

CHAPTER FOUR

COMMISSIONING TEST FOR INSTRUMENT TRANSFORMERS, DIRECT CURRENT SYSTEM, PROTECTIVE RELAYS AND POWER CABLE

4.1 introduction

A current transformer is used for measurement of alternating electric current. Current transformers, together with voltage (or potential) transformers (VT or PT), are known as instrument transformers. When current in a circuit is too high to apply directly to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments. Current transformers are commonly used in metering and protective relays in substation. Direct current (DC) system in a substation represents the nerves in human body. The function of the DC systems is to provide the DC supply for all auxiliary and substation DC dependent equipment, through the DC distribution boards. This equipment comprises the protection relays, control systems and the communication systems in addition to the emergency lighting.

High-voltage cables are used for supplying power in densely-populated areas or for example to offshore installations. Trouble free operation over decades with little or no maintenance is therefore a requirement to ensure a secure energy supply. A protective relay is a device designed to trip a circuit breaker when a fault of abnormal operating conditions such as over current, over voltage and reverse power flow is detected. In this chapter the commissioning test of all the above mentioned equipment is discussed to ensure that they work properly.

4.2 Commissioning test for current transformers

Current transformer is an instrument by which the high currents can be stepped down to be easy to be measured. Current transformer has a standard secondary current 1 and 5, so any CT transformation ratio is $X/1$ or $X/5$. The CT comprises number-letter-number. First number is the CT accuracy in percent as long as the CT burden is not exceeded, the letter indicates to the CT type (measurement or protection) and the last number indicates the accuracy limit factor.

Example: 5P10 CT means that it's a protection CT and it's accurate within 5% as long as the CT secondary current does not exceed 10 times the rated current. CT can be classified into measurement and protection depending on the purpose the CT will be used for. Measurement CT is very sensitive (accuracy around 0.5%) in the range below the nominal current and it used for tariff meters which payment will be based on. Protection CT is not with the same sensitivity like measurement CT (accuracy 5% and 10%) and it's able to measure high currents up to 20 times of the nominal current without saturation. Protection CT is dedicated to measure over and short circuit currents to disconnect the load. It's important to note that the CT secondary winding must always be kept shortened, otherwise the CT will get damaged due to the huge voltage generated on the secondary winding.

CTs commissioning tests are done to confirm the physical condition and electrical characteristics and to ensure the CT is connected to system properly (primary and secondary). These tests are as detailed below.

4.2.1 Insulation Resistance Test

The voltage shall be applied between Primary to secondary plus ground (covered during switchgear test), Secondary to primary plus ground and secondary core to core. The ambient temperature shall be noted down during test.

4.2.2 Polarity Test

Polarity test is to confirm the polarity marking on the CT primary and secondary and verify it is matching with drawing. More over it is giving an idea, how to connect the secondary to make the protection (like directional, differential), and metering function properly. Isolate CT secondary from the load and make circuit connection as shown in figure (4.1). Close and open the battery switch connected on the primary. Observe the pointer is moving +ve direction, while closing and – ve direction while opening for correct polarity.

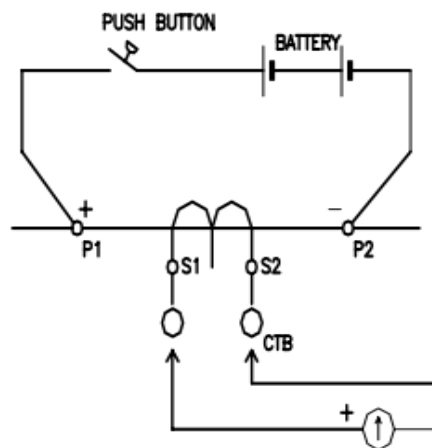


Figure 4.1 shows the polarity test

4.2.3 Secondary or Loop Resistance Test

Secondary resistance test is to verify the CT secondary winding resistance with specified one and no discontinuity in the winding. This value can be used in other calculations. Loop resistance test to ensure load is connected properly and circuits not left open. The circuit connection shall be made as shown figure (4.2) for secondary resistance. Measure the DC resistance value and record. The same shall be done for all taps and cores. These values are influenced by temperature, so that ambient temperature must be recorded during this test. Also measure the dc resistance including CT and load, phase by phase and values can be compared

between them. The value must be within specified on nameplate after the effect of temperature taken in to account. If not factory test results shall be taken as reference.

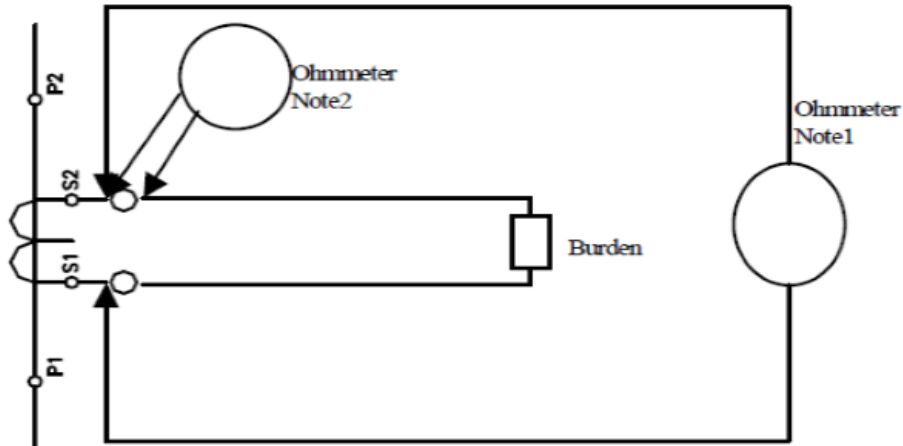


Figure 4.2 shows secondary/ loop resistance test

Note1: ohmmeter connection for CT resistance excluding burden.

Note2: ohmmeter connection for CT loop resistance including burden.

4.2.4 Burden Test

The secondary load of a current transformer is usually called the "burden" to distinguish it from the monitored-circuit load. The burden in a CT metering circuit is the (largely resistive) impedance presented to its secondary winding. Typical burden ratings for IEC CTs are 1.5 VA, 3 VA, 5 VA, 10 VA, 15 VA, 20 VA, 30 VA, 45 VA and 60 VA. ANSI/IEEE burden ratings are B-0.1, B-0.2, B-0.5, B-1.0, B-2.0 and B-4.0. This means a CT with a burden rating of B-0.2 can tolerate up to 0.2 Ω of impedance in the metering circuit before its secondary accuracy falls outside of an accuracy specification. Items that contribute to the burden of a current measurement circuit are switch-blocks, meters and intermediate conductors. The most common source of excess burden is the conductor between the meter and the CT. When substation meters are

located far from the meter cabinets, the excessive length of wire creates a large resistance. This problem can be reduced by using CTs with 1 ampere secondary, which will produce less voltage drop between the CT and its metering devices. Burden test is to ensure the connected burden to CT is within the rated burden, identified on the nameplate. Injected the rated secondary current of the CT, from CT terminals towards load side by isolating the CT secondary with all connected load and observe the voltage drop across the injection points. The burden VA can be calculated as:

$$\text{Burden VA} = \text{Voltage drop} \times \text{rated CT Current.} \quad (4.1)$$

the calculated burden should be less than rated CT burden. Ammeter selector switch should be at respective phase during test. High impedance relays shall be shorted during the test.

4.2.5 Magnetization Curve Test

Magnetizing Curve test is to confirm the magnetization characteristics of CT with nameplate specification like CT saturation point (knee point). CT knee point is the point at which 50% increase in magnetizing current cause 10% increase in voltage value. In protection CTs when high currents passing during faults and this produce high flux induced in CT core. In measuring CTs when the normal current exceeds the CT rating current. This test shall be conducted before ratio test and after secondary resistance and polarity test. Since residual magnetism left in the core due to DC test (polarity, resistance), which leads additional error in ratio test. The meters used for this test shall be having true RMS measurement. The circuit connection shall be made as shown figure (4.3). The primary should be open during test. Before start the test demagnetize the core by Inject voltage on secondary terminals and increase up to where considerable increment in current with small voltage increment. Now start decreasing the voltage to zero, the rate at which increased. Now increase the voltage and monitor the excitation current up

to the CT reaching near to saturation point. Record the reading of voltage and current at several points. Plot the curve and evaluate the voltage and magnetizing current at the knee point from the graph as in figure (4.4).

