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Relay Commissioning

Network Protection & Automation Guide

Life Is On | Schneider Electric

Chapter E2

Relay Commissioning

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1. Commissioning tests

Installation of a protection scheme at site creates a number of possibilities for errors in the implementation of the scheme to occur. Even if the scheme has been thoroughly tested in the factory, wiring to the CTs and VTs on site may be incorrectly carried out, or the CTs/VTs may have been incorrectly installed. The impact of such errors may range from simply being a nuisance (tripping occurs repeatedly on energisation, requiring investigation to locate and correct the error(s)) through to failure to trip under fault conditions, leading to major equipment damage, disruption to supplies and potential hazards to personnel. The strategies available to remove these risks are many, but all involve some kind of testing at site.

Commissioning tests at site are therefore invariably performed before protection equipment is set to work. The aims of commissioning tests are:

a. to ensure that the equipment has not been damaged during transit or installation

b. to ensure that the installation work has been carried out correctly

c. to prove the correct functioning of the protection scheme as a whole

The tests carried out will normally vary according to the protection scheme involved, the relay technology used, and the policy of the client. In many cases, the tests actually conducted are determined at the time of commissioning by mutual agreement between the client's representative and the commissioning team. Hence, it is not possible to provide a definitive list of tests that are required during commissioning. This section therefore describes the tests commonly carried out during commissioning.

The following tests are invariably carried out, since the protection scheme will not function correctly if faults exist.

a. wiring diagram check, using circuit diagrams showing all the reference numbers of the interconnecting wiring

b. general inspection of the equipment, checking all connections, wires on relays terminals, labels on terminal boards, etc.

c. insulation resistance measurement of all circuits

d. perform relay self-test procedure and external communications checks on digital/numerical relays

e. test main current transformers

f. test main voltage transformers

g. check that protection relay alarm/trip settings have been entered correctly

h. tripping and alarm circuit checks to prove correct functioning

In addition, the following checks may be carried out, depending on the factors noted earlier.

i. secondary injection test on each relay to prove operation at one or more setting values

j. primary injection tests on each relay to prove stability for external faults and to determine the effective current setting for internal faults (essential for some types of electromechanical relays)

k. testing of protection scheme logic

This section details the tests required to cover items (a)–(f) above.

Section 2 covers secondary injection test equipment

Section 3 details the secondary injection testing that may be carried out (i)

Section 4 covers primary injection testing (j)

Section 5 details the checks required on any logic involved in the protection scheme (k)

Section 6 details the tests required on alarm/tripping circuits tripping/alarm circuits (h).

1.1 Insulation tests

All the deliberate earth connections on the wiring to be tested should first be removed, for example earthing links on current transformers, voltage transformers and d.c. supplies. Some insulation testers generate impulses with peak voltages exceeding 5kV. In these instances any electronic equipment should be disconnected while the external wiring insulation is checked.

The insulation resistance should be measured to earth and between electrically separate circuits. The readings are recorded and compared with subsequent routine tests to check for any deterioration of the insulation.

The insulation resistance measured depends on the amount of wiring involved, its grade, and the site humidity. Generally, if the test is restricted to one cubicle, a reading of several hundred megohms should be obtained. If long lengths of site wiring are involved, the reading could be only a few megohms.

1.2 Relay self-test procedure

Digital and numerical relays will have a self-test procedure that is detailed in the appropriate relay manual. These tests should be followed to determine if the relay is operating correctly. This will normally involve checking of the relay watchdog circuit, exercising all digital inputs and outputs and checking that the relay analogue inputs are within calibration by applying a test current or voltage. For these tests, the relay outputs are normally disconnected from the remainder of the protection scheme, as it is a test carried out to prove correct relay, rather than scheme, operation.

Unit protection schemes involve relays that need to communicate with each other. This leads to additional testing requirements. The communications path between the relays is tested using suitable equipment to ensure that the path is complete and that the received signal strength is within specification. Numerical relays may be fitted with loopback test facilities that enable either part of or the entire communications link to be tested from one end.

1. Commissioning tests

After completion of these tests, it is usual to enter the relay settings required. This can be done manually via the relay front panel controls, or using a portable PC and suitable software. Whichever method is used, a check by a second person that the correct settings have been used is desirable, and the settings recorded. Programmable scheme logic that is required is also entered at this stage.

1.3 Current transformer tests

The following tests are normally carried out prior to energisation of the main circuits.

1.3.1 Polarity check

Each current transformer should be individually tested to verify that the primary and secondary polarity markings are correct; see Figure E2.1. The ammeter connected to the secondary of the current transformer should be a robust moving coil, permanent magnet, centre-zero type. A low voltage battery is used, via a single-pole push-button switch, to energise the primary winding. On closing the push-button, the d.c. ammeter, A, should give a positive flick and on opening, a negative flick.

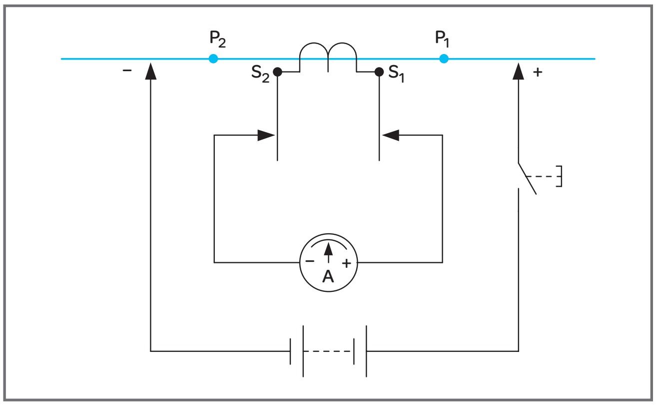

Figure E2.1:
Current transformer polarity check

1.3.2 Magnetisation curve

Several points should be checked on each current transformer magnetisation curve. This can be done by energising the secondary winding from the local mains supply through a variable auto-transformer while the primary circuit remains open; see Figure E2.2.

The characteristic is measured at suitable intervals of applied voltage, until the magnetising current is seen to rise very rapidly for a small increase in voltage. This indicates the approximate knee-point or saturation flux level of the current transformer. The magnetising current should then be recorded at similar voltage intervals as it is reduced to zero.

