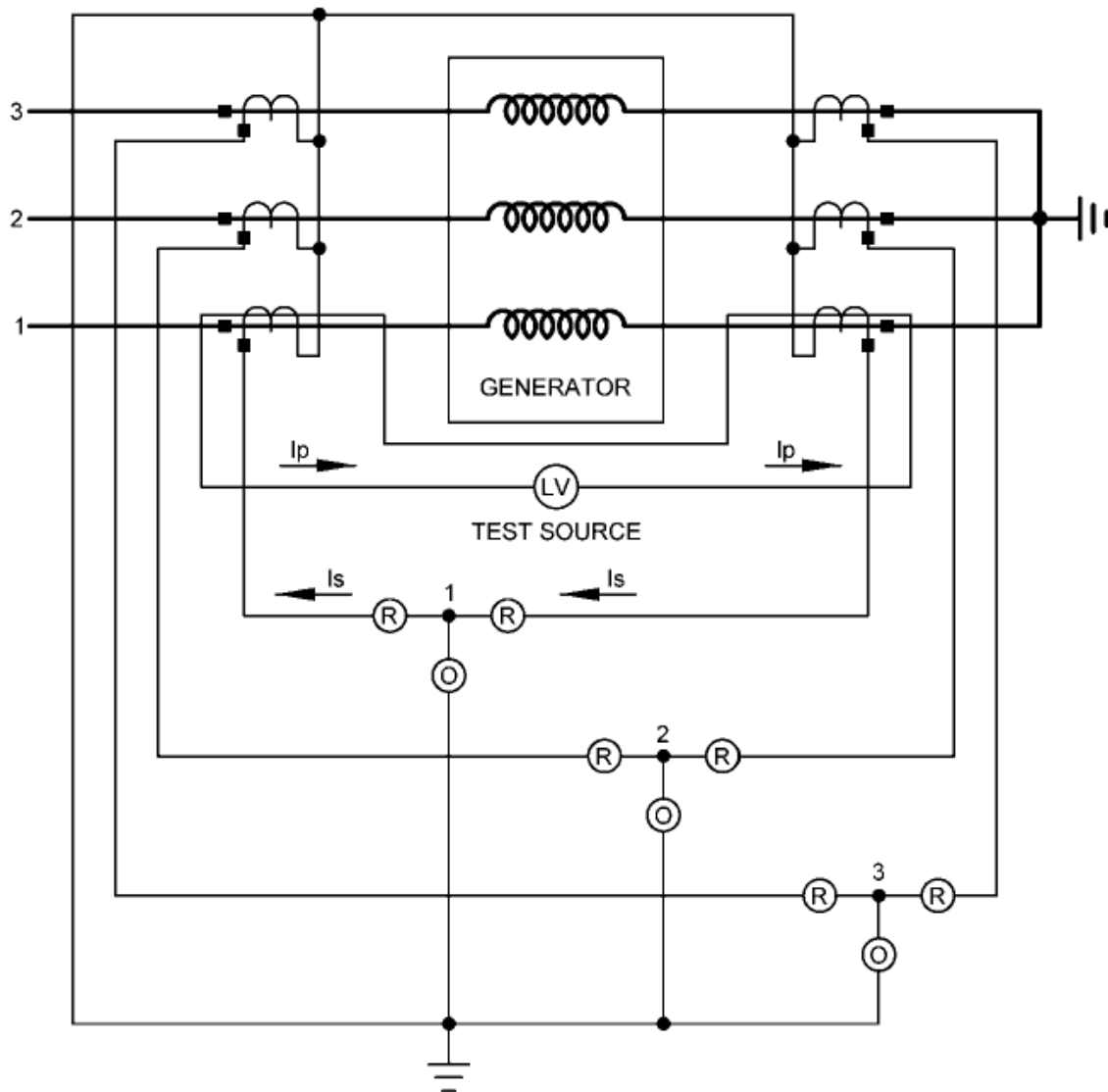
LEGEND

HV – PRIMARY INJECTION TEST SOURCE (HIGH VOLTAGE)