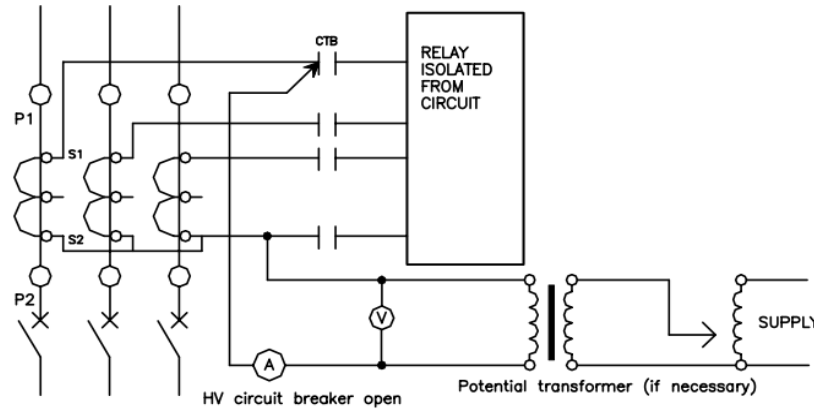


Figure 4.3 shows circuit connection the magnetization Curve Test

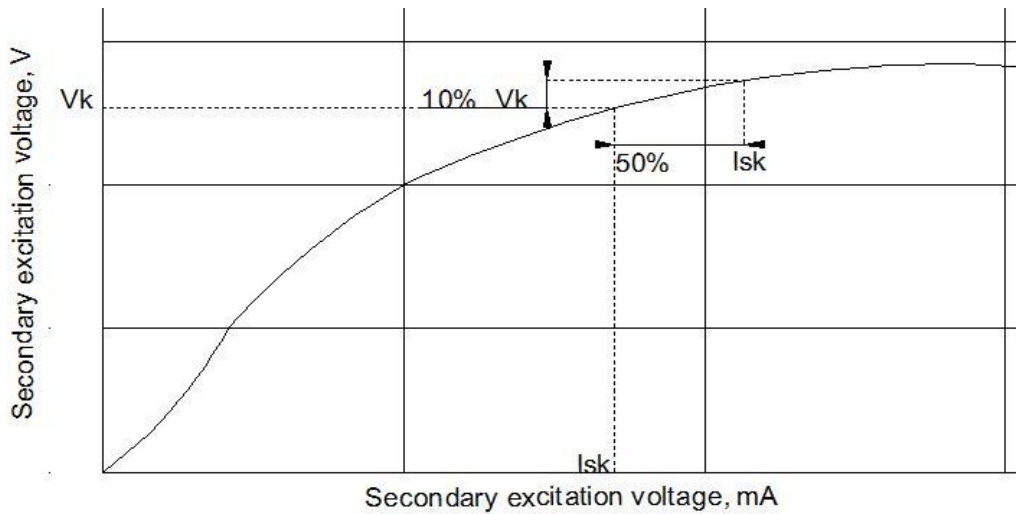


Figure 4.4 shows the curve of magnetization test

The knee point voltage can be calculated as follow

$$V_k = I_s * ALF (R_{ct} + (VA/I_s * I_s)) \quad (4.2)$$

Where:

I_s is rated secondary current

R_{ct} is CT secondary resistance

VA is rated CT burden

ALF is accuracy limit factor

Accuracy limit factor value gives you an indication for maximum primary current that follow without affecting the accuracy of secondary measurements, or we can say the maximum current that follow in primary before core saturates and secondary current distort.

4.2.6 Turns Ratio Test

This test is to ensure the turn's ratio of CT at all taps. The circuit connection shall be made as shown figure (4.5). The primary current of minimum of 25% rated primary current to be injected on primary side of CT with secondary shorted and the secondary current can be measured & recorded for all cores. The obtained turn's ratio should match with rated nameplate ratio.

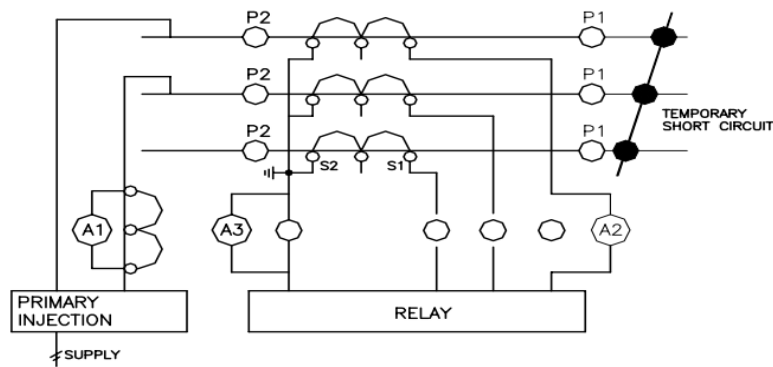


Figure 4.5 shows turns ratio test and primary injection test

4.2.7 Primary Injection Test

This test is to ensure the CT circuits are properly connected with respected cores and there is no mix up in the circuit (phase identification).The circuit connections shall be made as shown in Figure (4.5). Single point grounding shall be verified for CT circuits, before starting this test. Inject 25% of rated primary current between one phase and earth with all connected burden. Measure secondary current at all points of CT circuits. It shall be done for other phases. When one CT is having several cores used for different purposes the

cores should be identified. The cores can be identified during primary injection test by shorting the one of the core at CT terminal itself and check there is no current only at relevant load. The same can be verified for other cores. Inject 25% of rated primary current between phase to phase with all connected burden. Measure secondary current at all points of CT circuits. It shall be done for other phases. Secondary current should only be observed at respective phase and neutral leads during Phase to earth injection. Also secondary current should only be observed at respective phases and no current on neutral during Phase to phase injection.

4.2.8 High Voltage Test

In this test injecting 80% of the testing voltage used in the factory is applied, the required test voltage shall be raised gradually and maintained for one minute between one phase and the other phases connected to the ground and then reduced slowly to zero, test shall be repeated for other phases as mentioned above and leakage current shall be recorded during each test. No flashover or disruptive discharge should occur during test.

4.3 Commissioning Test for Voltage Transformers (VT)

Voltage transformer is an instrument by which the high voltage can be stepped down to be easy to be measured. Voltage transformers are used for measurement and protection; usual step down ratio is $X/110V$ where X is the bus bar voltage. With compare to CTs the secondary windings voltage is low and there is no hazard to open the secondary as in CTs. Circuit breakers or fuses are protect the secondary windings of voltage transformers against short circuits. VTs should be tested to ensure that they work properly.

4.3.1 Insulation Resistance Test:

Primary or secondary winding ground connection to be isolated. The voltage shall be applied between Primary to secondary and ground, Secondary to primary plus ground and secondary winding to winding.

4.3.2 Polarity Test

Polarity test is to confirm the polarity marking on the VT primary and secondary and verify it is matching with drawing. More ever it is giving an idea, how to connect the secondary to make the protection (like directional) and metering function properly. Isolate VT secondary from the load and make circuit connection as shown in figure (4.6). Close and open the battery switch connected on the primary. Observe the pointer is moving +ve direction, while closing and – ve direction while opening for correct polarity.

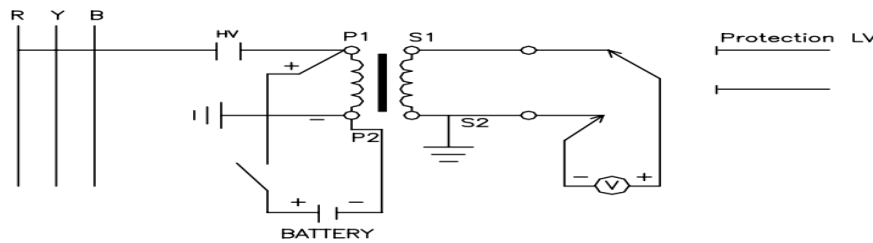


Figure (4.6) VT polarity test

4.3.3 Burden Test

Burden test is to ensure the connected burden to VT is within the rated burden, identified on the nameplate. Injected the rated secondary voltage of the VT, from VT terminals towards load side by isolating the VT secondary with all connected load and observe the current drawn by the load. The burden VA can be calculated as:

$$\text{Burden VA} = \text{Secondary Voltage} * \text{drawn load Current.} \quad (4.3)$$

the calculated burden should be less than rated VT burden. Voltmeter selector switch should be at respective phase during test.