Care must be taken that the test equipment is suitably rated. The short-time current rating must be in excess of the CT secondary current rating, to allow for the measurement of the

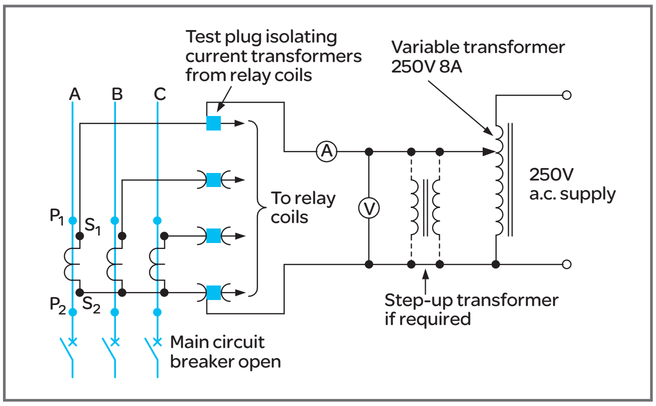

Figure E2.2:
Testing current transformer magnetising curve

saturation current. This will be in excess of the CT secondary current rating. As the magnetising current will not be sinusoidal, a moving iron or dynamometer type ammeter should be used.

It is often found that current transformers with secondary ratings of 1A or less have a knee-point voltage higher than the local mains supply. In these cases, a step-up interposing transformer must be used to obtain the necessary voltage to check the magnetisation curve.

1.4 Voltage transformer tests

Voltage transformers require testing for polarity and phasing.

1.4.1 Polarity check

The voltage transformer polarity can be checked using the method for CT polarity tests. Care must be taken to connect the battery supply to the primary winding, with the polarity ammeter connected to the secondary winding. If the voltage transformer is of the capacitor type, then the polarity of the transformer at the bottom of the capacitor stack should be checked.

1.4.2 Ratio check

This check can be carried out when the main circuit is first made live. The voltage transformer secondary voltage is compared with the secondary voltage shown on the nameplate.

1.4.3 Phasing check

The secondary connections for a three-phase voltage transformer or a bank of three single-phase voltage transformers must be carefully checked for phasing. With the main circuit alive, the phase rotation is checked using a phase rotation meter connected across the three phases, as shown in Figure E2.3. Provided an existing proven VT is available on the same primary system, and that secondary earthing is employed, all that is now necessary to prove correct phasing is a voltage check between, say, both 'A' phase secondary outputs. There should be nominally little or no voltage if the phasing is correct.

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1. Commissioning tests

However, this test does not detect if the phase sequence is correct, but the phases are displaced by 120° from their correct position, i.e. phase A occupies the position of phase C or phase B in Figure E2.3. This can be checked by removing the fuses from phases B and C for example and measuring the phase-earth voltages on the secondary of the VT. If the phasing is correct, only phase A should be healthy, phases B and C should have only a small residual voltage. Correct phasing should be further substantiated when carrying out 'on load' tests on any phase-angle sensitive relays, at the relay terminals. Load current in a known phase CT secondary should be compared with the associated phase to neutral VT secondary voltage. The phase angle between them should be measured, and should relate to the power factor of the system load.

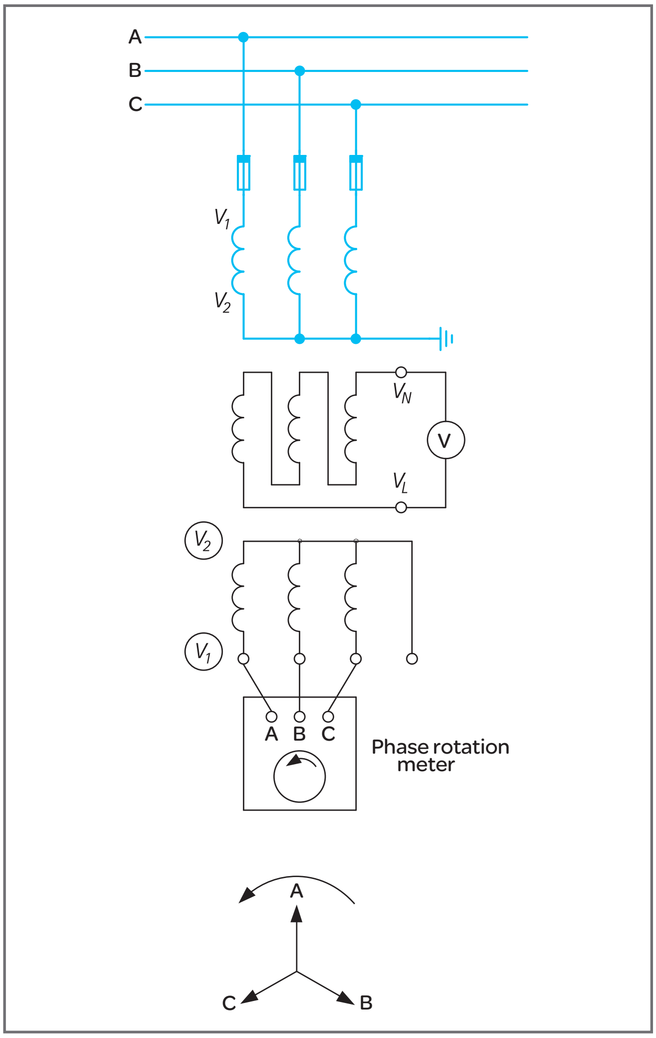

Figure E2.3:
Voltage transformer phasing check

If the three-phase voltage transformer has a broken-delta tertiary winding, then a check should be made of the voltage across the two connections from the broken delta V_N and V_L, as shown in Figure E2.3. With the rated balanced three-phase supply voltage applied to the voltage transformer primary windings, the broken-delta voltage should be below 5V with the rated burden connected.

1.5 Protection relay setting checks

At some point during commissioning, the alarm and trip settings of the relay elements involved will require to be entered and/or checked. Where the complete scheme is engineered and supplied by a single contractor, the settings may already have been entered prior to despatch from the factory, and hence this need not be repeated. The method of entering settings varies according to the relay technology used. For electromechanical and static relays, manual entry of the settings for each relay element is required. This method can also be used for digital/numerical relays. However, the amount of data to be entered is much greater, and therefore it is usual to use appropriate software, normally supplied by the manufacturer, for this purpose. The software also makes the essential task of making a record of the data entered much easier.

