Instrument Transformer Testing at Site

Introduction

Instrument transformer is in the forefront of system protection and metering train. Its correct functioning is of vital importance to successfully clear the fault in a selective manner and correct functioning of metering system. This article elaborates the electrical tests that are conducted at site to verify the healthiness of instrument transformer (current transformer and potential transformer) as well as correctness of wiring. Site acceptance tests are carried out during

- Commissioning during first installation
- Maintenance testing during routine and breakdown maintenance
- Auditing of existing installation.

To carry out this site tests high accuracy test kits are not required and laboratory standards are not being sought. There is no specific standard which spells out the requirement of site tests. The easy, appropriately accurate and low cost testing methods are discussed in this article.

Current Transformer Testing

Current Transformer consists of three main components: winding, core and insulation. The tests described below checks integrity of these and the correctness of wiring.

Summary of Tests

Current Transformer Testing covers following tests:

- IR value measurement - Insulation check
- Polarity check - Polarity marking check
- Ratio check - Winding healthiness check
- Excitation characteristic check - Core healthiness check
- Secondary winding and lead resistance measurement - Winding healthiness check
- Secondary injection - CT circuit check
- Primary injection - CT circuit check

IR Value Measurement

Before starting this test disconnect the CT secondary wiring and secondary earthing of all cores (Refer Fig.1). IR is measured between the following:

1 Primary to Earth: Select the megger rating as per voltage class of CT. Generally 2.5 kV or 5 kV megger should suffice. The connection diagram is shown in Fig 2. The minimum acceptable value is (kV+1) MΩ. For example, for 11 kV CT, the value should be 12 MΩ or above.

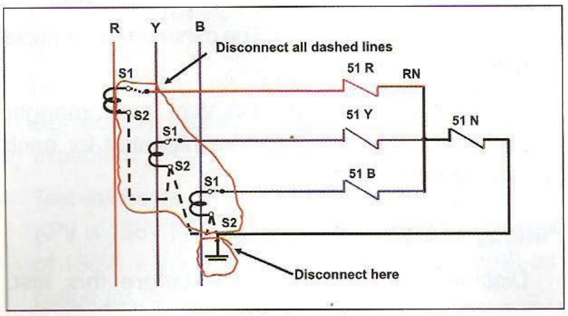

Fig 1 Typical CT Circuit

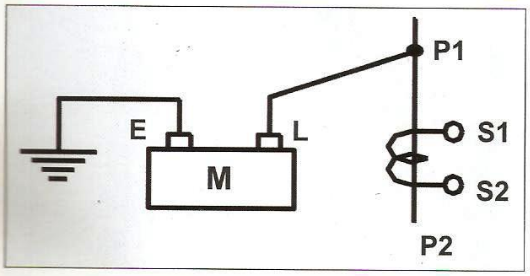

Fig 2 Primary to Earth

2 Primary to Secondary: Refer Fig 3. As in (1), the minimum acceptable value is (kV+1) MΩ for this test as well.

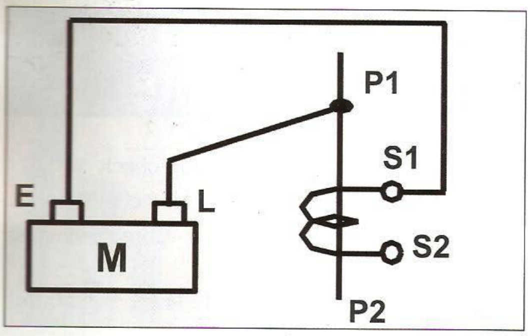

Fig 3 Primary to Secondary

3 Secondary to Earth: Refer Fig 4. The minimum acceptable value is 1 MΩ.

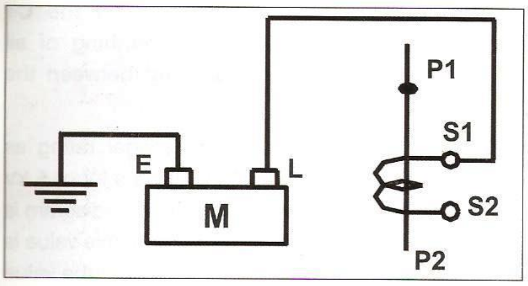

Fig 4 Secondary to Earth

4 Core to Core: Refer Fig 5. The minimum acceptable value is 1 MΩ.

For tests (3) and (4), 500 V or 1 kV megger can be used. The tests shall be repeated for each secondary core.

Polarity Check

Discharge the primary fully before this test. Use healthy / charged 1.5V or 3V cell. Deflection is measured using AVO set in mA range. Refer Fig

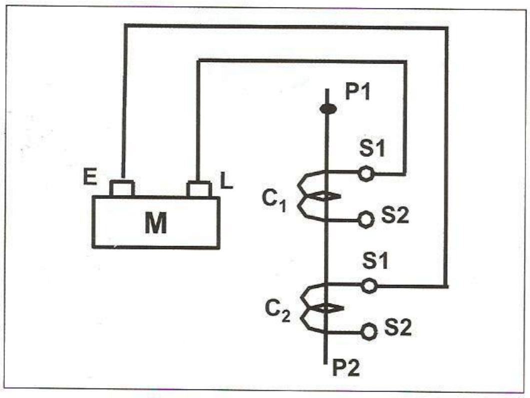

Fig 5 Core to Core

6 for set up. Momentarily touch lead connected at P1 to positive of the cell, AVO will show positive (clockwise) deflection. Meter will show negative (anti-clockwise) deflection when the cell is disconnected. This confirms that S1 terminal on secondary side is positive when P1 terminal on primary side is positive at the same instant. Repeat the test for all the cores. Short other CT cores, not under test, in case of multicore CT.

Do not connect the battery cell to the primary for a long time.

