

IEEE Guide for Differential and Polarizing Relay Circuit Testing

Circuits and Devices

Communications Technology

Computer

*Electromagnetics and
Radiation*

Energy and Power

Sponsored by the
Power System Relaying Committee of the
IEEE Power Engineering Society

Industrial Applications

*Signals and
Applications*

IEEE C37.103-1990



Published by the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017, USA.

August 9, 1990

SH13250

Recognized as an
American National Standard (ANSI)

IEEE C37.103-1990

IEEE Guide for Differential and Polarizing Relay Circuit Testing

Sponsor

**Power System Relaying Committee
of the
IEEE Power Engineering Society**

Approved February 15, 1990

IEEE Standards Board

Approved July 24, 1990

American National Standards Institute

Abstract: IEEE C37.103-1990, *IEEE Guide for Differential and Polarizing Relay Circuit Testing*, covers the testing and verification required to ensure correct connections for ground relay polarizing and differential relay connections. Relay calibration, setting, insulation, and instrument transformer tests are referred to in this guide and are assumed to be developed by the individual user. This guide is *not* intended to discuss these aspects in detail.

Keywords: Current injection, differential relay, directional ground relay polarizing, directional phase relay, operate winding, phase angle, restraint winding, tertiary current transformer.

ISBN 1-55937-058-0

Copyright © 1990 by

**The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA**

*No part of this publication may be reproduced in any form,
in an electronic retrieval system or otherwise,
without the prior written permission of the publisher.*

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

IEEE Standards documents are adopted by the Institute of Electrical and Electronics Engineers without regard to whether their adoption may involve patents on articles, materials, or processes. Such adoption does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the standards documents.

Foreword

(This Foreword is not a part of IEEE C37.103-1990, Guide for Differential and Polarizing Relay Circuit Testing.)

This document was prepared by the Differential and Polarizing Circuit Testing Working Group of the Relaying Practices Subcommittee of the Power Systems Relaying Committee of the IEEE Power Engineering Society. The Working Group expresses its appreciation to all persons who have contributed to this guide.

At the time this Guide was approved, the Differential and Polarizing Circuit Testing Working Group was as follows:

R. W. Ohnesorge, *Chairman*

C. W. Barnett
J. F. Criss
J. Esztergalyos

W. J. Marsh
J. Miller

G. R. Nail
L. J. Schulze
J. R. Turley

The Relaying Practices Subcommittee, which reviewed and approved this Guide had the following personnel at the time of approval:

L. E. Landoll, *Chairman*

J. K. Akamine
E. A. Baumgartner
C. H. Castro
D. M. Clark
D. H. Colwell
J. Criss
H. Disante
M. K. Enns
C. W. Fromen
A. T. Giuliantie

C. W. Barnett, *Vice Chairman / Secretary*

R. W. Haas
R. W. Hirtler
J. W. Ingleson
T. L. Kaschalk
D. K. Kaushal
W. J. Marsh
S. L. Nilsson
G. C. Parr
A. G. Phadke
A. Politis
L. Scharf

L. J. Schulze
H. S. Smith
R. P. Taylor
J. S. Thorp
J. R. Turley
E. A. Udren
C. L. Wagner
T. E. Wiedman
M. A. Xavier
S. E. Zocholl

At the time this guide was approved, the Power System Relaying Committee of the IEEE Power Engineering Society had the following membership:

C. H. Griffin, *Chairman*

J. R. Boyle, *Vice Chairman*

J. C. Appleyard
R. F. Arehart
C. W. Barnett
E. A. Baumgartner
R. W. Beckwith
J. J. Bonk
B. Bozoki
W. D. Breingan
J. A. Bright
H. J. Calhoun
J. W. Chadwick, Jr.
D. M. Clark
D. H. Colwell
S. P. Conrad
J. F. Criss
D. C. Dawson
R. W. Dempsey
H. DiSante
P. R. Drum
L. L. Dvorak
W. A. Elmore
J. T. Emery
E. J. Emmerling
J. Esztergalyos
W. E. Feero