Once the data has been entered, it should be checked for compliance with the recommended settings as calculated from the protection setting study. Where appropriate software is used for data entry, the checks can be considered complete if the data is checked prior to download of the settings to the relay. Otherwise, a check may be required subsequent to data entry by inspection and recording of the relay settings, or it may be considered adequate to do this at the time of data entry. The recorded settings form an essential part of the commissioning documentation provided to the client.

2. Secondary injection test equipment

The purpose of secondary injection testing is to prove the correct operation of the protection scheme that is downstream from the inputs to the protection relay(s). Secondary injection tests are always done prior to primary injection tests. This is because the risks during initial testing to the LV side of the equipment under test are minimised. The primary (HV) side of the equipment is disconnected, so that no damage can occur. These tests and the equipment necessary to perform them are generally described in the manufacturer's manuals for the relays, but brief details are given below for the main types of protection relays.

2.1 Test blocks/plugs for secondary injection equipment

It is common practice to provide test blocks or test sockets in the relay circuits so that connections can readily be made to the test equipment without disturbing wiring. Test plugs of either multi- finger or single-finger design (for monitoring the current in one CT secondary circuit) are used to connect test equipment to the relay under test.

The top and bottom contact of each test plug finger is separated by an insulating strip, so that the relay circuits can be completely isolated from the switchgear wiring when the test plug is inserted. To avoid open-circuiting CT secondary terminals, it is therefore essential that CT shorting jumper links are fitted across all appropriate 'live side' terminals of the test plug BEFORE it is inserted. With the test plug inserted in position, all the test circuitry can now be connected to the isolated 'relay side' test plug terminals. Some test blocks incorporate the live-side jumper links within the block and these can be set to the 'closed' or 'open' position as appropriate, either manually prior to removing the cover and inserting the test plug, or automatically upon removal of the cover. Removal of the cover also exposes the colour-coded face-plate of the block, clearly indicating that the protection scheme is not in service, and may also disconnect any d.c. auxiliary supplies used for powering relay tripping outputs.

Withdrawing the test plug immediately restores the connections to the main current transformers and voltage transformers and removes the test connections. Replacement of the test block cover then removes the short circuits that had been applied to the main CT secondary circuits. Where several relays are used in a protection scheme, one or more test blocks may be fitted on the relay panel, enabling the whole scheme to be tested, rather than just one relay at a time.

Test blocks usually offer facilities for the monitoring and secondary injection testing of any power system protection scheme. The test block may be used either with a multi-fingered test plug to allow isolation and monitoring of all the selected conductor paths, or with a single finger test plug that allows the currents on individual conductors to be monitored. A test block and test plugs are illustrated in Figure E2.4.

Figure E2.4:
Test block/plugs

2.2 Secondary injection test sets

The type of the relay to be tested determines the type of equipment used to provide the secondary injection currents and voltages. Many electromechanical relays have a non-linear current coil impedance when the relay operates and this can cause the test current waveform to be distorted if the injection supply voltage is fed directly to the coil. The presence of harmonics in the current waveform may affect the torque of electromechanical relays and give unreliable test results, so some injection test sets use an adjustable series reactance to control the current. This keeps the power dissipation small and the equipment light and compact.

Many test sets are portable and include precision ammeters and voltmeters and timing equipment. Test sets may have both voltage and current outputs. The former are high voltage, low current outputs for use with relay elements that require signal inputs from a VT as well as a CT. The current outputs are high current, low voltage to connect to relay CT inputs.

It is important, however, to ensure that the test set current outputs are true current sources, and hence are not affected by the load impedance of a relay element current coil. Use of a test set with a current output that is essentially a voltage

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2. Secondary injection test equipment

source can give rise to serious problems when testing electromechanical relays. Any significant impedance mismatch between the output of the test set and the relay current coil during relay operation will give rise to a variation in current from that desired and possible error in the test results. The relay operation time may be greater than expected (never less than expected) or relay 'chatter' may occur. It is quite common for such errors to only be found much later, after a fault has caused major damage to equipment through failure of the primary protection to operate. Failure investigation then shows that the reason for the primary protection to operate is an incorrectly set relay, due in turn to use of a test set with a current output consisting of a voltage source when the relay was last tested. Figure E2.5 shows typical waveforms resulting from use of test set current output that is a voltage source – the distorted relay coil current waveform gives rise to an extended operation time compared to the expected value.

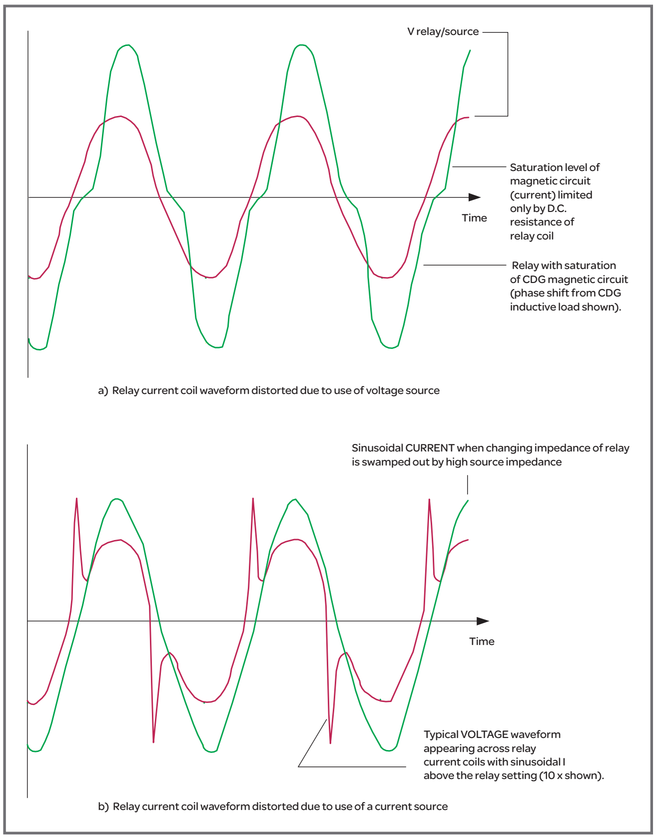

Figure E2.5:
Relay current coil waveforms

Test sets are computer based and comprise a PC (usually a standard laptop PC with suitable software) and a power amplifier that takes the low level outputs from the PC and amplifies them into voltage and current signals suitable for application to the VT and CT inputs of the relay. The phase angle between voltage and current outputs will be adjustable, as also will the phase angles between the individual voltages or currents making up a 3-phase output set. Much greater precision in the setting of the magnitudes and phase angles is possible, compared to traditional test sets. Digital signals to exercise the internal logic elements of the relays may also be provided. The alarm and trip outputs of the relay are connected to digital inputs on the PC so that correct operation of the relay, including accuracy of the relay tripping characteristic, can be monitored and displayed on-screen, saved for inclusion in reports generated later, or printed for an immediate record to present to the client. Optional features may include GPS time synchronising equipment and remote-located amplifiers to facilitate testing of unit protection schemes, and digital I/O for exercising the programmable scheme logic of relays.