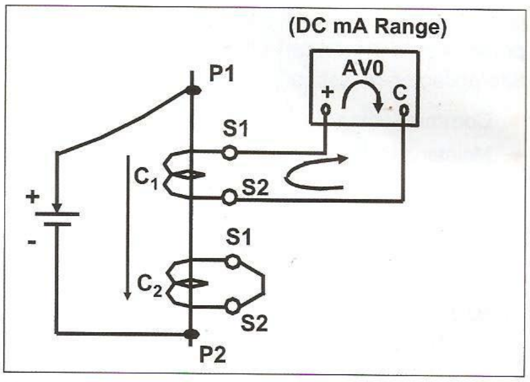

Fig 6 Polarity Test

Excitation (Saturation) Characteristic Check

This is the critical test to verify the magnetic healthiness of the CT. A saturated CT renders the protection useless even if sophisticated numerical relays are used. It is also useful to resolve any mix-up in metering and protection cores at site. The test set up is shown in Fig 7. A 230 V single phase variac is used to apply voltage on secondary side of CT. Increase the voltage gradually and measure the current. Continue the test till KPV (Knee Point

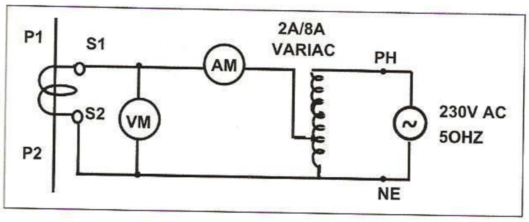

Fig 7 Excitation Test

Voltage) is reached. Do not exceed the CT rated current (1A or 5A).

A typical satcurve is shown in Fig 8. Applied voltage is plotted on Y axis and resultant exciting current is plotted on X axis. KPV is defined as that point at which 10% increase in voltage results in 50% increase in exciting current. Below KPV, the relationship between voltage and current is linear. Above KPV this linearity is destroyed. Even for a small increase in voltage the resultant current is excessive. In a saturated CT most of the primary ampere turn (AT) is consumed in exciting the core with little output on secondary. This may lead to core damage.

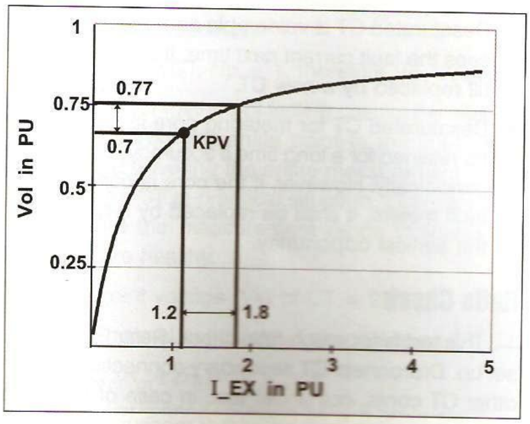

Fig 8 Saturation Curve

Following points are to be noted before the test:

- For class PS CTs, note Knee Point Voltage (KPV) and I_{EX} (exciting current) at V_K / 4 or V_K / 2 where V_K is the Knee Point Voltage (KPV). Typically I_{EX} is less than 30 mA at V_K / 4 for 1A CT and 150 mA at V_K / 4 for 5A CT.
- For a protection class CT, KPV is not specified directly. KPV has to be derived from the specified ALF, burden and CT rated current. The minimum design value of KPV is given by,

$$V_{DESIGN} = \frac{\text{Burden x Accuracy Limit Factor (A.L.F)}}{I_{sec} \text{ (Secondary)}}$$

While carrying out the test following are to be ensured:

- Readings for the three phases on the same core shall be nearly equal (need not be identical). To make this comparison easy, measure the exciting current at the same voltage for all the three phases.
- KPV of metering core in general will be less than that of protection core. Otherwise a mix up of metering and protection cores is indicated.

The excitation characteristic is illustrated with typical test results for a three core CT with following specification:

Metering Ratio - 1600/5A, Cl. 0.5, 15VA

Protection Ratio - 1600/5A, Cl. 5P20, 20VA

Differential Ratio - 1600/5A, Cl. PS, Vk > 130, I_{EX} < 150mA @ Vk/2, Rct < 0.8 ohm

The test results are given in Table I.

Table I

Special Protection Class		General Protection Class		Metering Class	
1600/5A, Cl. PS, V_K > 130, Ie < 150mA @ V_K/2, Rct < 0.8 ohm		1600/5A, Cl. 5P20, 20VA		1600/5A, Cl. 0.5, 15VA	
Volts	Current (mA)	Volts	Current (mA)	Volts	Current (mA)
10	10	10	5	6	5
75	42	40	12	10	7
130	71	80	20	20	12
143	85	120	33	**30 (V_K)**	**22**
158 (V_K)	**111**	**171 (V_K)**	**77**	33	33
174	181	190	132		

From Table I following can be concluded:

1 KPV of metering core is 30V. 10% increase in voltage (30V to 33V) results in about 50% increase in exciting current (22mA to 33mA).

2 KPV of protection core is 171V. The actual KPV (171V) is higher than the designed value (80V) as desired. (Design value of KPV = ALF (20) x Burden (20)/ CT rating (5)).

3 From (1) and (2), KPV of metering core is significantly less than that of protection core as expected.

4 Test values for differential core are also given. The KPV is 158V (above the specification requirement of 130V). I_{EX} is less than 150mA at 75V (V_K/2) as called for in the specification.

5 The site test results indicates that the exciting

current for a protection class CT could be less than that of a Class PS CT and can have higher knee point voltage compared to a Class PS CT.

Table II shows typical tests results for differential CT with specification:

200/1; Class - PS; KPV > 50V, (EX < 30mA @ Vk/2, Rct < 1 ohm.

Table II

R Phase		Y Phase		B Phase	
V_EX Volts	I_EX mA	V_EX Volts	I_EX mA	V_EX Volts	I_EX mA
10	15	10	14	10	15
20	18	20	17	20	19
25	22	25	21	25	23
30	31	30	30	30	32
40	42	40	41	40	43
50	58	50	58	50	60
{55	70	{55	69	{55	70
60	104	60	103	60	106
Class PS : KPV: 55V					

The KPV is 55V (above the specification requirement of 50V). I_{EX} is less than 30mA at 25V as called for in the specification.