R – RESTRAINT COIL

O – PRERATE COIL

Figure 3—Generator differential—Primary current injection through winding ~~(see 7.1)~~



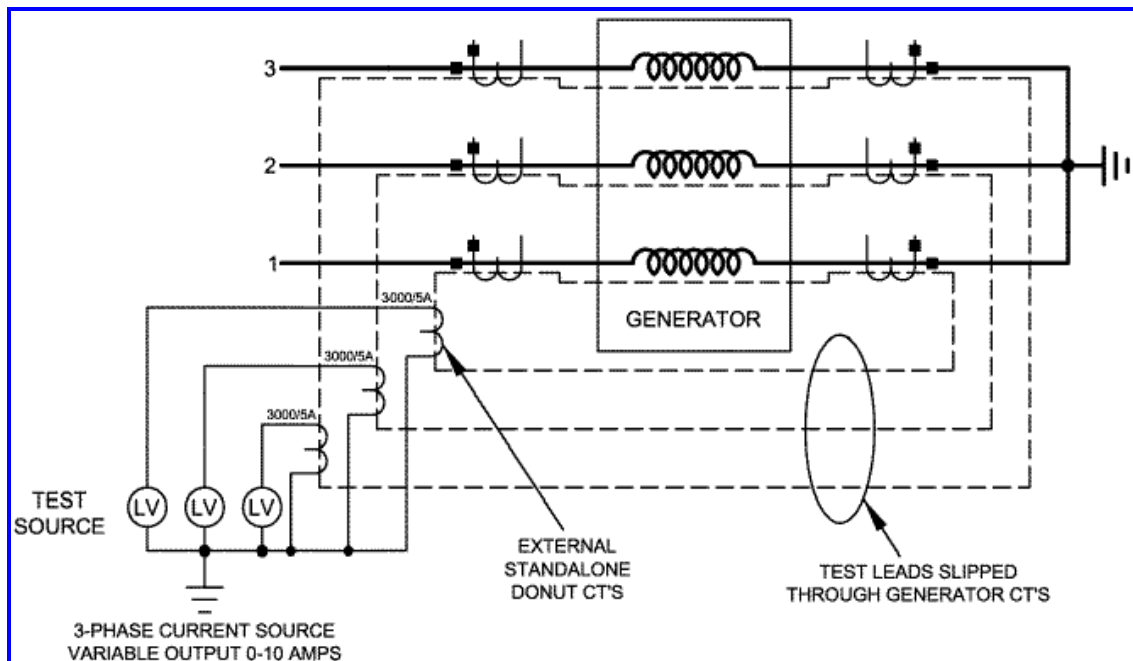
LEGEND

HV – PRIMARY INJECTION TEST SOURCE (HIGH VOLTAGE)