The software for test sets is capable of testing the functionality of a wide variety of relays, and conducting a set of tests automatically. Such sets ease the task of the commissioning engineer. The software will normally offer options for testing, ranging from a test carried out at a particular point on the characteristic to complete determination of the tripping characteristic automatically. This feature can be helpful if there is any reason to doubt that the relay is operating correctly with the tripping characteristic specified. Figure E2.6 illustrates a PC-based test set.

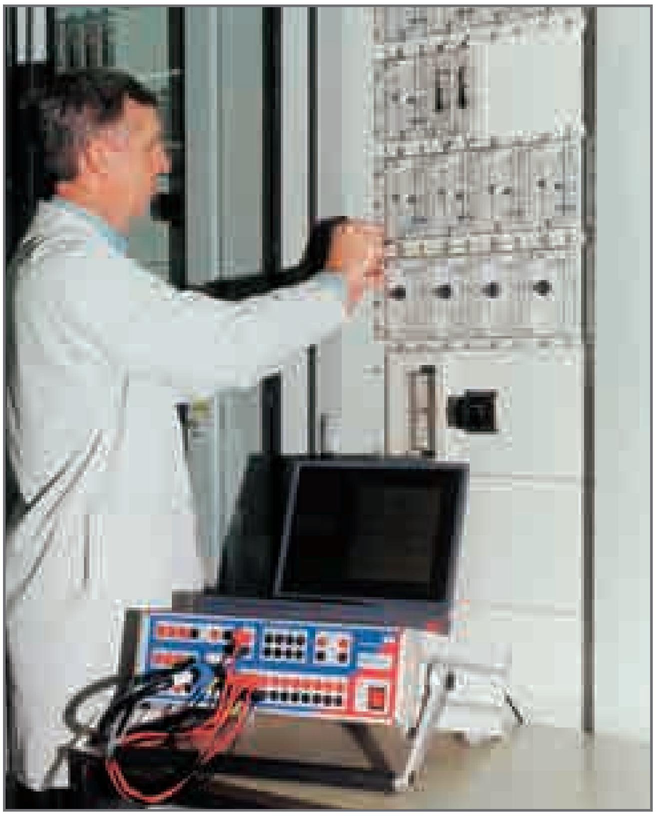

Figure E2.6:
PC-based secondary injection test set

2. Secondary injection test equipment

Traditional test sets use an arrangement of adjustable transformers and reactors to provide control of current and voltage without incurring high power dissipation. Some relays require adjustment of the phase between the injected voltages and currents, and so phase shifting transformers may be used. Figure E2.7 shows the circuit diagram of a traditional test set suitable for overcurrent relay resting, while Figure E2.8 shows the circuit diagram for a test set for directional/ distance relays. Timers are included so that the response time of the relay can be measured.