Typical test values for a healthy CT, saturated CT and failed CT are given in Table III. The corresponding excitation curves are shown in Fig 9. If the current increases rapidly even when a very small voltage is applied (e.g. 500mA at 0.5V) abort the test as it indicates insulation failure and the failed CT is discarded. In case of saturated CT steep increase in exciting current occurs at a voltage much below expected KPV. Sometimes desaturation of saturated CT is attempted at site. The procedure is as follows:

Table III

Healthy CT		Saturated CT		Failed CT	
V_EX: Volts	I_EX: mA	V_EX Volts	I_EX mA	V_EX Volts	I_EX mA
50	8	5	30	0.1	15
60	11	7	50	0.3	40
150	25	10	140	0.5	500
170	32	12	300		
175	34	20	900		
185	48				

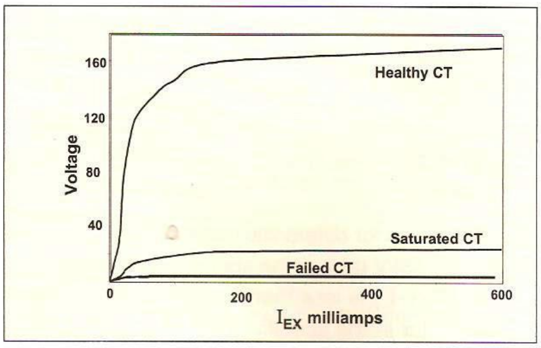

Fig 9 CT Healthiness Test

- Gradually increase the voltage to pass rated current on secondary (say 1A)
- Gradually decrease the voltage to zero.
- Initially even at low voltage CT may take rated current
- Repeat the above cycle 50 to 100 times. Each time observe that rated current is drawn at higher and higher voltages.
- When performing the above test, do not apply large voltage suddenly or switch off the supply abruptly. Increase or decrease in voltage shall be smooth and gradual.
- If near to original KPV could be obtained, desaturation is successful.

Following recommendations are made for use of desaturated CT:

- Avoid using desaturated CT for protection core. Desaturated CT is vulnerable and may fail when it sees the fault current next time. It can be retained till replaced by a new CT.
- Desaturated CT for metering core in general can be retained for a long time if accuracy is monitored periodically. However, if the core is connected to tariff meters, it shall be replaced by a new one at the earliest opportunity.

Ratio Check

This test is for rough ratio check. Refer Fig 10 A for set up. Disconnect CT secondary connections. Short other CT cores, not under test, in case of multicore CT. Use portable multimeter that measures true RMS current and primary injection set that delivers high current at low voltage. Typical rating of the kit:

Input - 230V, 3KVA, 1 phase loading transformer

Output - 250A at 12V, 500A at 6V, 1000A at 3V

Inject current on the primary and measure current on the secondary and check ratio. It is not mandatory to do the test at rated primary current. Eg: For 3000/1 CT, testing at 500A is sufficient.

The ratio error is calculated as follows:

Ratio error = $[(I_P - K_N I_S) / I_P] \times 100$

Example: CT ratio-1000/1; Ideal Ratio K_N = 1000

Injected I_P = 500A; Measured I_S = 0.49A

Ratio error = [(500-1000x0.49)/500] x100 = 2%

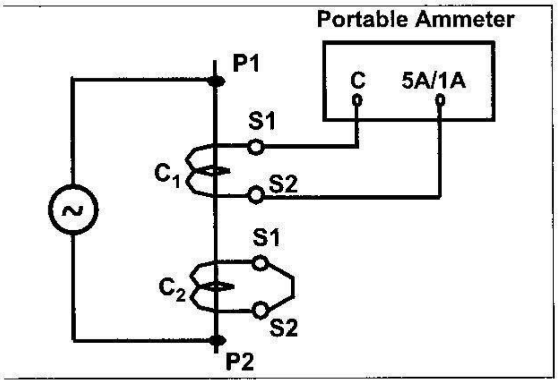

Fig 10 A Ratio Test

Voltage measurement method

(We acknowledge Mr. Patrick Hawes of Transformer Test Instruments, SA for his suggestions)

This test is for ratio check by measuring primary voltage when voltage is applied to secondary. This test works on the transformer principle that:

Vp/Vs = Np/Ns ; where Vp and Vs are Primary and Secondary voltage, Np and Ns are primary and secondary turns respectively.

For bar primary CT, Np = 1, therefore Vp =Vs/Ns

This indirect method of testing checks the integrity of windings from the ankle point to the knee point and beyond covering the entire measurement range faced by the CT in practical situation. Constant ratio through out the measurement range indicates CT windings are healthy.

Knee point voltage (Vk) of CT = $2I_F(R_{CT} + 2R_L)$

Under normal conditions, voltage across CT

$V_{CT}=I_{RAT}(R_{CT}+2R_L)=[V_K]I_{RAT}/2I_F$

e.g. $I_{RAT}/2I_F$=800A/(2x8000 A) = 0.05 ⇒ 5%

As seen from above, under healthy conditions, voltage required to be developed by CT is only 5% of the knee point voltage.

The advantage of this method is that even by applying a small voltage across secondary, the voltage developed across CT under fault conditions can be simulated and CT windings healthiness for worst conditions can be checked.

The direct current measurement method explained earlier, checks the thermal capability of the winding upto the rated current which is not the intent of the test. In current measurement method, there is no voltage stress on the secondary insulation which is actually developed across the CT under fault conditions.

It is very difficult to inject very high current to get near knee point voltage as the injection kits in such cases will be very bulky.

Refer Fig 10 B for test set up. Disconnect CT secondary connections and keep primary open. Use portable mili-voltmeter and 230V single phase variac to apply voltage on secondary side of CT. Increase the voltage gradually and measure primary voltage, secondary voltage and current and continue till the rated current is reached.

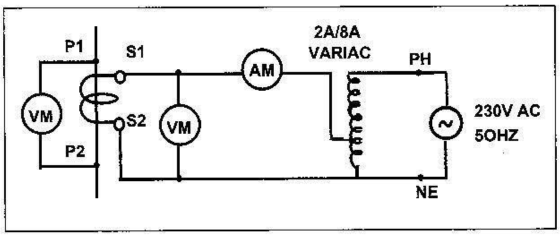

Fig 10 B Ratio Test - Voltage Measurement Method

This test can be combined with Excitation Characteristic check explained earlier.