4.3.4 Ratio Test

This test is to ensure the turn's ratio of VT. The circuit connection shall be made as shown figure (4.7). The primary voltage of 220 V applied on primary terminals and secondary voltage measured from secondary terminals. The obtained turn's ratio should match with rated nameplate ratio.

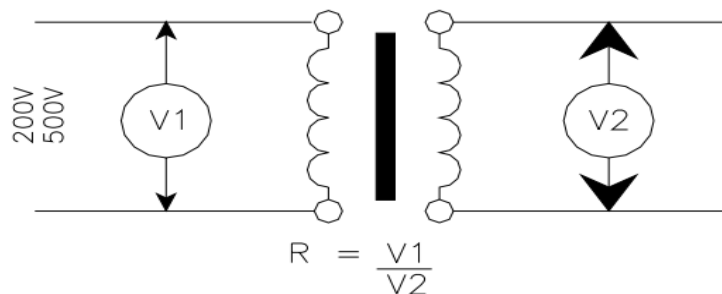


Figure 4.7 VT ratio test

4.3.5 Voltage Transformer (VT) Circuit Check

This test is to confirm all the loads of VT are connected properly and no mix-up between phases. Inject three-phase voltage with different magnitude at each phase, on the secondary circuit (VT side isolated), and measure voltage at all points. Verify that there is no mix-up between phases.

4.3.6 High Voltage Test

In this test injecting 80% of the testing voltage used in the factory is applied, the required test voltage shall be raised gradually and maintained for one minute between one phase and the other phases connected to the ground and then reduced slowly to zero, test shall be repeated for other phases as mentioned above and

leakage current shall be recorded during each test. No flashover or disruptive discharge should occur during test.

4.4 Commissioning Test for Direct Current (DC) System

DC system in a substation represents the nerves in human body. The function of the DC systems is to provide the DC supply for all auxiliary and substation DC dependent equipment, through the DC distribution boards. This equipment comprises the protection relays, control systems and the communication systems in addition to the emergency lighting. DC system components are Batteries bank connected in series, AC to DC converter (charger) and DC distribution board as shown in figure (4.8).

AC/DC converter is sized so that it can cater for 100% of the load and the Battery is sized so that it can cater for 100% of the load plus 25% for ageing. This system in a substation can comprise single or dual charger with one or two battery bank. The output voltage of the DC system can be 110V or 48V depending on the load requirements. AC supply of the DC system can be three or single phase. In normal operation of the DC system, the load is fed by the AC supply (through AC/DC converter) and in case of supply absence, the load is fed by the battery bank.

DC system is equipped with over/under voltage protection relays as well as earth fault monitor relay to check that positive & negative poles of the DC system are strictly insulated from the earth and in case of any insulation failure it detects the leakage current and hence launches earth fault alarm. Earth fault monitor relay has three terminals, those terminals are connected to earth, positive and negative poles.

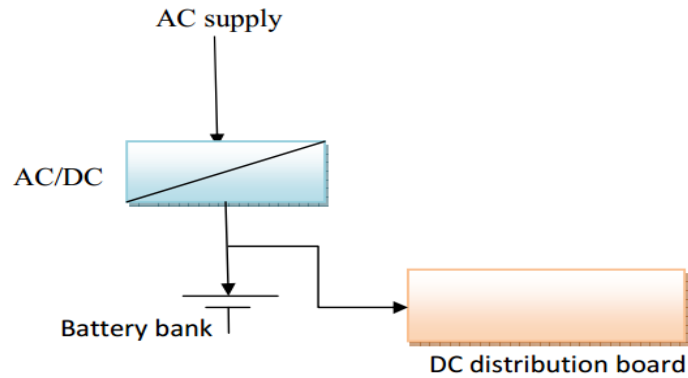


Figure 4.8 shows DC system

Batteries used in the DC systems are rechargeable and can be categorized into lead acid battery and Nickel Cadmium battery which has a long life approximately 20 years with reliable efficiency, the cell voltage is 1.4V and the total voltage of the battery bank used can be 110V or 48V on the number of series cells. Lead acid battery has life reaches around 5 years with reliable efficiency. DC system commissioning tests are capacity test, insulation test, polarity test and voltage level test.

4.4.1 Capacity Test

In this test the DC system is connected to the supply to charge the batteries with the load disconnected and the current & time are recorded till the battery reaches full charge and the same is done during discharging test, then compare to the manufacturer data given for the DC system.

4.4.2 Insulation Resistance

Positive and negative poles must be fully insulated from the earth; to verify the insulation Megger is used to check the insulation between these poles and the earth.

4.4.3 Polarity Test

The load must be connected in a correct manner to the DC distribution board to avoid any problems for the system, this is simply verified by multi- meter.

4.4.4 Voltage Level

DC output voltages are to be checked by voltmeter.

4.5 Commissioning Test for Protective Relays

The commissioning tests normally carried out for protective relays are to measure the insulation resistance for the equipment in the protection circuits, test main current transformers for ratio and polarity, and check points on the magnetization curve and test main voltage transformers for ratio, polarity and phasing as mentioned in the previous sections. In addition to that testing the main types of protective relay in substation by secondary injection and primary injection tests to determine the effective current setting for internal fault and to prove stability for external faults. These tests depends on the deal between the manufacture and the customer.

4.5.1 Secondary Injection Test

These tests and the equipment necessary to perform them are described below.

They are quick, less expensive than primary injection test and kit is small and portable.

a. Over Current Relays

A typical test set for over current relays is shown in figure (4.9). The current is controlled by means of tapped reactors in the primary circuit of the injection transformer. The injection transformer is provided with secondary tapings chosen to correspond with the current setting of the relay. The test set for incorporates a

digital timer with alternative setting ranges of 0.1 ms to 10 s or 1ms to 100 s, which enables modern over current relays of the inverse definite minimum time type to be checked most accurately. When using the set, the test current should first be set approximately with the relay coil shorted out to prevent unnecessary heating the coil can then be unsorted for the final adjustment of the test current. Instantaneous over current relays should be checked by measuring the minimum current that gives operation at each current setting and measuring the maximum current at which resetting takes place.

To check the performance of the inverse time or definite time relays the above tests for instantaneous relays may be performed in full. The result should be compared with factory test result.