R. J. Fernandez
C. M. Gadsden
A. T. Giuliantie
S. E. Grier
R. W. Haas
R. E. Hart
M. Hirakami
R. W. Hirtler
J. W. Ingleson
R. H. Jones
E. W. Kalkstein
T. L. Kaschalk
D. K. Kaushal
K. J. Khunkhun
W. C. Kotheimer
M. E. Kuczka
L. E. Landoll
J. R. Latham
J. R. Linders
F. N. Meissner
J. Miller
R. J. Moran
C. J. Mozina
J. J. Murphy
T. J. Murray
K. K. Mustaphi

J.A. Zulaski, *Secretary*

G. R. Nail
S. L. Nilsson
R. W. Ohnesorge
G. C. Parr
A. G. Phadke
A. C. Pierce
A. Politis
L. J. Powell
G. D. Rockefeller
M. S. Sachdev
E. T. Sage
D. E. Sanford
L. Scharf
H. S. Smith
J. E. Stephens
A. Sweetana
R. P. Taylor
J. R. Turley
E. A. Udren
D. R. Volzka
C. L. Wagner
J. E. Waldron
J. W. Walton
T. E. Wiedman
S. E. Zocholl



Documents

Document Sharing Hub

When the IEEE Standards Board approved this standard on February 15, 1990, it had the following membership:

Marco W. Migliaro, *Chairman*

James M. Daly, *Vice Chairman*

Andrew G. Salem, *Secretary*

Dennis Bodson
Paul L. Borrill
Fletcher J. Buckley
Allen L. Clapp
Stephen R. Dillon
Donald C. Fleckenstein
Jay Forster*

Thomas L. Hannan
Kenneth D. Hendrix
John W. Horch
Joseph L. Koepfinger*
Michael A. Lawler
Donald J. Loughry
John E. May, Jr.
Lawrence V. McCall

L. Bruce McClung
Donald T. Michael*
Stig Nilsson
Roy T. Oishi
Gary S. Robinson
Terrance R. Whittemore
Donald W. Zipse

*Member Emeritus

The Accredited Standards Committee on Power Switchgear, C37, that reviewed and approved this document, had the following members at the time of approval:

T. C. Burtnett, *Chairman*

C. H. White, *Secretary*

M. B. Williams, *Program Administrator*

A. K. McCabe, *Executive Vice-Chairman of High-Voltage Switchgear Standards*

S. H. Telander, *Executive Vice-Chairman of Low-Voltage Switchgear Standards*

D. L. Swindler, *Executive Vice-Chairman of IEC Activities*

Organization Represented

Name of Representative

Association of Iron and Steel Engineers	J. M. Tillman
Electric Light and Power Group	R. L. Capra
	G. R. Brandenberger (<i>Alt.</i>)
	T. E. Bruck (<i>Alt.</i>)
	M. J. Eckelkamp
	K. D. Hendrix
	M. C. Mingoia (<i>Alt.</i>)
	J. H. Provanzana
	D. T. Weston
Institute of Electrical and Electronics Engineers	H. W. Mikulecky
	S. C. Atkinson (<i>Alt.</i>)
	R. W. Haas
	W. F. Hoenigmann
	D. G. Kumbera (<i>Alt.</i>)
	D. M. Larson
	E. W. Schmunk
	C. A. Schwalbe
National Electrical Manufacturers Association	R. A. McMaster
	T. C. Burtnett
	R. H. Miller
	H. L. Miller (<i>Alt.</i>)
	R. O. D. Whitt
Tennessee Valley Authority	R. B. Rotton
Testing Laboratory Group	L. Frier
	W. T. O'Grady
	R. W. Seelbach (<i>Alt.</i>)
US Department of Agriculture, REA	H. L. Bowles
Western Area Power Administration	G. D. Birney
US Department of the Army, Office of the Chief of Engineers	W. M. Jones
US Department of the Interior, Bureau of Reclamation	J. W. Reif
US Department of the Navy, Naval Construction Battalion Center	R. L. Clark