Test was conducted on a Class PS CT with following specification: 800-1600/1A, Cl PS, Rct < 5 Ω, Vk > 100V, Iex @ Vk/4 < 30 mA. Test was carried out to check both ratio and excitation characteristics at 800/1A CTR. Test results are given in Table IV. Refer Fig. 10 C and 10 D. The figures indicate healthiness of CT as the CT ratio is constant from normal operating point to knee point and beyond knee point.

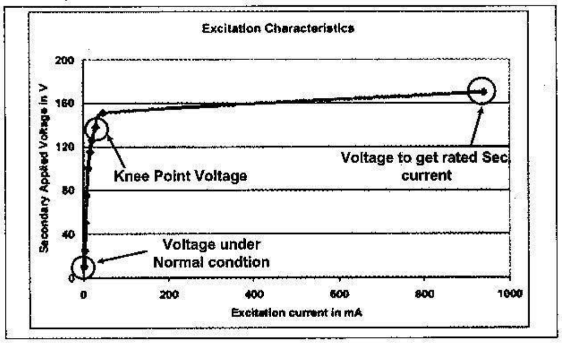

Fig 10 C CT Excitation Characteristics

In this case, primary current injection for ratio check is obviated. Field engineers, used to ratio test by high current injection on primary side, must overcome this psychological barrier and accept primary voltage measurement method.

Secondary and lead resistances

CT secondary resistance (R_{CT}) and lead resistance (R_L) can be measured using low resistance micro-

Table IV

Sec. Voltage applied (Vs), Volts	Excitation current (Iex), mA	Measured Pri. voltage (Vp), Volts	Pri. voltage (Calc. = Vs/Ns), Volts	Remarks
10	2	0.013	0.013	
25	4	0.032	0.031	Results @ Vk/4. Iex < 30mA
50	6	0.065	0.063	
75	8	0.093	0.094	
100	12	0.127	0.125	
115	16	0.145	0.144	
126	21	0.159	0.158	
138	30	0.174	0.173	Kpv = 138V as against design Kpv = 100V
151	47	0.189	0.189	
170	940	0.213	0.213	

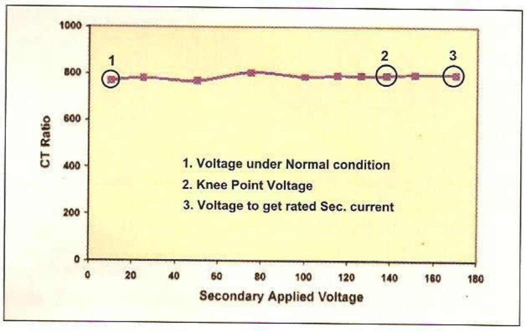

Fig 10 D CT Radio Test - Voltage Measurement Method

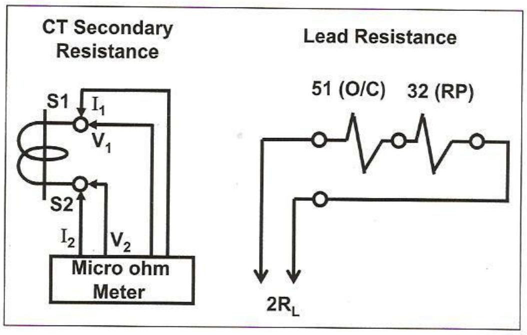

Fig 11 Secondary Winding and Lead Resistance Measurement

ohmmeter. The test set up is shown in Fig 11. For class PS CTs, R_{CT} should be less than the specified value. Also R_{CT} should not be significantly different for the three phases of the same core. Values of R_{CT} and R_L are used in calculation of KPV and stabilizing resistor value in high impedance differential scheme.

Secondary Injection test

This test verifies correctness of wiring from CT secondary terminals to relay terminals. A current source of 10 A will be adequate for secondary injection. In this test no current flows through either primary or secondary of CT. When performing this test, disconnection is required only at S1 terminals but loop connection of S2 terminals can be retained. Refer Fig 12 to 17. Initially inject current in R, Y and B

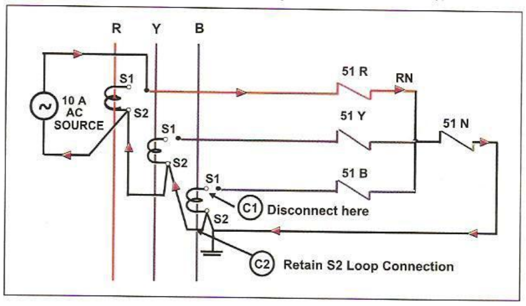

Fig 12 Secondary Injection - R Phase

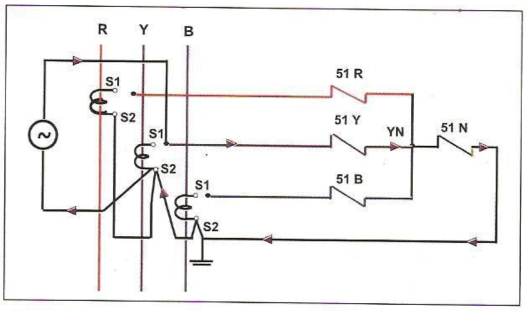

Fig 13 Secondary Injection - Y Phase

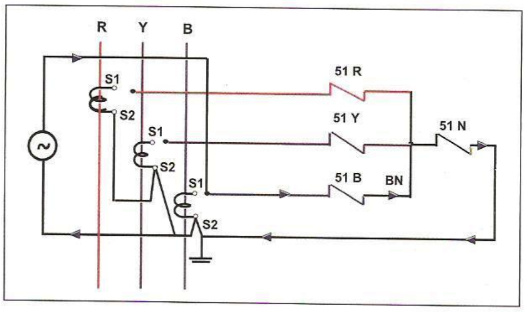

Fig 14 Secondary Injection - B Phase

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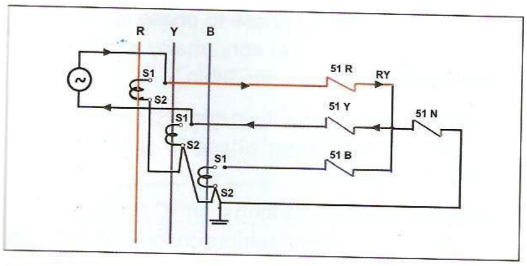