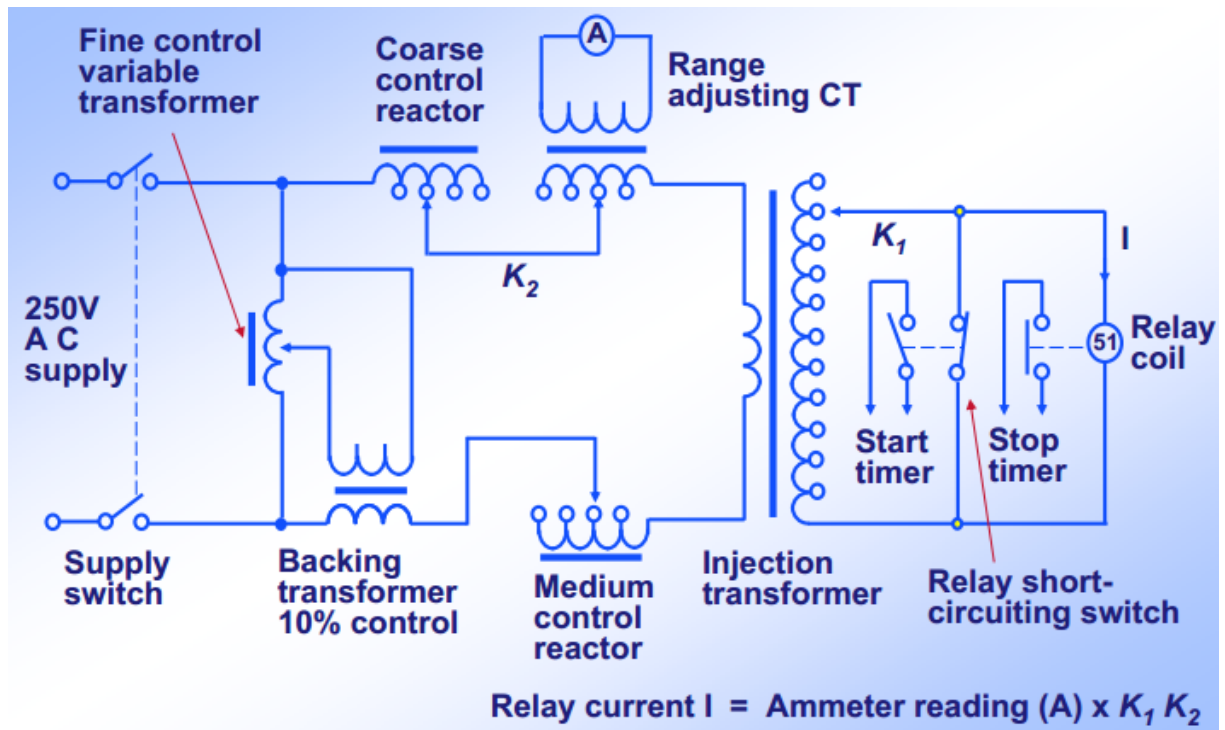


Figure 4.9 over current test set

b. Differential Relays

The sensitivity of the differential relays can be checked with the over current test set described above. It might be argued that these secondary injection test are not

necessary as the sensitivity is checked again later by primary injection. Secondary injection is never the less recommended, because the recorded figures form a reference for future routine maintenance checks on the relay, and also because if the relay is faulty, it is better to find these out during a simple secondary injection test rather than when a primary injection test is being carried out, as the later sometimes takes a great deal of organizing.

When testing unbiased differential relay, the current setting should be checked using over current test set, slowly raising the current until the relay operates. These should be done at all the current settings and finally at the required setting. The results should be recorded for future reference and they should agree approximately with manufacturer's declared current setting. The current setting of generator or transformer biased relay should be checked as above with over current test set. Injection should be made into one bias coil and out of the operating coil as shown in figure (4.10).

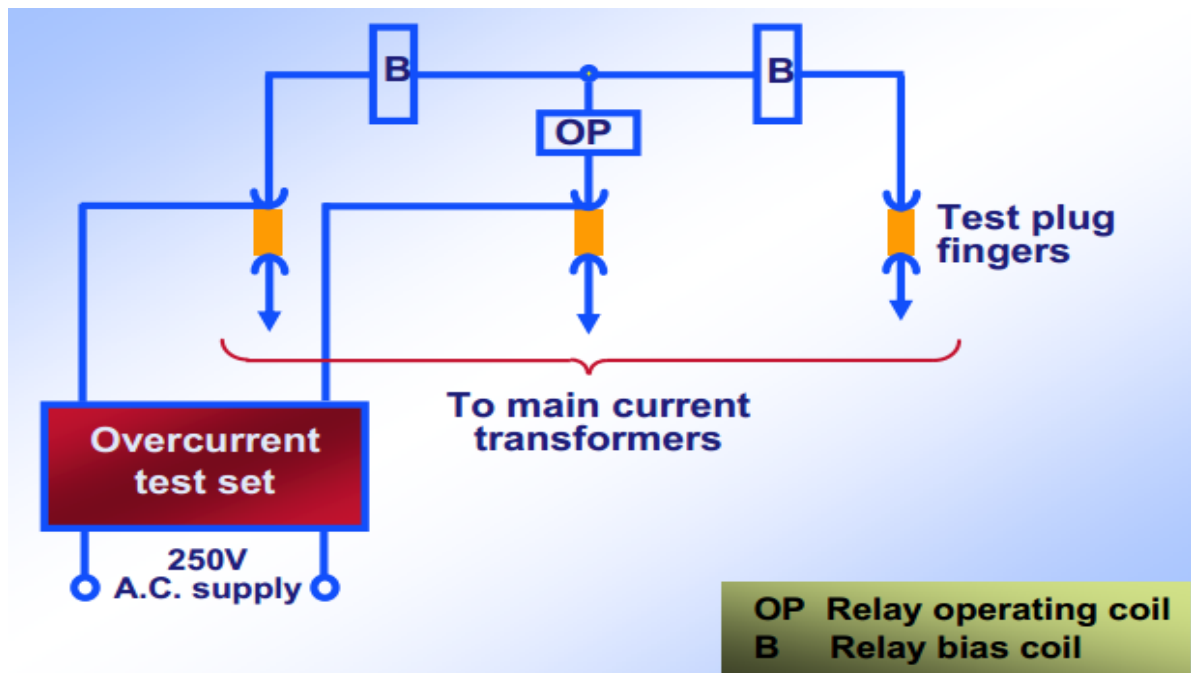


Figure 4.10 Sensitivity check on biased differential relay

C. Pilot Wire Relay

The various current settings for pilot wire relays can be checked using the over current test set. To obtain the correct settings, the pilot wires must be connected to the relays at each end of the line and the correct pilot compensation must be set on the relays.

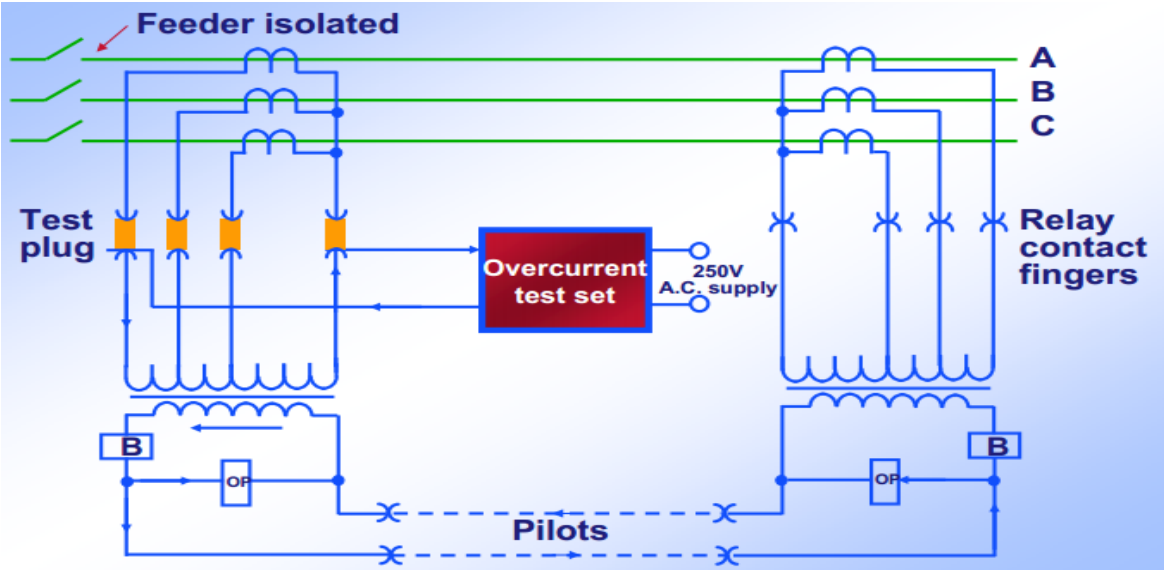
The current settings of the relays may then be checked by injection into each phase in turn, see figure (4.11) (a). The results obtained should approximate to the manufacturer's declared current setting for the length and type of pilots in use. The stability of the protection can be checked by using the feeder conductors to connect the summation current transformers at each end of the feeders in series. Secondary injection can then be made as shown in figure (4.11) (b), the current circulating through the feeder conductors, summation transformers and pilot wires. Several times the relay rated current can be made to circulate through the summation transformer primaries. Corresponding current circulates through the pilots. This test is very useful, as it is practically impossible to produce the same magnitude of circulating current in the pilots when carrying out the primary injection test.