Contents

SECTION	PAGE
1. Introduction.....	9
1.1 References.....	9
2. Safety Considerations for Personnel and Equipment.....	9
2.1 Primary Testing	9
2.2 Secondary Testing	9
2.3 Current Transformer Circuits	10
2.4 Current Transformer Short Circuiting Devices.....	10
3. Preparatory Tests.....	10
3.1 Current Transformers.....	10
3.1.1 Ratio Test.....	10
3.1.2 Polarity Test.....	10
3.1.3 Excitation Test.....	10
3.1.4 Resistance Measurement.....	10
3.1.5 Insulation Test.....	10
3.2 Wiring Checks	11
3.3 Test Switches.....	12
3.3.1 Test Jacks.....	12
3.3.2 Current Shorting Switch	12
3.4 Test Equipment.....	12
3.4.1 Transformer Loading	12
3.4.2 Resistance Loading	12
3.4.3 Solid-State or Electronic Techniques	13
3.4.4 Size	13
3.4.5 Accuracy.....	13
3.4.6 Waveform	13
4. Power Supplies for Testing.....	13
4.1 AC Current - Secondary Injection Testing.....	13
4.2 AC Current -Primary Injection Testing.....	13
4.3 DC Current - Primary and Secondary Injection Testing.....	13
5. Generator, Motor, and Reactor Differential Relaying.....	14
5.1 Primary Current Injection Testing.....	14
5.2 Secondary Current Injection Testing.....	14
5.3 In-Service Testing	18
6. Bus Differential Relaying.....	18
6.1 Primary Current Injection Testing.....	18
6.2 Secondary Current Injection Testing.....	20
6.3 In-Service Testing	20
7. Transformer Differential Relaying.....	21
7.1 Primary Current Injection Testing.....	21
7.1.1 Current Transformers Located in Breakers	21
7.1.2 Current Transformers Located in the Transformer	21
7.2 Secondary Current Injection Testing.....	21
7.3 In-Service Test.....	26

SECTION	PAGE
8. Potential Polarized Phase Relays.....	26
8.1 Primary Current Injection Testing.....	26
8.2 Secondary Injection Testing.....	26
8.2.1 Current Circuit Current Injection Testing.....	26
8.2.2 Current Circuit Voltage Injection Testing.....	28
8.2.3 Voltage Circuit Voltage Injection Testing.....	28
8.3 In-Service Test.....	29
9. Potential Polarized Ground Relays.....	29
9.1 Voltage Circuit Secondary Voltage Injection Testing.....	29
9.2 In-Service Test (Refer to Fig 20).....	30
10. Neutral Current Polarized Ground Relays.....	33
10.1 Primary Current Injection Testing - Primary of All Current Transformers Accessible ..	33
10.2 Primary Current Injection Testing—Primary of Neutral Current Transformer Not Accessible.....	34
11. Tertiary Current Polarized Ground Relays.....	34
11.1 Primary Current Injection Testing-Tertiary Current Transformers Not Accessible, Breaker Current Transformers Accessible	34
11.1.1 Closing Torque Test (Method 1).....	34
11.1.2 Opening Torque Test (Method 2).....	34
APPENDIX	
Results of IEEE Survey.....	43
FIGURES	
Fig 1	
Ratio Check of Current Transformer Within Delta Winding.....	11
Fig 2	
Excitation Test-More Than One Current Transformer Within Delta Winding.....	11
Fig 3	
Typical Test Switch	12
Fig 4	
Generator Differential-Primary Current Injection Through Winding	15
Fig 5	
Generator Differential-Primary Current Injection Tests Leads Slipped Through Current Transformer Window.....	16
Fig 6	
Generator Differential Secondary Current Injection.....	17
Fig 7	
Bus Differential-Current Transformers-Primary Current Injection.....	19
Fig 8	
Bus Differential-Linear Couplers Primary Current Injection	19
Fig 9	
Transformer Differential-Primary Current Injection-Current Transformers in Circuit Breaker.....	22