Fig 15 Secondary Injection - RY

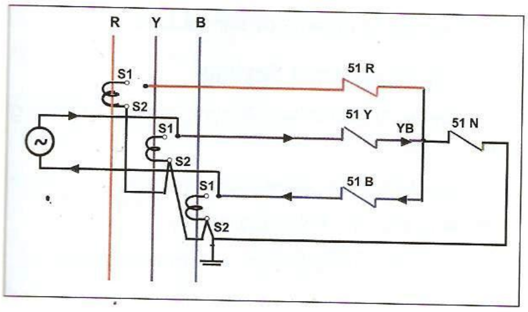

Fig 16 Secondary Injection - YB.

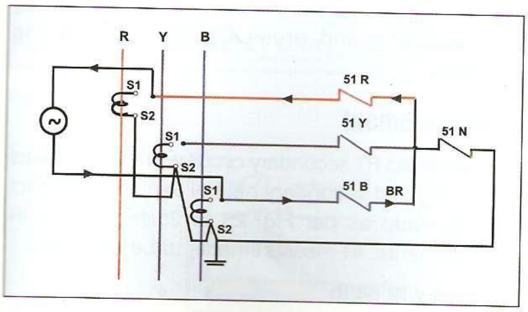

Fig 17 Secondary Injection - BR

Table V				
Injected Current	Relay Operation or Measured Current in Phases			
Phase	51R	51Y	51B	51N
RN	Yes	No	No	Yes
YN	No	Yes	No	Yes
BN	No	No	Yes	Yes
RY	Yes	Yes	No	No
YB	No	Yes	Yes	No
BR	Yes	No	Yes	No

phases and observe relay or meter current/ operation. For R phase current injection, only R phase relay (51R) and ground relay (51N) should respond and relays on Y and B phases should not respond. Then inject current between phases. For (R-Y) injection, only 51R and 51Y should respond and 51B and 51G should not respond. No abnormality is indicated if current distribution is as per Table V.

Primary Injection test

This test verifies correctness of connection from primary side of CT to relay terminals on the secondary side. Any wrong polarity in CT connection also gets verified. If ratio check is done with voltage measurement, then this is the only test that needs primary injection. Since the purpose of this test is only wiring check, it can be performed at a current much lower than rated current.

The typical rating of primary injection kit is as follows (similar to that used for ratio check test):
Input - 230V, 3KVA, 1 phase loading transformer
Output - 250A at 12V, 500A at 6V, 1000A at 3V

The connections for R phase, Y phase and B phase injection are shown in Fig 18 to 20.