4.5.2 Primary Injection Test

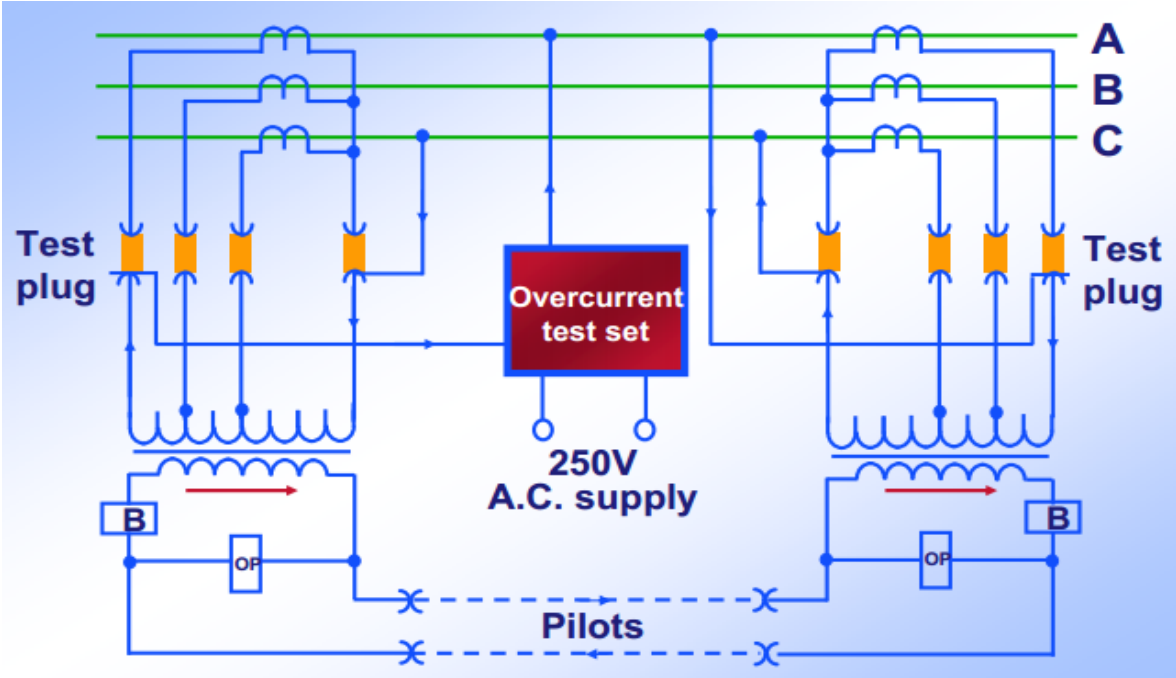
In this test there is no need to disturb wiring, which obviates the hazard of open-circuiting current transformers, and there is generally no need for any switching in the current transformer or relay circuits.

An alternator is the most useful source of power for providing the heavy current necessary for primary injection. Protection types which can be tested by primary injection test are described below.

Primary injection is usually carried out by means of a portable injection transformer as in figure (4.12), arranged to operate from the local mains supply and having several low voltage heavy current windings.



(a) Sensitivity test



(b) Stability test

Figure 4.11 Testing pilot wire relay

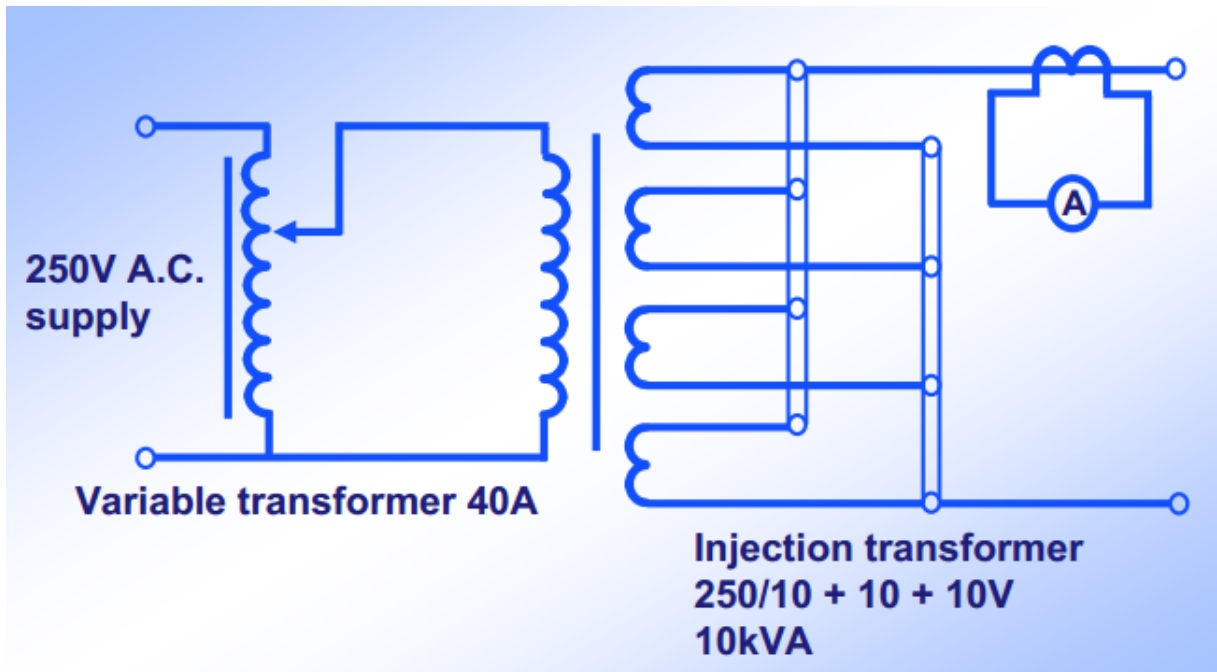


Figure 4.12 primary injection test set

a. Over Current and Earth Fault Relay

If the equipment includes directional, differential or earth fault relays, the polarity of the main current transformers must be checked. The circuit for checking the polarity with a single-phase test set is shown in figure (4.13). 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 residual circuit will give a reading of few milli amperes with rated current injected if the current transformers are of correct polarity, but a reading proportional to twice the primary current if they are of wrong polarity. If an earth fault relay with a low setting is also connected in the residual circuit, it is advisable temporarily to short-circuit its operating coil during coil during the test, to prevent possible overheating. The single-phase should be carried out for each pair of phases.

Because the amount of primary current available is limited, the operating time of the relay cannot be checked at high currents. While phase to phase injection is

satisfactory for checking over current relays. Single phase injection should be used to check the earth fault setting of residually connected relays as shown in figure (4.14).