FIGURE	PAGE
Fig 10 Transformer Differential-Primary Current Injection-Current Transformers in Transformer.....	23
Fig 11 Transformer Differential-Secondary Current Injection —Method 1.....	24
Fig 12 Transformer Differential-Secondary Current Injection—Method 2.....	25
Fig 13 Directional Phase Relay, Current Circuit-Primary Current Injection.....	27
Fig 14 Directional Phase Relay, Current Circuit-Secondary Current Injection.....	28
Fig 15 Directional Phase Relay, Current Circuit-Secondary Voltage Injection.....	30
Fig 16 Directional Phase Relay, Voltage Circuit Secondary Voltage Injection—Method 1.....	31
Fig 17 Directional Phase and Ground Relay, Voltage Circuit Secondary Voltage Injection— Method 2.....	32
Fig 18 Directional Ground Relay, Voltage Circuit, Secondary voltage Injection—Method 1.....	33
Fig 19 Directional Ground Relay, Voltage Circuit, Secondary Voltage Injection—Method 2.....	35
Fig 20 Directional Ground Relay, Directional Check, In-Service Quantities.....	36
Fig 21 Directional Ground Relay (Current Polarized-Transformer Neutral Current Transformer), Current Polarize Circuit, Primary Current Injection—Method 1.....	37
Fig 22 Directional Ground Relay (Current Polarized-Transformer Neutral Current Transformer), Current Polarize Circuit, Primary Current Injection—Method 2.....	38
Fig 23 Directional Ground Relay (Current Polarized-Transformer Neutral Current Transformer), Current Polarize Circuit, Primary Current Injection—Method 3.....	39
Fig 24 Directional Ground Relay (Current Polarized-Transformer Neutral Current Transformer), Current Polarize Circuit, Primary Current Injection—Method 4.....	40
Fig 25 Directional Ground Relay (Current Polarized-Transformer) Current Polarized Circuit, Primary Current Injection—Method 1.....	41
Fig 26 Directional Ground Relay (Current Polarized-TransformerTertiary Current Transformer Tertiary Current Transformer) Current Polarized Circuit, Primary Current Injection— Method 2.....	42

IEEE Guide for Differential and Polarizing Relay Circuit Testing

1. Introduction

Wiring errors have caused relays to operate erroneously, thus causing many serious power interruptions. In most cases, thorough testing would have disclosed these incorrect connections. Ground relay polarizing and differential relay connections are the most troublesome; therefore, this guide will be devoted to the testing and verification of these circuits.

This guide covers only the tests required to ensure correct connections. Relay calibration, setting, insulation, instrument transformer tests, etc., are referred to in the guide and these tests are assumed to be developed by the individual user. It is not intended to discuss these aspects in detail. Methods for testing differential and polarizing circuits have never really been defined by the manufacturers due to the considerable choices of relay application. As a result, the tendency has been for the various utilities to develop their own testing techniques, which can vary widely depending upon such things as the availability of test switches, test gear, test philosophy, and manpower. Good testing practices should include systematic documentation of the test and the test procedures. This should include documentation of all measurements and a comparison with desired results.

Comments on the advantages and disadvantages of some of the different techniques are presented. Safety considerations for personnel and equipment are also 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 voltage source will be higher. For secondary testing, the voltage source may be relatively low. For some of these circuit tests, variable voltages are used. In each case, the source is identified on the figure involved.

1.1 References

This guide shall be used in conjunction with the following publications:

- [1] IEEE C57.13.1-1981 (R 1986), IEEE Guide for Field Testing of Relaying Current Transformers (ANSI).¹

2. Safety Considerations for Personnel and Equipment

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

2.1 Primary Testing. Whenever it becomes necessary to work on primary equipment, it is essential that all the necessary switching or locking and tagging procedures are observed and obeyed in a rigid and formalized manner.