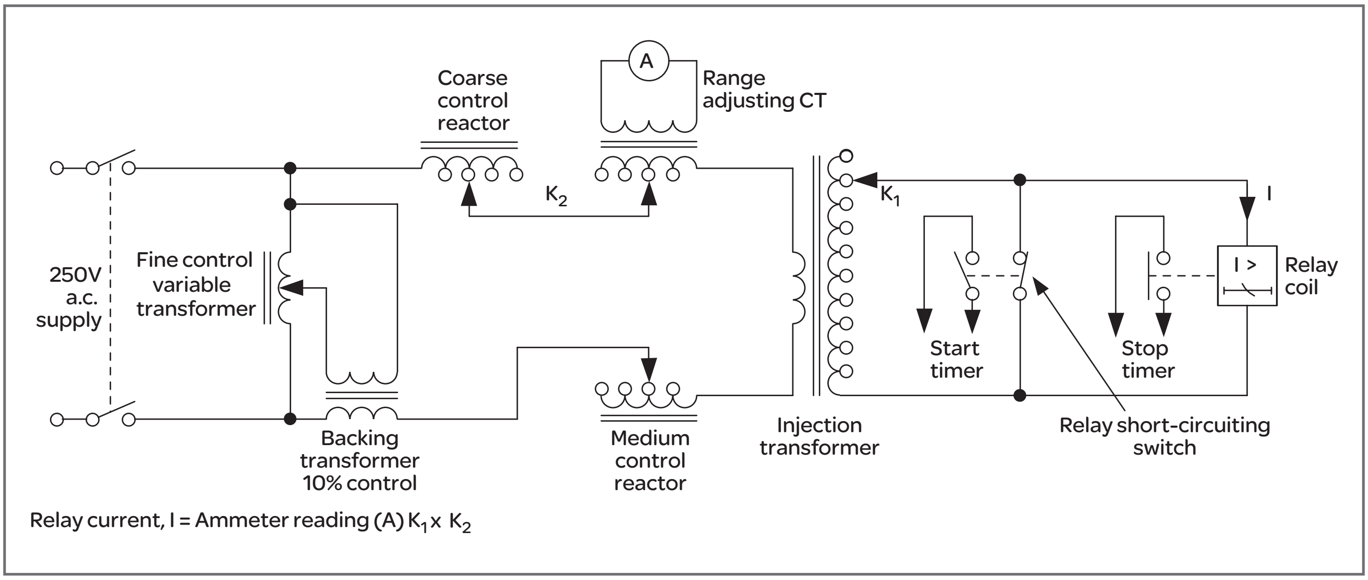

Figure E2.7:
Circuit diagram of traditional test set for overcurrent relays

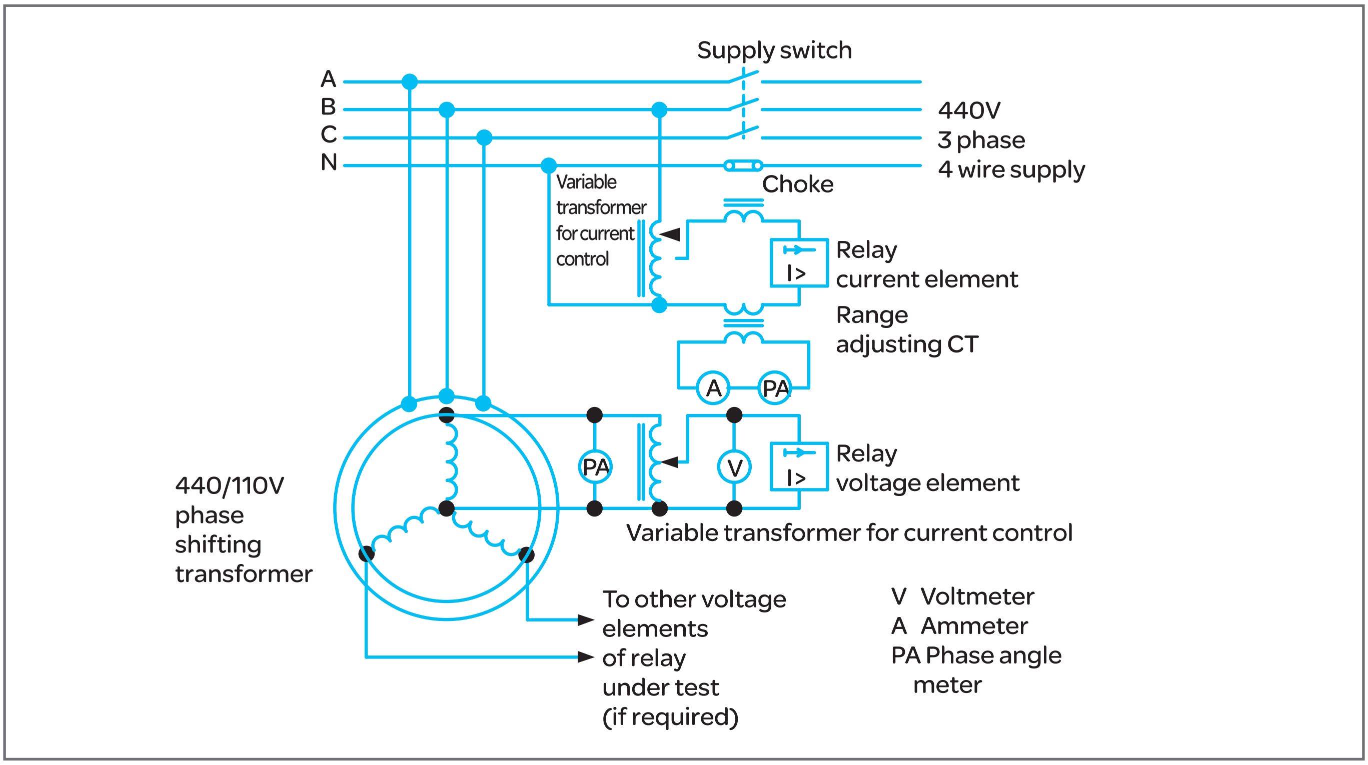

Figure E2.8:
Circuit diagram for traditional test set for directional / distance relays

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3. Secondary injection testing

The purpose of secondary injection testing is to check that the protection scheme from the relay input terminals onwards is functioning correctly with the settings specified. This is achieved by applying suitable inputs from a test set to the inputs of the relays and checking if the appropriate alarm/ trip signals occur at the relay/control room/CB locations. The extent of testing will be largely determined by the client specification and relay technology used, and may range from a simple check of the relay characteristic at a single point to a complete verification of the tripping characteristics of the scheme, including the response to transient waveforms and harmonics and checking of relay bias characteristics. This may be important when the protection scheme includes transformers or generators.

The testing should include any scheme logic. If the logic is implemented using the programmable scheme logic facilities available with most digital or numerical relays, appropriate digital inputs may need to be applied and outputs monitored (see Section 13). It is clear that a test set can facilitate such tests, leading to a reduced time required for testing.

3.1 Schemes using digital or numerical relay technology

The policy for secondary injection testing varies widely. In some cases, manufacturers recommend, and clients accept, that if a digital or numerical relay passes its' self-test, it can be relied upon to operate at the settings used and that testing can therefore be confined to those parts of the scheme external to the relay. In such cases, secondary injection testing is not required at all. More often, it is required that one element of each relay (usually the simplest) is exercised, using a secondary injection test set, to check that relay operation occurs at the conditions expected, based on the setting of the relay element concerned.

Another alternative is for the complete functionality of each relay to be exercised. This is rarely required with a digital or numerical relay, probably only being carried out in the event of a suspected relay malfunction.

To illustrate the results that can be obtained, Figure E2.9 shows the results obtained by a test set when determining the reach settings of a distance relay using a search technique. Another example is the testing of the power swing blocking element of a distance relay. Figure E2.10 illustrates such a test, based on using discrete impedance points.

This kind of test may not be adequate in all cases, and test equipment may have the ability to generate the waveforms simulating a power swing and apply them to the relay (Figure E2.11).

3.2 Schemes using electromechanical / static relay technology

Schemes using single function electromechanical or static relays will usually require each relay to be exercised. Thus a scheme with distance and back-up overcurrent elements will require a test on each of these functions, thereby taking up

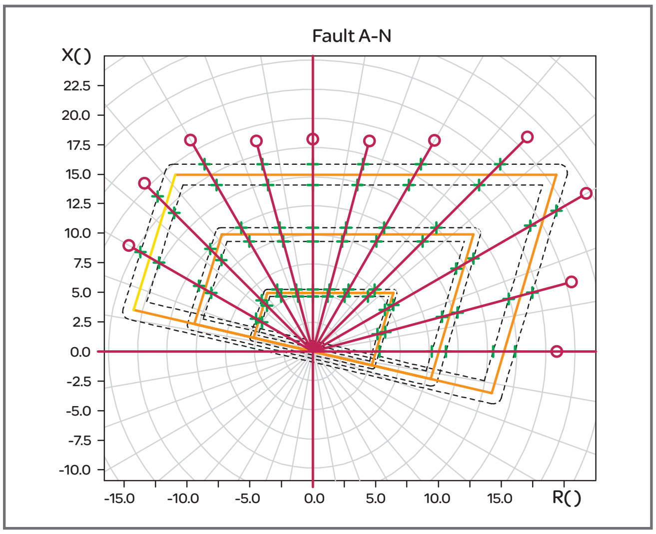

Figure E2.9:
Distance relay zone checking using search technique and tolerance bands