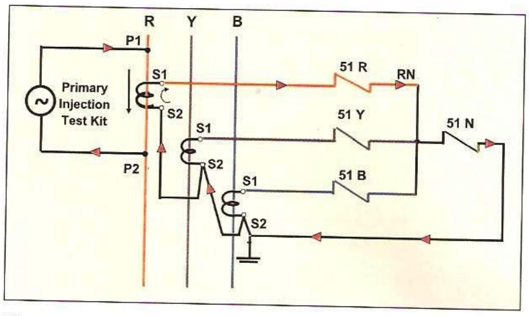

Fig 18 Primary Injection - R Phase

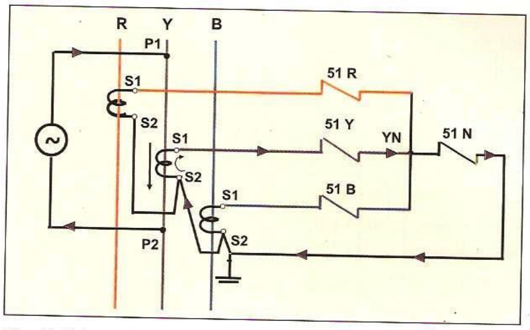

Fig 19 Primary Injection - Y Phase

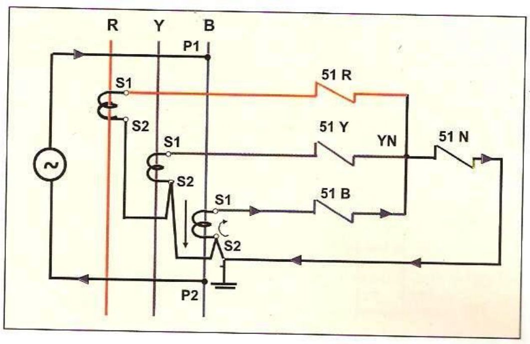

Fig 20 Primary Injection - B Phase

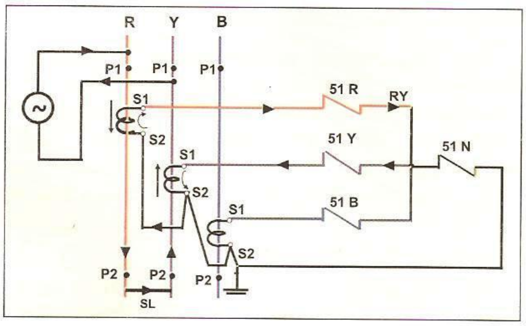

Fig 21 Primary Injection - RY

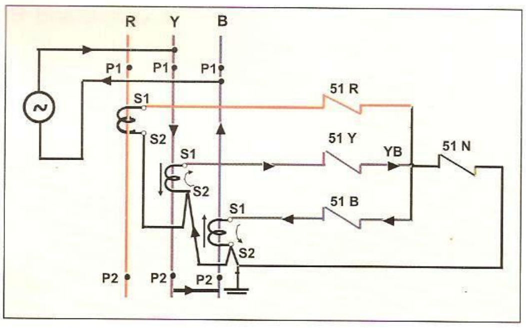

Fig 22 Primary Injection - YB

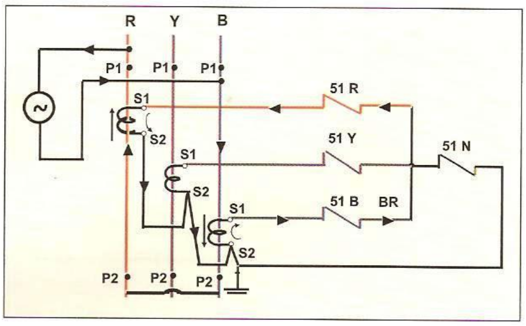

Fig 23 Primary Injection - BR

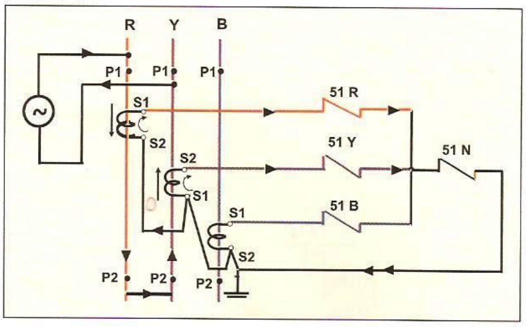

Fig 24 Wrong CT Polarity

The connections for phase to phase injection are shown in Fig 21 to 23. No abnormality is indicated if current distribution is as per Table V.

If there is wrong polarity in connection then there is neutral current during phase to phase current injection.

Assume polarity markings on Y phase CT are wrong. In Fig 24, current distribution for (R-Y) injection is shown. Current flows through 51R and 51Y and almost twice the current flows through 51N clearly indicating wrong polarity or connections.

Potential Transformer Testing

Potential Transformer Testing cover following tests:

- IR measurement - Insulation check
- Polarity check - Polarity marking
- Ratio check - Healthiness of winding check
- Secondary injection testing of metering and protection winding - Wiring check.
- Combined primary and secondary injection testing of metering and protection winding - Wiring check.

IR Measurement

Disconnect PT secondary circuit wiring. Disconnect PT primary and secondary neutral earthing. Connect the test setup as per Fig. 25 to 28 for various IR measurements. IR measurements to be done for

- Primary to earth
- Primary to Secondary
- Secondary to earth
- Winding to Winding

The procedure and acceptance criteria are same as that for a current transformer. Reconnect the

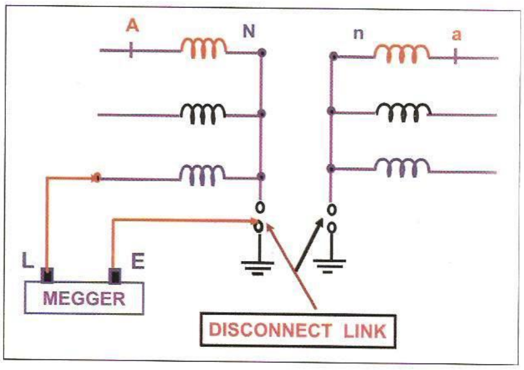

Fig 25 Primary to Earth

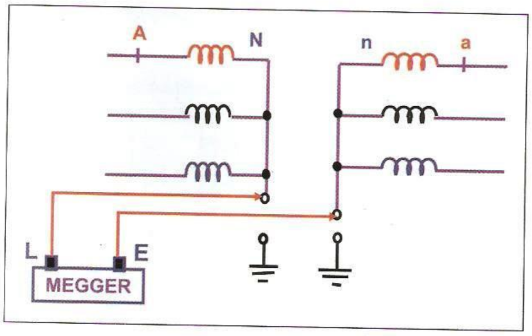

Fig 26 Primary to Secondary

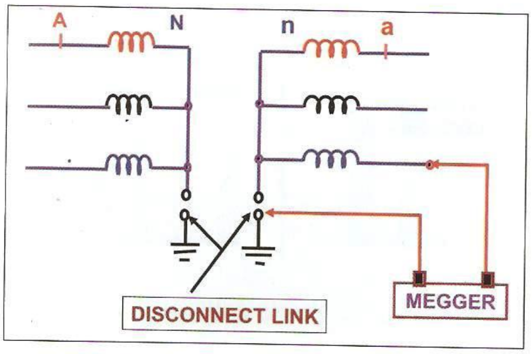

Fig 27 Secondary to Earth

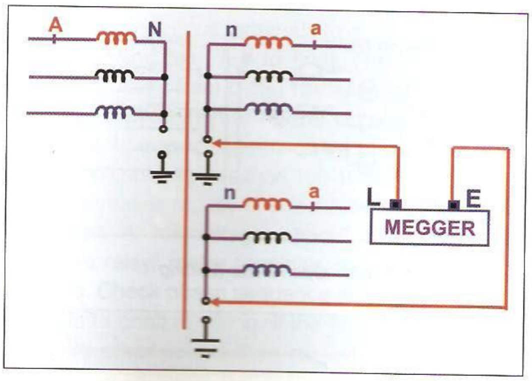

Fig 28 Winding to Winding

primary and secondary neutral earthing after all the IR measurements are done. Verify by meggaring that the value is zero.

Polarity Checks

Isolate PT from main bus and disconnect PT secondary circuit before testing. Connect the test setup as per Fig. 29. The procedure to be followed is same as that for a current transformer. The test is to be repeated for all phases and all windings except open delta winding.

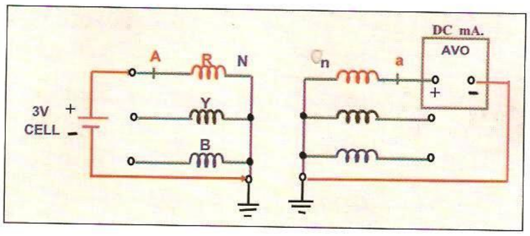

Fig 29 Polarity Check

Ratio Checks

Ratio check for star winding

Isolate PT primary from main bus and PT secondary circuit. Before starting the testing ensure primary and secondary earthing connections are firm. Arrange the test setup as per Fig. 30 A. Apply 3 phase, 415V gradually on PT primary side. Measure voltage at primary and secondary terminals. Check PT ratio vis a vis the PT specification.