Safety procedures must be followed to assist the relay testers from being exposed to substation equipment that has not been properly de-energized.

2.2 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 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 to try to keep 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 the tester does work from

¹ IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

that side, he or she should find all components clearly labeled including wiring, terminal strips, and fuse blocks. If a tester must work behind a live panel for extended periods of time, the tester can use rubber blankets to help prevent electrical contact to his person and to avoid accidental tripouts by inadvertent bridging or grounding of electrical connections.

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

2.3 Current Transformer Circuits. An open-circuited current transformer secondary whose primary circuit is carrying current is quite hazardous since the secondary current transformer voltage attempts to rise to a value sufficient to drive the proper secondary current through the impedance created by the open-circuit air gap.

CAUTION: No attempt should be made to reroute the relay currents by disconnecting current circuit wires from terminal blocks or relay terminals. In the event that a current transformer circuit carrying current is inadvertently open-circuited, immediate action must be taken to eliminate the resulting high voltage and arcing. Action taken may include closing the circuit back, shorting the circuit closer to the current transformer, or opening the current transformer primary circuit.

2.4 Current Transformer Short Circuiting Devices. Most current transformers are connected to their burdens through a short-circuiting device located on the current transformer secondary lead termination point. By proper use of the current transformer shorting device, it is possible to work on energized current transformer secondary wiring circuits without necessarily taking primary equipment out of service, but there are pitfalls.

Care should be taken beforehand to properly identify the current transformer to be shorted. An ammeter should be connected in the secondary burden to monitor the circuit before, during, and after the current transformer is shorted and unshorted. Affected relays such as differential, ground, and polyphase relays should be taken out of service beforehand and complete load tests should be made afterwards before returning the relays to service.

3. Preparatory Tests

Before attempting any specific tests to prove the wiring, the following tests should have been completed:

3.1 Current Transformers

3.1.1 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.

3.1.2 Polarity Test. This test is required to prove 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.

3.1.3 Excitation Test. This test confirms that the current transformer, as supplied, is of the correct accuracy rating and that there are no shorted turns in the current transformer. Manufacturer's design curves should be available for the current transformer to which the actual results can be compared.

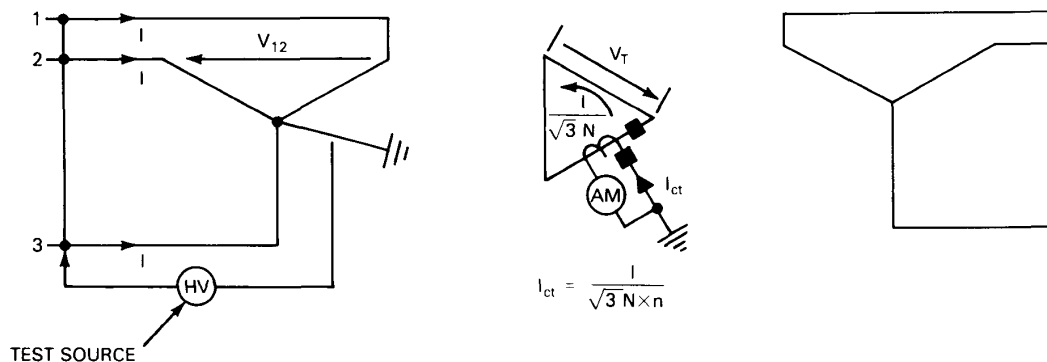
3.1.4 Resistance Measurement. Measure the current transformer secondary winding dc resistance.

3.1.5 Insulation Test. The current transformer should be tested to prove that the insulation of the secondary winding-to-ground is satisfactory.

CAUTION: Where high-voltage insulation tests are made, care must be taken not to expose solid-state relays/devices to the high voltage.