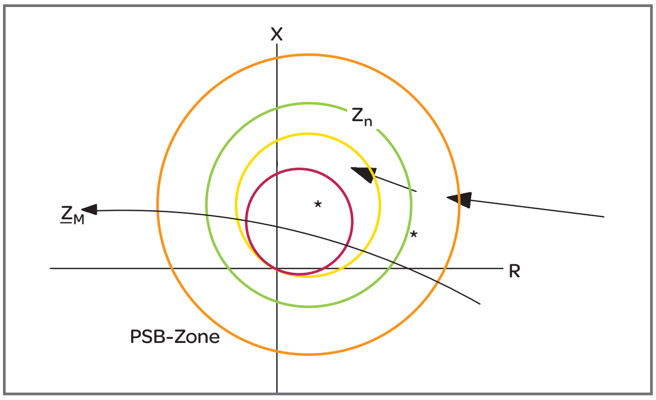

Figure E2.10
Testing of power swing blocking element – discrete points

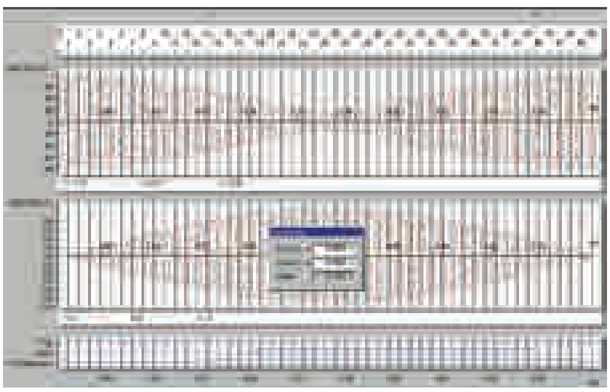

Figure E2.11:
Simulated power swing waveform

3. Secondary injection testing

more time than if a digital or numerical relay is used. Similarly, it may be important to check the relay characteristic over a range of input currents to confirm parameters for an overcurrent relay such as:

a. the minimum current that gives operation at each current setting

b. the maximum current at which resetting takes place

c. the operating time at suitable values of current

d. the time/current curve at two or three points with the time multiplier setting TMS at 1

e. the resetting time at zero current with the TMS at 1

Similar considerations apply to distance and unit protection relays of these technologies.

3.3 Test circuits for secondary injection testing

The test circuits used will depend on the type of relay and test set being used. Unless the test circuits are simple and obvious, the relay commissioning manual will give details of the circuits to be used. Commonly used test circuits can also be found in reference [Ref E2.1: Protection Relay Application Guide, Chapter 23]. When using the circuits in this reference, suitable simplifications can easily be made if digital or numerical relays are being tested, to allow for their built-in measurement capabilities – external ammeters and voltmeters may not be required.

All results should be carefully noted and filed for record purposes. Departures from the expected results must be thoroughly investigated and the cause determined. After rectification of errors, all tests whose results may have been affected (even those that may have given correct results) should be repeated to ensure that the protection scheme has been implemented according to specification.

4. Primary injection testing

This type of test involves the entire circuit; current transformer primary and secondary windings, relay coils, trip and alarm circuits, and all intervening wiring are checked. There is no need to disturb wiring, which obviates the hazard of open-circuiting current transformers, and there is generally no need for any switching in the current transformer or relay circuits. The drawback of such tests is that they are time consuming and expensive to organise. Increasingly, reliance is placed on all wiring and installation diagrams being correct and the installation being carried out as per drawings, and secondary injection testing being completed satisfactorily. Under these circumstances, the primary injection tests may be omitted. However, wiring errors between VTs/CTs and relays, or incorrect polarity of VTs/CTs may not then be discovered until either spurious tripping occurs in service, or more seriously, failure to trip on a fault. This hazard is much reduced where digital/numerical relays are used, since the current and voltage measurement/display facilities that exist in such relays enable checking of relay input values against those from other proven sources. Many connection/wiring errors can be found in this way, and by isolating temporarily the relay trip outputs, unwanted trips can be avoided.

Primary injection testing is, however, the only way to prove correct installation and operation of the whole of a protection scheme. As noted in the previous section, primary injection tests are always carried out after secondary injection tests, to ensure that problems are limited to the VTs and CTs involved, plus associated wiring, all other equipment in the protection scheme having been proven satisfactory from the secondary injection tests.

4.1 Test facilities

An alternator is the most useful source of power for providing the heavy current necessary for primary injection. Unfortunately, it is rarely available, since it requires not only a spare alternator, but also spare busbars capable of being connected to the alternator and circuit under test. Therefore, primary injection is usually carried out by means of a portable injection transformer (Figure E2.12), arranged to operate from the local mains supply and having several low voltage, heavy current windings.

These can be connected in series or parallel according to the current required and the resistance of the primary circuit. Outputs of 10V and 1000A can be obtained. Modern PC-controlled test sets have power amplifiers capable of injecting currents up to about 200A for a single unit, with higher current ratings being possible by using multiple units in parallel.

If the main current transformers are fitted with test windings, these can be used for primary injection instead of the primary winding. The current required for primary injection is then greatly reduced and can usually be obtained using secondary injection test equipment. Unfortunately, test windings are not often provided, because of space limitations in the main current transformer housings or the cost of the windings.