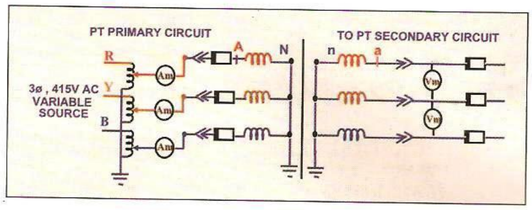

Fig 30 A. Ratio Check - Star Winding

Sometimes it is insisted to do ratio check at the rated voltage. To arrange three phase high voltage transformer is very difficult. For such cases, ratio check is done with single phase supply. High voltage low current set is used to derive high voltage from LT supply. (In CT primary injection test, low voltage high current set is used.) Assume ratio check is done on 11kV/√3/110/√3 PT. Following three methods are adopted for testing 3 phase PT. Refer Fig 30 B, 30 C and 30 D.

1 In Fig 30 B, 11kV voltage is applied across RY and then across YB. Corresponding RY and YB voltages are measured respectively on the secondary side.

2 In Fig 30 C, 11kV/√3 is applied across R-N, Y-N and B-N. Corresponding r-n, y-n and b-n voltages are measured respectively on the secondary side.

3 In Fig 30 D, all three phases are shorted on primary side and the three phases are shorted on secondary side. 11kV/√3 is applied on the primary side and the corresponding voltage is measured on the secondary side.

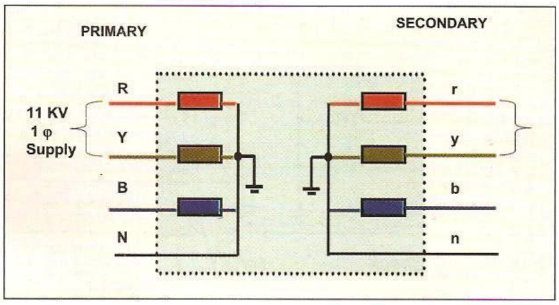

Fig 30 B. Ratio Check - Star Winding

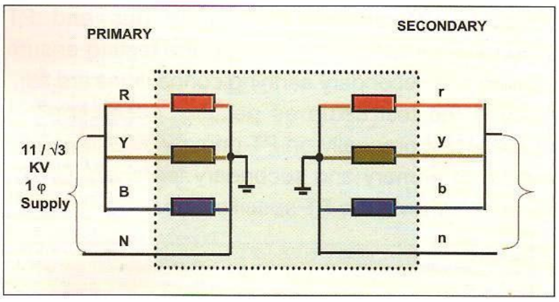

Fig 30 C Ratio Check - Star Winding

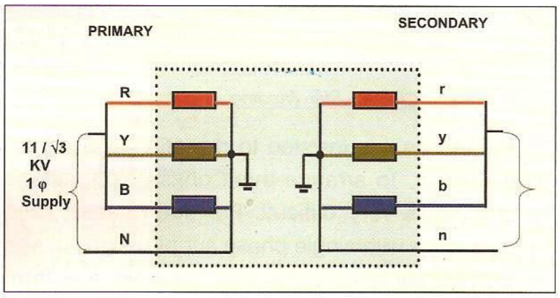

Fig 30 D Ratio Check - Star Winding

Of the above, methods (1) and (2) are the recommended methods. Method (3) is not recommended as it may lead to burning of winding due to flow of huge zero sequence current. The flux distribution is shown in Fig. 30E.

However if five (5) limb PT is used method (3) can also be used as the zero sequence can flow through the side limbs of five (5) limb PT. Refer Fig. 30F.

It is emphasized that ratio check need not be carried out at rated voltage.

Ratio Check for open delta winding

Isolate PT primary from main bus and PT secondary circuit. Before starting the test, ensure primary earthing connections are firm. Refer Fig. 31A, 31B, 31C for the test setup Apply 3 phase, 415V gradually on PT primary side. Measure open