The techniques for carrying out these tests on the current transformers are described in IEEE C57.13.1-1981 (R1986) [1].

Under certain circumstances, it may be difficult to obtain access to the current transformer in order to carry out the desired tests. An example of this is ground polarizing current transformers that are located within a tertiary winding that is not brought to terminals outside the tank. This creates problems for carrying out ratio tests, polarity tests, and excitation tests in that access is not available for making measurements on the primary of the current transformer, and the

**LEGEND**

AM - AMMETER
 HV - PRIMARY INJECTION TEST SOURCE (HIGH VOLTAGE)
 I - PRIMARY INJECTION CURRENT
 N - V_T/V_{12}
 n - CURRENT TRANSFORMER RATIO
 V_{12} - INJECTION WINDING LINE-TO-LINE VOLTAGE RATING
 V_T - TERTIARY LINE-TO-LINE VOLTAGE RATING

See 3.1

Fig 1**Ratio Check of Current Transformer Within Delta Winding**

primary can not be open-circuited for the excitation test. These disadvantages can sometimes be overcome by primary injection and back-to-back operation of the current transformers.

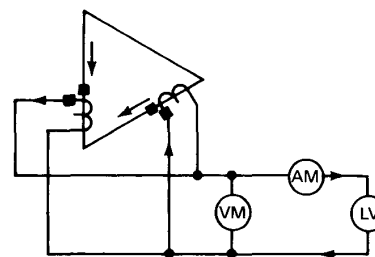
Figure 1 shows how primary injection can be used to carry out the ratio test. While this does not check actual current transformer ratio, it does check the overall ratio through the tertiary, which is important.

By using a dual trace oscilloscope, this same connection can be used for checking polarity based on the comparison of injection-current to current-transformer current when related to the transformer phasor diagram and polarity markings.

Excitation checks can be carried out by using a circuit as shown in Fig 2 where primary currents are arranged to oppose each other to create an apparent open circuit on the primary. However, this is possible only where there is more than one current transformer within the delta.

3.2 Wiring Checks. Some people consider that a detailed check of wiring to verify agreement with the elementary diagram should be carried out prior to injection testing. Other people believe that any wiring errors will be

disclosed by the actual injection tests. It is true that actual injection testing will disclose some wiring errors, but it should be realized that this procedure can result in damage to 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.



See: 3.1

LEGEND

AM - AMMETER
 LV - SECONDARY INJECTION TEST SOURCE (LOW VOLTAGE)
 VM - VOLTMETER

Fig 2**Excitation Test-More Than One Current Transformer Within Delta Winding**

When carrying out single-phase injection, three-phase monitoring of the current should be performed to verify presence of current where it should be and 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.

Whatever a person's philosophy on wiring checks, a test can be carried out to check that multiple grounds do not exist. This test is best carried out by removing the known or desired ground, and at this same location, checking insulation to ground.

CAUTION: 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 in the current transformer.

3.3 Test Switches. Current switches consisting of a test jack and current-shortening elements are placed in current circuits to facilitate check-out, troubleshooting, calibration and periodic testing of relays, meters, transducers, and instrumentation. These switches permit testing to take place without de-energizing the primary circuit and may be separate or built into a protective relay case.

3.3.1 Test Jacks. The test jack feature is used to make current measurements without opening the circuit by inserting a test plug into the jack. The test plug is a two-wire device to which meters are connected. Inserting the test plug puts the meters in series with the current circuit. Before the test plug is inserted in the jack, care should be taken to make sure that a complete low-impedance circuit exists through the ammeter or other test apparatus. This can readily be accomplished by using a volt-ohmmeter on the low-ohm scale. A low resistance from the polarity blade to nonpolarity 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 current transformer secondary makes its frequent use worthwhile.