4. Primary injection testing

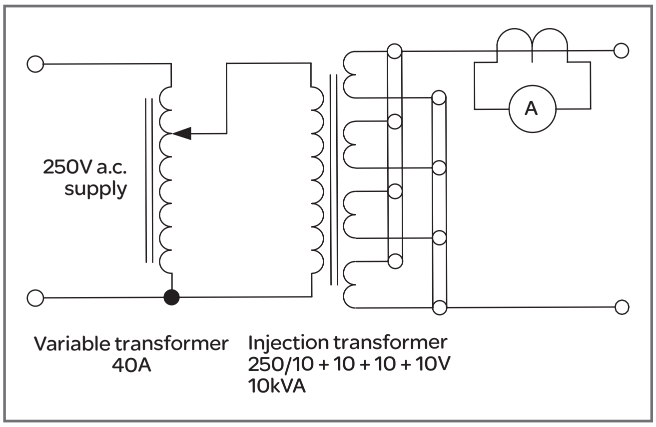

Figure E2.12:
Traditional primary injection test set

4.2 CT ratio check

Current is passed through the primary conductors and measured on the test set ammeter, A_1 in Figure E2.13. The secondary current is measured on the ammeter A_2 or relay display, and the ratio of the value on A_1 to that on A_2 should closely approximate to the ratio marked on the current transformer nameplate.

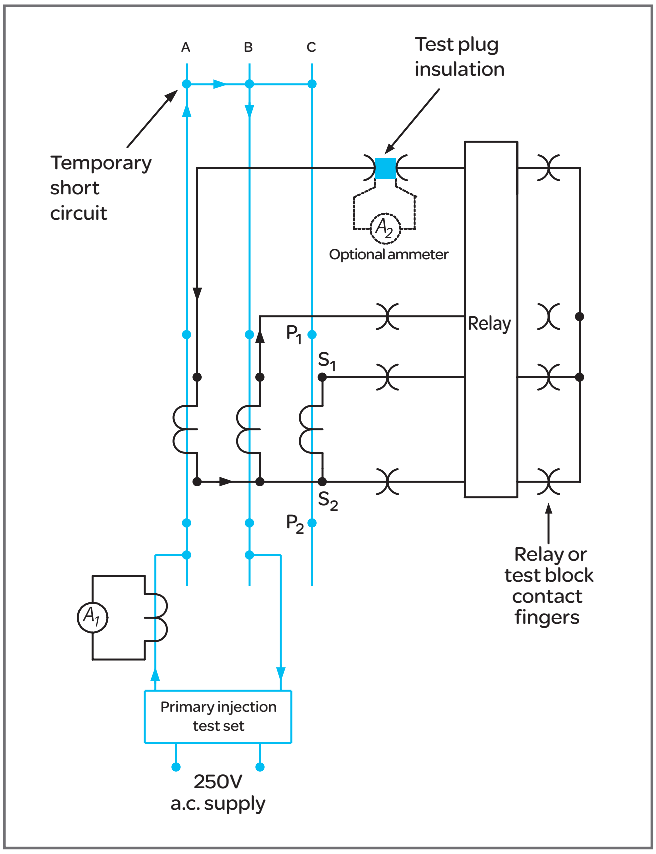

Figure E2.13:
Current transformer ratio check

4.3 CT polarity check

If the equipment includes directional, differential or earth fault relays, the polarity of the main current transformers must be checked. It is not necessary to conduct the test if only overcurrent relays are used.

The circuit for checking the polarity with a single-phase test set is shown in Figure E2.14.

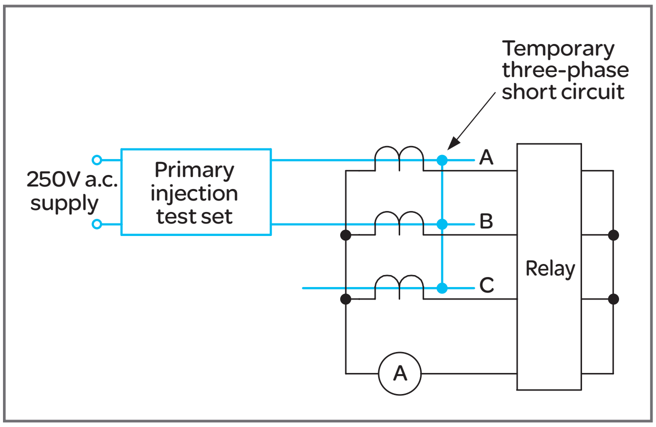

Figure E2.14:
Polarity check on main current transformers

A short circuit is placed across the phases of the primary circuit on one side of the current transformers while single-phase injection is carried out on the other side. The ammeter connected in the residual circuit, or relay display, will give a reading of a few milliamperes with rated current injected if the current transformers are of correct polarity. A reading proportional to twice the primary current will be obtained if they are of wrong polarity. Because of this, a high-range ammeter should be used initially, for example one giving full-scale deflection for twice the rated secondary current. If an electromechanical earth-fault relay with a low setting is also connected in the residual circuit, it is advisable to temporarily short-circuit its operating coil during the test, to prevent possible overheating. The single-phase injection should be carried out for each pair of phases.

4.4 Primary injection testing of relay elements

As with secondary injection testing, the tests to be carried out will be those specified by the client, and/or those detailed in the relay commissioning manual. Digital and numerical relays usually require far fewer tests to prove correct operation, and these may be restricted to observations of current and voltage on the relay display under normal load conditions.

5. Testing of protection scheme logic

Protection schemes often involve the use of logic to determine the conditions under which designated circuit breakers should be tripped. Simple examples of such logic can be found in Chapters [C1: Overcurrent Protection for Phase and Earth Faults] and [D1: Auto-Reclosing]. Traditionally, this logic was implemented by means of discrete relays, separate from the relays used for protection. Such implementations would occur where electromechanical or static relay technology is used. However, digital and numerical relays normally include programmable logic as part of the software within the relay, together with associated digital I/O. This facility (commonly referred to as Programmable Scheme Logic, or PSL) offers important advantages to the user, by saving space and permitting modifications to the protection scheme logic through software if the protection scheme requirements change with time. Changes to the logic are carried out using software hosted on a PC (or similar computer) and downloaded to the relay. Use of languages defined in IEC 61131, such as ladder logic or Boolean algebra is common for such software, and is readily understood by Protection Engineers. Further, there are several commonly encountered protection functions that manufacturers may supply with relays as one or more 'default' logic schemes.