R – RESTRAINT COIL

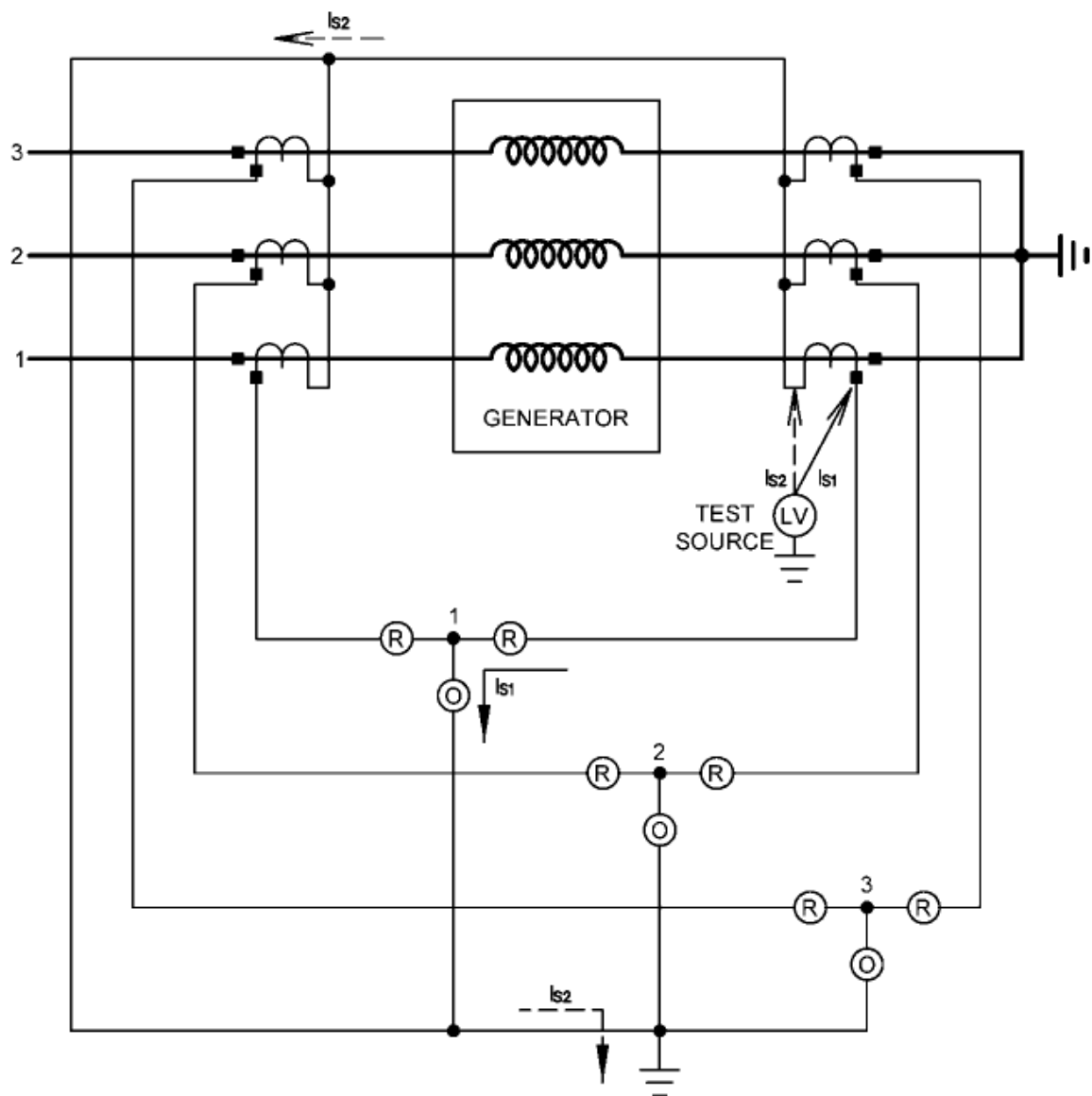
O – PRERATE COIL

Figure 4—Generator differential—Primary current injection test leads slipped through CT window (see 7.1)



[\(New\)](#)

Figure 5—Generator differential—Primary current injection test leads slipped through standalone donut CT window



LEGEND

HV – PRIMARY INJECTION TEST SOURCE (HIGH VOLTAGE)

R – RESTRAINT COIL

O – PRERATE COIL

Figure 6—Generator differential—Secondary current injection ~~(see 7.2)~~

The continuous and short-time current ratings of the “restraint” and operate windings of the relay ~~must~~ should not be exceeded when injection tests are conducted. The current ratings of the operate windings of a relay are usually less than the ratings of its restraint windings.

As in other applications, some machine differential relays, such as microprocessor relays, may not have conventional restraint and operate windings. In such cases, the relay currents of the corresponding phases are essentially electrically isolated. As opposed to an actual network summation of the current inputs, the microprocessor package difference currents are determined electronically, by digital means.

The following subclauses describe current injection tests (primary and secondary) and in-service tests. Only one type of current injection test is required (either primary or secondary), followed by the in-service tests. Primary injection tests can verify CT ratio and polarity, but secondary injection tests cannot, so these must be verified by conventional methods (see Clause 5).