3.3.2 Current Shorting Switch. The current-shortening switch is usually found mounted next to 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 current transformer secondary. As its name implies,

it does this by shorting the switch source-side circuit and disconnecting the switch load-side circuit, in that order, by means of make-before-break contacts. This bypasses and open-circuits the device to be tested. An important point to remember is that this switch does not ground the current transformer. 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 plug is inserted into the test jack without the shorting switch operated, the circuit from the test plug must be complete in order to keep the current transformer circuit closed. Figure 3 illustrates a test jack and current-shortening switch as it would appear in a schematic diagram.

3.4 Test Equipment. Test equipment for protective relays falls into three basic categories:

- (1) Transformer loading,
- (2) Resistance loading, and
- (3) Solid-state /electronic techniques.

3.4.1 Transformer Loading. This type of test set derives its test voltages and/or currents from a variable autotransformer. This technique is especially useful in high-current testing since the currents are developed at lower voltages, thus reducing the power requirements for the testing source.

3.4.2 Resistance Loading. This is the "classical" technique for developing test values. A variable resistance is placed in series with the test specimen and the assembly is connected to a voltage source. Current control is then effected by variations of the resistance.

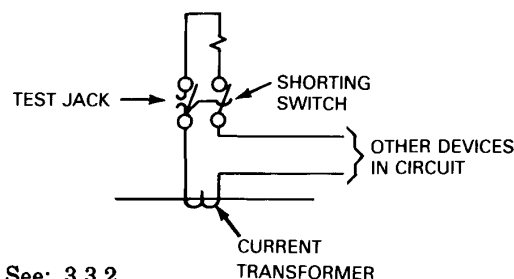


Fig 3
Typical Test Switch

3.4.3 Solid-State or Electronic Techniques.

This method is the most recent addition to commercially available test sets. The principle is that electronic circuitry is used to very accurately control the magnitude, waveshape, and phase angle relationship of the various test quantities.

There are three major areas of comparison for the three techniques:

- (1) size,
- (2) accuracy, and
- (3) waveform.

3.4.4 Size. Transformer and electronic techniques are, in general, smaller than equivalently rated resistance-loaded units. This is due to the low heat dissipation requirements. Of the three types, transformer-loaded sets are much smaller, particularly for very high current requirements.

3.4.5 Accuracy. At lower currents, the three methods provide generally equivalent accuracy and repeatability. The transformer-loading method can give generally satisfactory results if the burden and source nonlinear characteristics are considered. The accuracies provided are well within the precision of protective relay applications. At relatively high test currents (approximately 10 A to 30 A), the electronic techniques maintain a high level of accuracy in setting relays, with the resistance-loading method giving generally equivalent results in relay setting accuracy.

3.4.6 Waveform. Transformer loading is particularly likely to cause waveshape distortion. However, realization of the problem and proper caution eliminates most of these problems. If commercially available equipment is used at the highest voltage output taps that will produce the required currents, experience shows that errors in relay performance, because of deviation from sinusoidal currents, are reduced to acceptable levels.

Noninductive resistance loading at higher currents is superior in general. Since relays present nonlinear loads, the current waveforms tend to be nonlinear. The resistor in resistance-loading techniques tends to "swamp" the load's nonlinearity and thus, a relatively sinusoidal waveform is assured.

Electronic techniques assure clean waveforms electronically. At present, however, current limitations may be significant.

4. Power Supplies for Testing

4.1 AC Current - Secondary Injection Testing.

When selecting a power supply for secondary current injection testing, two things should be kept in mind. One is the full scale range of the other instruments found in circuits tested. The second is the impedance of the relay units involved. There should not be any need for more than one ampere of current to obtain proper readings on the test instruments. The station service supply will provide more power than necessary to overcome whatever impedance may be encountered. A variable resistor can be used to control the amount of current that is injected into the circuit under test.

There are also a number of commercially available current sources that are primarily used for calibration testing which could be used for a secondary injection source.