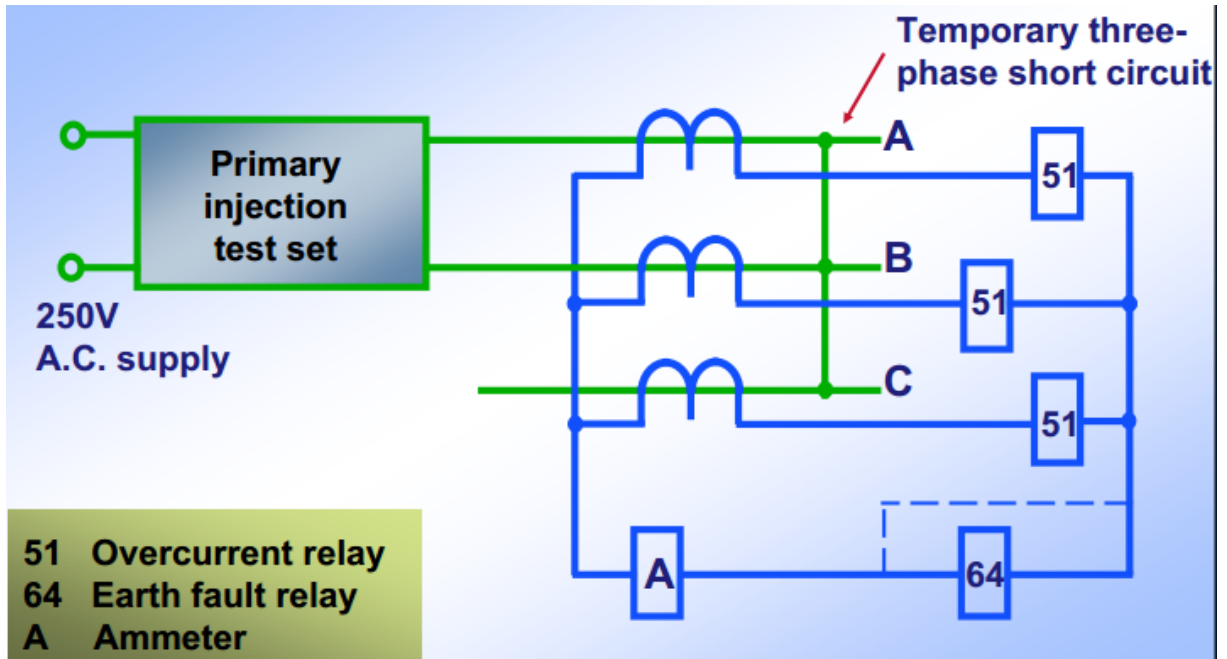


Figure 4.13 primary check on main current transformers

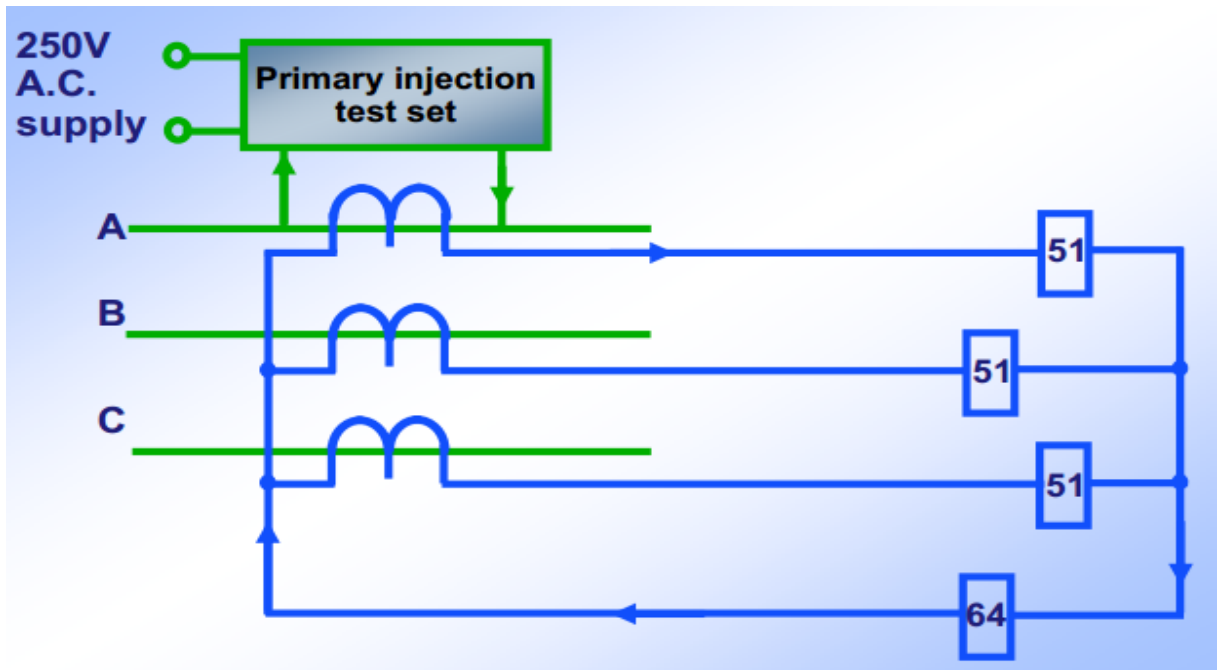


Figure 4.14 Sensitivity test on earth fault relay

b. Transformer Biased Differential Protection

The sensitivity can be checked with the single phase primary injection test set. Primary current is passed through one of the main current transformers and slowly raised until the relay just operates. This gives the true effect fault current necessary in the primary to cause operation and includes the relay current plus the magnetizing current of the current transformers shunting the relay.

This test can be carried out by injection through two current transformers of simulate phase to phase fault in figure (4.15).

To check the stability of the protection, full load current must be passed through the main current transformer primary windings. The best source of power for this test is a generator. If one adequate current rating is available, the primary full load current can be made to circulate through the transformer by putting a three phase short circuit on one side of the transformer external to the protection in figure (4.16) the machine should then couple to the other side of the transformer, the generator run up to speed and the excitation slowly raised until full load flows through the primary windings of the transformer. With the load current flowing through the transformer windings, the protective relay should remain stable and the reading on the ammeters in the relay operating coil circuit should be very small.

c. Restricted Earth Fault Protection

This is sometimes combined with the transformer biased differential protection but is generally energized from separate current transformers. The sensitivity of the protection can be checked by injecting with the single phase test through each of the main current transformers in turn. While carrying out this test it is advisable to measure the voltage across the relay coil and stabilizing resistance, and so to

check the approximate voltage devolved by the main current transformer to cause relay operation.

The stability of the scheme can be checked by injecting through the neutral current transformer and each phase current transformer in turn as shown in figure (4.17).