Because software is used, it is essential to carefully test the logic during commissioning to ensure correct operation. The only exception to this may be if the relevant 'default' scheme is used. Such logic schemes will have been proven during relay type testing, and so there is no need for proving tests during commissioning. However, where a customer generates the scheme logic, it is necessary to ensure that the commissioning tests conducted are adequate to prove the functionality of the scheme in all respects. A specific test procedure should be prepared, and this procedure should include:

a. checking of the scheme logic specification and diagrams to ensure that the objectives of the logic are achieved

b. testing of the logic to ensure that the functionality of the scheme is proven

c. testing of the logic, as required, to ensure that no output occurs for the relevant input signal combinations

The degree of testing of the logic will largely depend on the criticality of the application and complexity of the logic. The responsibility for ensuring that a suitable test procedure is produced for logic schemes other than the 'default' one(s) supplied lies with the specifier of the logic. Relay manufacturers cannot be expected to take responsibility for the correct operation of logic schemes that they have not designed and supplied.

6. Tripping and alarm annunciation tests

If primary and/or secondary injection tests are not carried out, the tripping and alarm circuits will not have been checked. Even where such checks have been carried out, CB trip coils and/or Control Room alarm circuits may have been isolated. In such cases, it is essential that all of the tripping and alarm circuits are checked.

This is done by closing the protection relay contacts manually and checking that:

a. the correct circuit breakers are tripped

b. the alarm circuits are energised

c. the correct flag indications are given

d. there is no maloperation of other apparatus that may be connected to the same master trip relay or circuit breaker.

Many designs of withdrawable circuit breaker can be operated while in the maintenance position, so that substation operation can continue unaffected except for the circuit controlled by the circuit breaker involved. In other cases, isolators can be used to avoid the need for busbar de-energisation if the circuit involved is not ready for energisation.

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7. Periodic maintenance tests

Periodic testing is necessary to ensure that a protection scheme continues to provide satisfactory performance for many years after installation. All equipment is subject to gradual degradation with time, and regular testing is intended to identify the equipment concerned so that remedial action can be taken before scheme maloperation occurs. However, due care should be taken in this task, otherwise faults may be introduced as a direct result of the remedial work.

The clearance of a fault on the system is correct only if the number of circuit breakers opened is the minimum necessary to remove the fault. A small proportion of faults are incorrectly cleared, the main reasons being:

a. limitations in protection scheme design

b. faulty relays

c. defects in the secondary wiring

d. incorrect connections

e. incorrect settings

f. known application shortcomings accepted as improbable occurrences

g. pilot wire faults due to previous unrevealed damage to a pilot cable

h. various other causes, such as switching errors, testing errors, and relay operation due to mechanical shock

The self-checking facilities of numerical relays assist in minimising failures due to faulty relays. Defects in secondary wiring and incorrect connections are virtually eliminated if proper commissioning after scheme installation/alteration is carried out. The possibility of incorrect settings is minimised by regular reviews of relay settings. Network fault levels change over time, and hence setting calculations may need to be revised. Switching and testing errors are minimised by adequate training of personnel, use of proven software, and well-designed systematic working procedures. All of these can be said to be within the control of the user.

The remaining three causes are not controllable, while two of these three are unavoidable – engineering is not science and there will always be situations that a protection relay cannot reasonably be expected to cover at an affordable cost.

7.1 Frequency of inspection and testing

Although protection equipment should be in sound condition when first put into service, problems can develop unchecked and unrevealed because of its infrequent operation. With digital and numerical relays, the in-built self-testing routines can be expected to reveal and annunciate most faults, but this does not cover any other components that, together, comprise the protection scheme. Regular inspection and testing of a protection scheme is therefore required. In practice, the frequency of testing may be limited by lack of staff or by the operating conditions on the power system.

It is desirable to carry out maintenance on protection equipment at times when the associated power apparatus is out of service. This is facilitated by co-operation between the maintenance staff concerned and the network operations control centre. Maintenance tests may sometimes have to be made when the protected circuit is on load. The particular equipment to be tested should be taken out of commission and adequate back-up protection provided for the duration of the tests. Such back-up protection may not be fully discriminative, but should be sufficient to clear any fault on the apparatus whose main protection is temporarily out of service.

Maintenance is assisted by the displays of measured quantities provided on digital and numerical relays. Incorrect display of a quantity is a clear indication that something is wrong, either in the relay itself or the input circuits.

7.2 Maintenance tests

Primary injection tests are normally only conducted out during initial commissioning. If scheme maloperation has occurred and the protection relays involved are suspect, or alterations have been made involving the wiring to the relays from the VTs/CTs, the primary injection tests may have to be repeated.

Secondary injection tests may be carried out at suitable intervals to check relay performance, and, if possible, the relay should be allowed to trip the circuit breakers involved. The interval between tests will depend upon the criticality of the circuit involved, the availability of the circuit for testing and the technology of the relays used. Secondary injection testing is only necessary on the selected relay setting and the results should be checked against those obtained during the initial commissioning of the equipment.

It is better not to interfere with relay contacts at all unless they are obviously corroded. The performance of the contacts is fully checked when the relay is actuated.

Insulation tests should also be carried out on the relay wiring to earth and between circuits, using a 1000V tester. These tests are necessary to detect any deterioration in the insulation resistance.

8. Protection scheme design for maintenance

If the following principles are adhered to as far as possible, the danger of back-feeds is lessened and fault investigation is made easier:

a. test blocks should be used, to enable a test plug to be used, and a defective unit to be replaced quickly without interrupting service

b. circuits should be kept as electrically separate as possible, and the use of common wires should be avoided, except where these are essential to the correct functioning of the circuits

c. each group of circuits which is electrically separate from other circuits should be earthed through an independent earth link

d. where a common voltage transformer or d.c. supply is used for feeding several circuits, each circuit should be fed through separate links or fuses. Withdrawal of these should completely isolate the circuit concerned

e. power supplies to protection schemes should be segregated from those supplying other equipment and provided with fully discriminative circuit protection

f. a single auxiliary switch should not be used for interrupting or closing more than one circuit

g. terminations in relay panels require good access, as these may have to be altered if extensions are made. Panels are provided with special test facilities, so that no connections need be disturbed during routine testing

h. junction boxes should be of adequate size and, if outdoors, must be made waterproof

i. all wiring should be ferruled for identification and phase-coloured

j. electromechanical relays should have high operating and restraint torques and high contact pressures; jewel bearings should be shrouded to exclude dust and the use of very thin wire for coils and connections should be avoided. Dust-tight cases with an efficient breather are essential on these types of electromechanical element

k. static, digital and numerical relays should have test facilities accessible from the front to assist in fault finding. The relay manual should clearly detail the expected results at each test point when healthy

9. References

[E2.1] Protective Relays Application Guide
3rd edition, 1987.