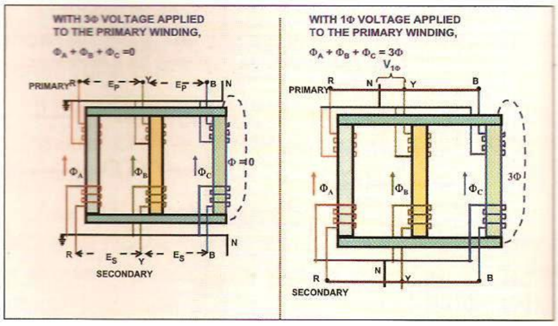

Fig 30 E. Flux Distribution

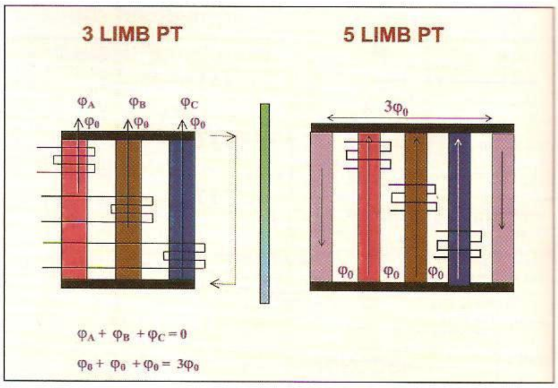

Fig 30 F Limb PT Vs. 5 Limb PT

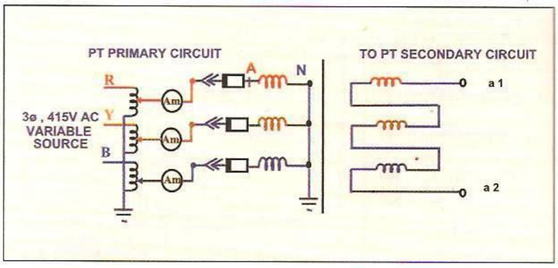

Fig 31 A Ratio Check - Open Delta Winding

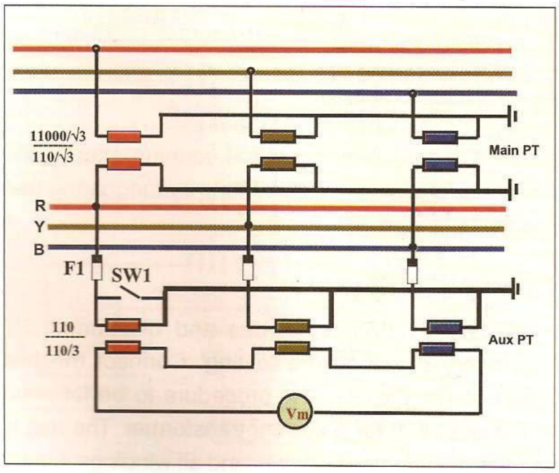

Fig 31 B Ratio Check - Open Delta Winding

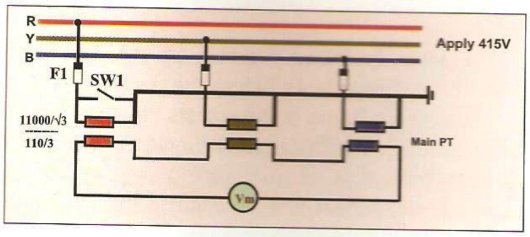

Fig 31 C Ratio Check - Open Delta Winding

delta voltage 'V'. It should be nearly zero. Remove fuse F1 on R phase and then short R phase primary winding (to simulate VR= 0). Apply 3 phase, 415V gradually on PT primary side and then measure open delta voltage 'V' again. It shall be as per PT ratio of open delta winding.

Eg. PT ratio 12kV/√3/120/3, then open delta voltage will be 4.15V for applied voltage of 415V on primary side.

Repeat the test for 'Y' and 'B' phase by removing the respective fuse and shorting the corresponding winding.

PT secondary injection check

This testing is done ensure correctness of secondary wiring. Connect the test setup as per Fig. 32. Isolate PT secondary winding at terminals from secondary circuit terminals to avoid PT primary winding getting live due to back charging. Apply voltage gradually from 0 to 110V. Monitor current of each phase while increasing the voltage. This shall be less than the specified ratings. At 110V, secondary current shall not be more than 100-150mA normally. If current increases rapidly check the secondary circuit for a short. At full voltage, check phase to phase voltage at relay/ meter terminals as per Schematic drawings. Check phase sequence at relay and meter terminals to confirm wiring. If the same PT supply is tapped to other panels then remove PT secondary circuit fuses of those particular panels. Check the voltage and phase sequence upto fuse incoming. Carry out PT secondary injection for other panels from fuse outgoing to check each panel PT circuit.

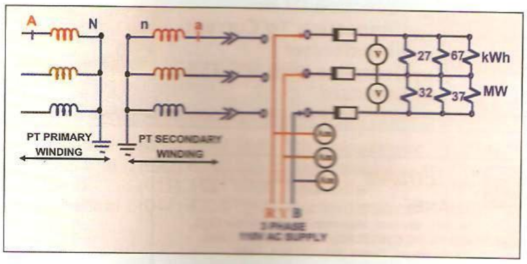

Fig 32 PT Secondary Injection

PT combined primary and secondary injection check

Restore connection of PT secondary circuit to PT secondary terminals and secondary and primary winding earthing. Isolate PT primary from main bus. Arrange the test set up as per Fig. 33. Apply 3phase, 415V supply to PT primary. Measure corresponding secondary voltage at meters/relay terminals and across open delta winding. Voltage shall be zero across open delta when 3 phase, 415V is applied at primary winding.

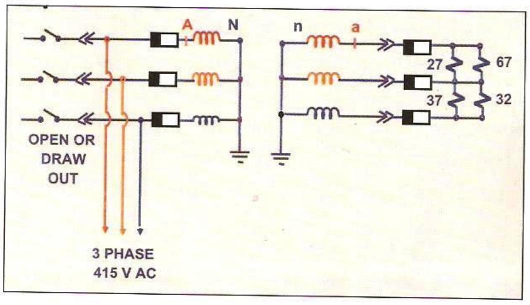

Fig 33 Combined Primary and Secondary Injection

General checks for Potential transformer

- Mechanical alignment for PT power jaws.
- PT primary winding star earthing
- Free movement of PT trolley.
- Tightness of all connections
- Primary/ Secondary fuse ratings
- PT specifications

Conclusion

Procedures for testing of instrument transformer and secondary wiring are presented. The field engineers are encouraged to use the material presented above for successfully commissioning the protection schemes at site.

Scrutineers comments and Authors Reply

Comment 1

Technical errors in the content (e.g. Knee Point Voltage for "P" class crores; Insulation Resistance Values Guidelines (i.e. KV + 1); VT Megger measurements are same as CT).

Reply

Since what is perceived to be correct and what is not correct are not spelt out, I can only guess and answer:

a) Knee Point Voltage for "P" class crores: In the article, under Excitation (saturation) characteristic check, in cl (2), following is stated:

"For a protection class CT,... The design value of KPV is given by,,".

For more clarity, 'The design value of KPV' will be replaced by "The minimum design value of KPV'.

(b) Insulation Resistance Values Guidelines (i.e. KV + 1): VT Megger measurements are same as CT.

This is the generally accepted value. Refer one of the most referred books 'Electrical power equipment maintenance and testing' by Paul Gill, pp 77. It is stated: "Rule of thumb - Minimum acceptable value of insulation to place equipment in service is 1 Megaohms per rated Kilovolts plus 1 Megaohms."

Comment 2

Tests related to maintenance during routine and breakdown maintenance are not addressed.

Reply

The tests described in article are carried out as precommissioning tests before the switch board is commissioned. Some of these tests are also carried out in case of suspected malfunctioning of protective relays. In this article we are confining to only electrical tests. Non-electrical tests are not covered in the present article.

To be precise, the third sentence under 'Introduction' will be changed from 'This article elaborates the tests..'

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Bina Mitra

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