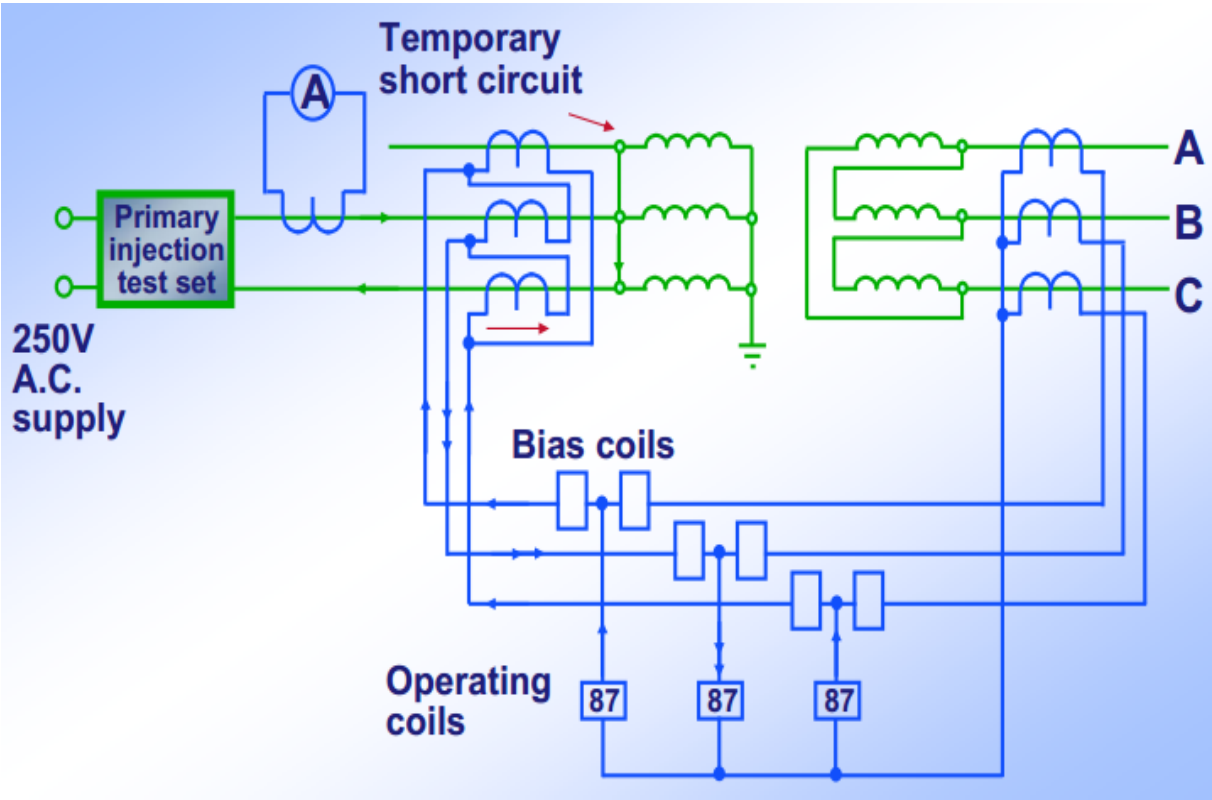


Figure 4.15 Phase Fault Sensitivity Check on Transformer
Differential Protection

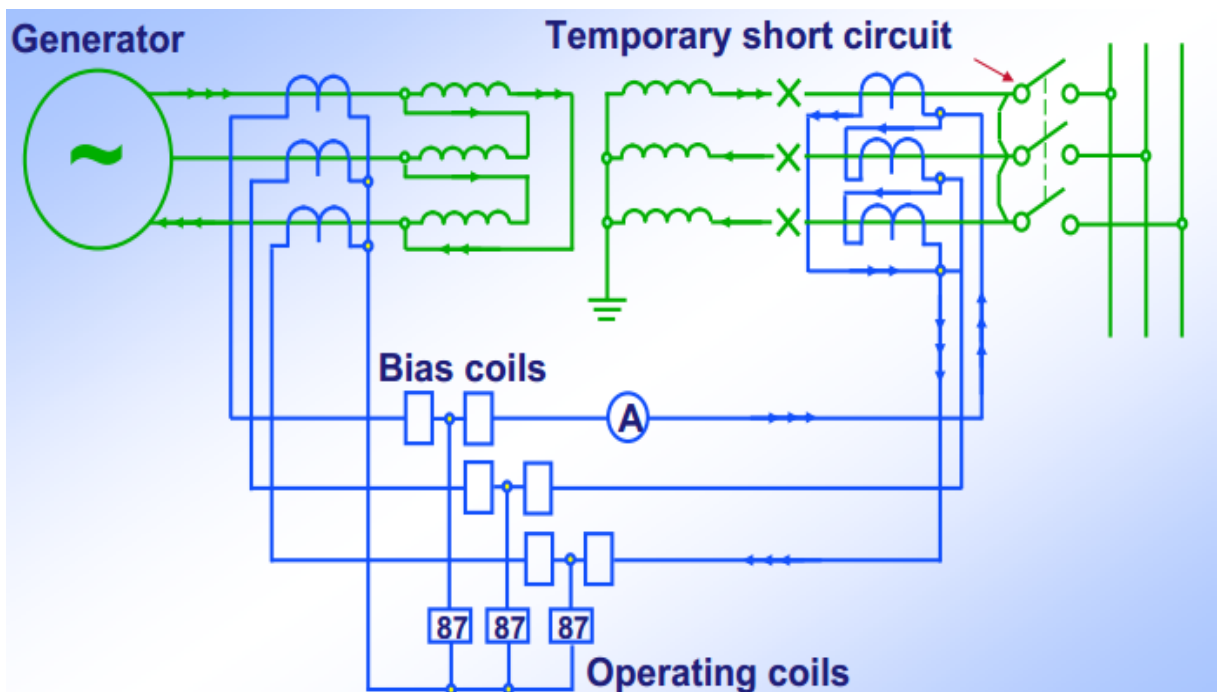


Figure 4.16 Stability Check on Transformer Differential Protection

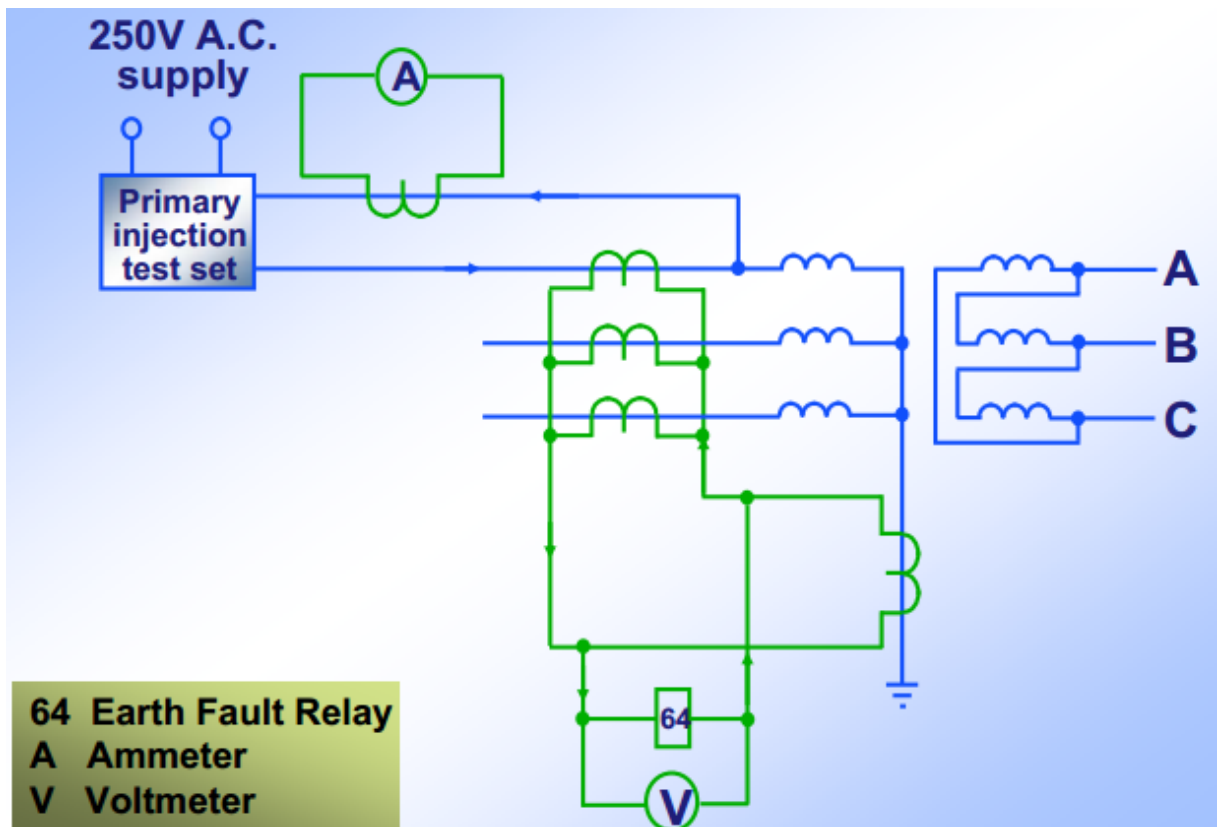


Figure 4.17 Sensitivity Check of Restricted Earth Fault Protection

d. Bus Bars Protection

The sensitivity of bus bar protection is checked by passing single phase primary current through one current transformer only and measuring the current necessary to cause operation of the circulating current relay 87 with the maximum number of current transformer in idle shunt. If the scheme is provided with an overall checked feature and supervision relay, the sensitivity of these can be checked in the same manner and at the same time. It should be appreciated that the supervision relay 95 the very low setting and is arranged to operate the bus wire shorting relay 95X. It is there for necessary to render this feature inoperative while checking the sensitivity of the circulating current relay 87.

To check that correct value of stabilizing resistor is used in series with the relays 87, a voltammeter should be connected across the relay coil and stabilizing resistor as shown figure (4.18). The voltammeter reading should be noted as the relay operates and this value should agree closely with that predicted by the supplier. The effective minimum primary currents that cause relay operation should approximate closely to those forecast by supplier of the protection scheme.

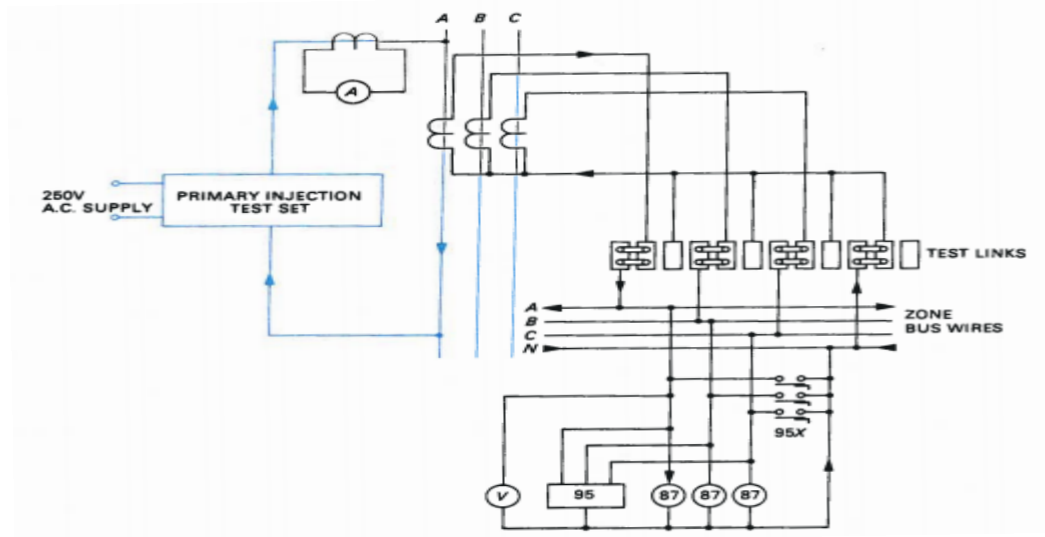


Figure 4.18 Sensitivity check on bus bar protection

4.6 Commissioning Test for Electrical Cables

Electrical cables are used to transfer power from supply to the load. Generally cables are classified based on the insulation material, conductor material, voltage level, cross section and number of cores as in figure (4.19). As for insulation materials the most commonly used are XLPE (cross linked polyethylene) and PVC (polyvinyl chloride) cables. Each one has characteristics as in table (4.1). Cable can be single or multi-cores also cores can be either copper or aluminum.