4.2 AC Current - Primary Injection Testing.

The philosophy of primary current injection testing is directly related to the tester's desire to simulate the actual working conditions of the protective equipment as closely as physically possible under nonlaboratory conditions. The primary concern of the tester is availability and portability of the power supply. There are several good power supplies being marketed today with output ranging from 1 to 15 kVA. There is little probability that anyone will ever have need to calibrate a relay while applying primary current. Primary injection is used in proving the integrity and polarity of various protection schemes including differential and complicated line protection circuitry and is usually the final test before energization and in-service testing.

4.3 DC Current - Primary and Secondary Injection Testing. The dc primary injection test is used for proving the proper polarity of the current transformer mechanical installation and electrical connections. The current flow through the primary winding causes a flux build up on the secondary winding. Cessation of the current flow through the primary winding causes a rapid decay of the flux field in the secondary winding which can be observed with an analog milliammeter. The

positive or negative deflection of the needle will indicate the polarity of the current transformer. A readily available source of power to perform this test on current transformers that is most familiar to the power industry is the common 6-V bell set or lantern battery. For safety reasons, it is suggested that the station battery not be used for this type of testing. The station battery is, however, the most logical power source for testing the integrity of the dc tripping circuits and the operating ranges of the tripping relays.

If it is known or suspected that a current transformer has been magnetized during a dc test, excessive fault current, or accidental open circuiting of the secondary, a demagnetizing procedure can be used. Magnetization of current transformers may be removed by exciting the core to the saturation voltage on the tap involved. The point of excitation may be obtained either with the current transformer in or out of service. To demagnetize the core with the current transformer in service, it is only necessary to insert a variable resistor and an ammeter in series with the burden. The resistance should be increased from zero to such a magnitude that the secondary current, as determined by the ammeter reading, will fall to one-half its original value or less. The resistance is then slowly reduced to zero and the resistor and ammeter removed from the circuit.

To demagnetize the core with the current transformer out of service, gradually apply ac voltage to the secondary tap used until the current transformer is saturated with at least 2.5 A flowing. This current must then be reduced to zero with all the other tap leads open-circuited. This process of gradually reducing the amperes to zero from the saturation level will demagnetize the current transformer.

5. Generator, Motor, and Reactor Differential Relaying

The purpose of circuit testing is to insure that the relays will not operate for an external fault and will operate for an internal fault. When the current flowing out of one phase of the generator equals the current flowing into the same phase, then no current should flow in the operate winding of the relay connected to this

phase. A motor or reactor protected like the generator shown in Figs 4, 5, and 6, would require identical tests.

When using injection testing, consideration should be given to the continuous and short-time current rating of both the restraint and operate windings. The operate windings usually are rated lower than the restraint windings.

5.1 Primary Current Injection Testing. For primary current injection tests, the protected equipment shall not be in service. Ideally, primary injection of test current could be used to test the differential connection throughout. With the test set connected as in Fig 4, secondary current flowing in the restraint windings and none in the operate windings would ascertain correct connections to the restraint windings. Additional tests are needed to test the connections to the operate winding. The proximity of the load-side current transformers to the neutral-side current transformers on turbine generators make this connection feasible. However, primary injection could be difficult. Due to the impedance of the generator winding, most test sets could not inject enough primary current to make the test. The accessibility of the current transformers and the method of mounting the current transformers on the generator leads may allow the test leads to be slipped through the current transformers as shown in Fig 5. A problem still exists, however, because of the high ratio of current transformers on large generators. With the use of a 20 000:5 ratio, or higher, most test sets cannot inject enough primary current to produce a readable current in the secondary. For instance, a test set producing 400A in the primary of a 40 000:5 ratio current transformer will cause only 50 mA in the secondary. Test sets able to produce high currents along with sensitive ammeters are needed to make this test.

5.2 Secondary Current Injection Testing. For secondary current injection tests, the secondary circuits shall be isolated, but the protected equipment may still be in service. Equipment condition shall be carefully reviewed and understood. Another method is to apply an ac current source to the terminals of the current transformer, as shown in Fig 6.