7.1 Primary current injection tests

The protected equipment ~~shall~~ must not be in service when primary current injection tests are performed. ~~Ideally, primary injection of current could be used to test the differential connections to ensure correct response during internal as well as external faults.~~ The arrangement of Figure 3 can be used to test the circuit of a generator differential relay. A high-voltage source is used to inject currents in the primary circuits. These arrangements are convenient to use because in most cases, the load-side CTs are physically located close to the neutral-side CTs. ~~Ideally~~ The test current level should be sufficiently high to confirm that the relay will not operate during external faults. However, most test sets are unable to inject currents of the required levels in the winding of large generators, and therefore, the arrangements of Figure 3 cannot be used for testing relay circuits of large generators.

~~The~~ An alternative arrangement, shown in Figure 4 can be used if it is possible to slip the test leads through the CTs. Test sets able to produce sufficiently high currents along with sensitive ammeters are needed to perform this test. This alternative does not totally resolve the problem of the adequacy of test sets. Consider that a test set can produce a maximum of 400 A and the set is used to test the circuit of a differential relay protecting a 1000 MVA generator equipped with 40000/5 ratio CTs. The maximum current from the test set converts to only 50 mA in the relay circuit. This level of current is not sufficient to test a relay rated for 1 A or 5 A nominal current but may be sufficient to verify the circuit connection.

Another arrangement is to use an external standalone donut CT of ratio 3000-5A as shown in Figure 5. Figure 5 is the modified arrangement that uses the magnetic induction coupling approach. The test leads are slipped through the generator CTs and the stand alone donut CT to form a closed loop. This testing method will be able to produce 3000 A by injecting 5 A on the secondary side of the CT provided the test leads have low burden. The test leads should be very heavy conductor able to carry 3000 A.

Most microprocessor or IED relays require a minimum of 0.25 A input to the relay to achieve reasonable measurements for current magnitude and phase angle. The test set capacity must take this into account.

The following equation can be used to calculate the test set VA requirement for primary injection test:

$$kVA = \frac{3 * (CT * V_{LL} * I_{sec})^2 * X_{Gen}}{1000 * MVA_{Gen}} \quad (1)$$

(New)

where

CT $\equiv$ CT ratio

V_{L-L} $\equiv$ Generator rated phase-to-phase voltage in kilovolt

I_{sec} $\equiv$ CT secondary current (default 0.25 A)

X_{Gen} $\equiv$ Generator impedance (synchronous)

MVA_{Gen} $\equiv$ Rated generator megavolt-ampere

As an example, consider a 1200 MVA, 13.8 kV generator with 8% impedance and CTs having 30000/5 ratio. The required test set kVA for 0.25 A secondary is thus about 86 kVA.

When using the primary current injection test method, the typical microprocessor or IED relay can be used to display the measured current quantities and the phase angles. Once the primary injection testing is in progress, the user should trigger an event to capture the disturbance waveform. The user can then extract the captured waveform and analyze it in order to verify the following: proper phase sequence, applied CT ratio, CT polarity connected, differential current, restraint currents, and current phase angle.

7.2 Secondary current injection tests

These tests are ~~to be conducted~~ performed after all wiring changes have been completed and before the protected equipment is energized. The test source should be applied first to the phase terminal of the CT, as shown in Figure 6, to confirm the integrity of the path for the flow of current (IS1) through one restraint winding and the operate winding. This test should result in the operation of the relay if the circuit is properly connected and the current level is sufficient. The source should then be applied to the neutral terminal of the CTs to confirm the integrity of the path for the flow of current (IS2) to ground without going through the other restraint winding and the operate winding. This test should not result in the operation of the relay if the circuit is properly connected.

The current should be present only in the respective relay phase operate and restraint windings when a phase-to-neutral connection is verified. No significant current flows in the windings of the CTs because they are high-impedance (virtual open circuits). The excitation impedance is very high at the low test voltage used. Check to make sure that the primary of the CT is not shorted with an operational ground.