The most important commissioning tests of power cables are phase sequence, insulation resistance test, high voltage test at very low frequency, Conductor DC resistance test and DC sheath test.

Table 4.1: shows cable insulation material characteristic

Characteristic	XPPE	PVC
Max. continuous operating temperature c°	90	70
Max. conductor temperature at short circuit current c°	250	160
Fire resistance	Poor	Excellent
Flexibility	Good	Excellent

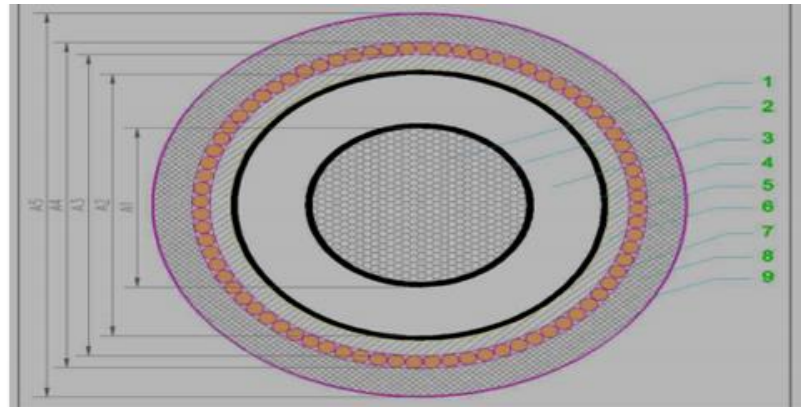


Figure 4.19 sectional area of single phase cable

- | | | |
|---------------------|--------------------|--------------------|
| 1-Conductor | 2-Conductor screen | 3-Insulation |
| 4-Insulation screen | 5-Metalic layer | 6-Inner sheath |
| 7-Armour | 8-Outer sheath | 9-Conductive layer |

4.6.1 Phase Sequence Test

Before proceeding in cable testing, the phase identification must be carried out to avoid serious problems to personnel and equipment. Phase identification can be carried out using Megger. Remote side of one phase is earthed and other phases are left open as in figure (4.20), apply voltage (low value e.g. 50V) to the phase which remote side earthed and note the reading, if zero then the first phase is identified as figure, repeat the same steps for other phases.

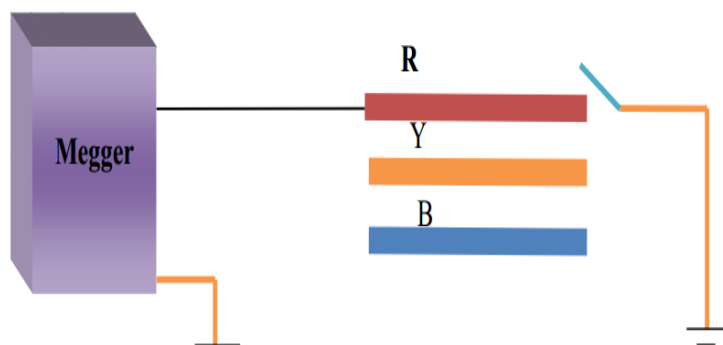


Figure 4.20 phase sequence test

4.6.2 Insulation Resistance Test

Using Megger the insulation level can be checked. This test is carried out before and after high voltage test. For high voltage cables 15KV is applied DC for 60 seconds duration. Compare the result with factory test.

4.6.3 Very Low Frequency Test (VLF)

Very Low Frequency Test testing is a modern method of cable testing, it guarantees damage free of the cable under test. A high voltage with very low frequency is applied to the cable to check the dielectric strength as in figure (4.21). The voltage applied is three times of the cable phase voltage with 0.1HZ for 30 minutes.

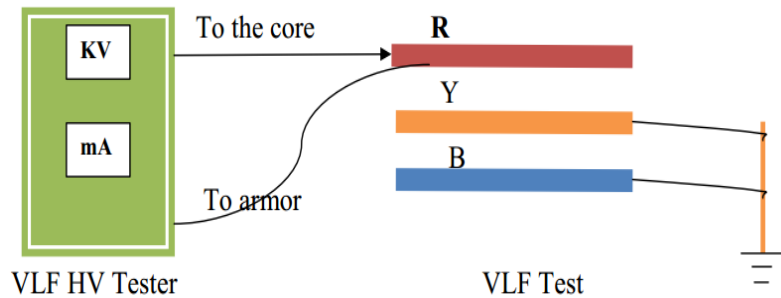


Figure 4.21 shows very low frequency test connection

4.6.4 Conductor DC Resistance Test

For a cable it's required to transfer the power from supply to the load without any significant losses (ideal case zero losses) as the power losses in the cable appears in the image of heat which deteriorate the insulation and consequently the cable life time. Another point the DC resistance causes voltage drop across the cable terminals, thus the DC resistance of the live part (cable core) is required to be minimum. At site the cable is laid and the two terminals are no longer accessible so the current is applied to two phases and the remote terminals of the two phases

shall be shortened together as shown in figure (4.22). The same steps are repeated for other two phases.

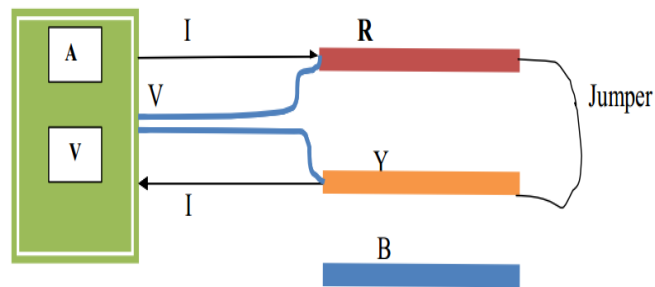


Figure 4.22.: conductor dc resistance test

And the resistances can be calculated as follows:

$$\text{Resistance in R} = 0.5 (A + C - B)$$

$$\text{Resistance in Y} = 0.5 (A + B - C)$$

$$\text{Resistance in B} = 0.5 (B + C - A)$$

Where:

A= the resistance measured in R and Y

B=the resistance measured in Y and B

C=the resistance measured in B and R

4.6.5 Dc Sheath Test

Outer sheath is the last layer of the cable and usually made of PVC or PE, this layer is used for cable protection from environmental conditions. DC sheath test is used to make sure that no cracks or damage happened to the cable during cables installations. The test is implemented by applying 10kV DC for 1 minute to the outer sheath as shown in figure (4.23), the test is assumed successful as long as no breakdown occurs.

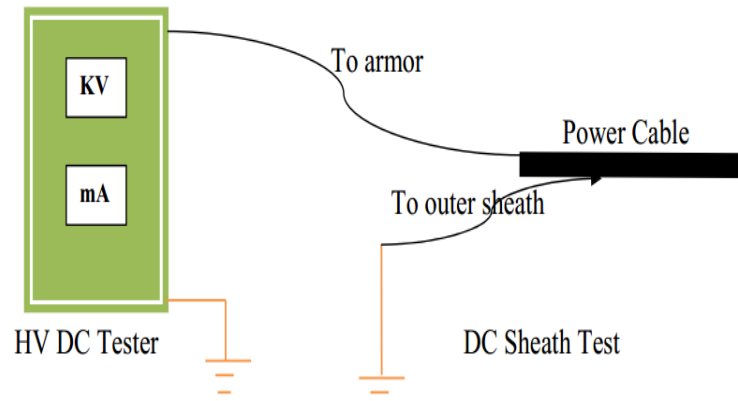


Figure 4.23 shows the DC sheath test