These tests should be repeated by applying the test source to the terminals of the remaining five CTs. A phase-angle meter may be used in conjunction with the ammeter, in which case a suitable voltage should be selected and used as a reference throughout the tests. [Modern test sets can apply one or more currents at the same time, so it may be possible to test multiple phases at one time.](#)

[For microprocessor-based relays, the operate winding may not be a physical circuit element as shown in Figure 3, Figure 4, Figure 5, and Figure 6, but calculated restraint and operate currents may be observed on the relay front panel display, or via a portable computer connected to the relay.](#)

7.3 In-service tests

An in-service test should be performed, in addition to the previous tests, before releasing the protection scheme for normal service. This test should be conducted with the differential relay in service and the protected apparatus carrying sufficient load to produce CT secondary current sufficient for obtaining meaningful measurements, but less than the current required to trip the differential relay. It is advisable to have the differential trip in service for initial energization of the protected equipment, ~~and then~~. Disabling the trip circuit for ~~this test (disabling the trip circuit in-~~ [service tests](#) should only be ~~done~~ [performed in compliance with all appropriate safety practices, after considering any possible risk to the protected equipment from such an action\).](#) [Disabling differential protection with protected equipment energized is never advised unless other adequate protection for faults in the differential zone is provided.](#)

The amplitude and phase angle of the current in each restraint winding should be measured using a reference source, phase-angle meter, and ammeter.

Alternatively, a microprocessor relay may display the required values on the front panel or via a portable computer interface, including direct readout of differential current. The currents flowing from the line-side CTs to the restraint windings of the three phases should be equal in magnitude, but displaced by 120° from each other. The currents flowing from the neutral-side CTs to the restraint windings of the three phases should also be equal in magnitude, but displaced by 120° from each other. The currents flowing in the restraint windings connected to the line and neutral-end CTs of each phase should be equal in magnitude and 180° displaced. The currents flowing in the operate windings should also be checked to verify that they are essentially zero.

8. Bus differential relaying

It is possible to apply primary and secondary injection tests to most bus differential relaying schemes. A proper application of phase-angle meters and/or oscilloscopes, in addition to ammeters and voltmeters, provides measurements which can be used to determine the appropriateness of connections and integrity of components. In-service tests, in which load current quantities can be measured at the relay panel, are also very effective in determining the integrity of the relay circuit being tested.

[As mentioned in Clause 7, only one type of current injection test is required \(either primary or secondary\), followed by the in-service tests.](#)

8.1 Primary current injection tests

Typically, bus differential protection schemes either use CTs to convert system level currents to relay level currents or use linear couplers ([LC](#)) to convert system level currents to relay level voltages. The primary objective is to balance the secondary signals and produce a net current through, or a voltage across, the protective relay that identifies each ~~disturbance~~ [event](#) either as an external fault or as an internal fault.

When a fault is outside the bus zone, the [CT](#) connections are ~~appropriate~~ [correct](#), and the ~~components~~ [bus differential relays](#) are functioning properly, the net current [measured](#) in (or the net voltage [measured](#) across) the operate element of the relay is extremely small, and therefore, the relay does not operate. [The measured operating quantities are large when a fault occurs or is simulated in the bus protection zone.](#) An incorrect connection ~~or~~ [short-circuit](#), [or multiple grounds](#) could also cause operating element quantities to be ~~small~~ [large](#) when simulating an external fault. ~~The operating signals are large when a fault is experienced or simulated in the bus protection zone,~~ [resulting in a misoperation.](#)

The primary injection tests of a bus differential relay circuit consist of applying a suitable current source across the primary winding of each CT, or linear coupler, and measuring the secondary quantities at the relay location. Each measurement provides an indication that the CT, or the ~~bus~~ [linear](#) coupler, is connected in the proper phase. It also provides a rough check for the ratio of the primary to secondary signals.