Testing & Maintenance of Transformers.

Testing of Transformers :-

When the T/Fs are manufactured in the industry as per the particular design, testing is required to determine whether performance of T/F is as per the designed data or not.

We have to check the actual values & designed values variation is within permissible limit as per ISI.

If the variation in the results, such as efficiency, regulation, iron losses, copper losses, no-load current etc. are not within the permissible limit, the reason should be investigated and manufacturing process should be modified accordingly.

From the testing we can also determine the quality of workmanship, quality of material used etc.

Testing in all respect is required new design or modified design of T/F is used for manufacturing it, to check all results and assembled T/F condition.

Hence every T/F manufactured in industry is required to undergo certain tests.

The test to be conducted on T/F can be classified as follows :-

a) Routine Tests
b) Type Tests
c) Supplimentory tests
d) special tests.

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a) The routine test are those test which are conducted on each and every T/F manufactured in a industry. They are enlisted below:-

i) Polarity Test
ii) Phasing out test (for 3-ϕ T/F)
iii) Voltage Ratio
iv) D.C. resistance
v) Magnetising current and core loss
vi) Measurement of impedance voltage, short ckt impedance and copper loss.
vii) Measurement of insulation resistance.
viii) H.V. Test

b) Type test are those test which are carried out on only few pieces, manufactured in a lot of same design. It means that when 100 T/Fs are manufatured of same design then, type test will be conducted only for 1 or 2 transformers out of 100. They are as follows:

i) Temperature rise Test.
ii) Impulse test.
In addition iii, iv, v, vii, viii test from the routine test.

c) Supplementory test are those test which are conducted on T/F when additional information is required in respect of particular T/F, either by manufacturer or purchaser. These are as follows:
i) Efficiency Test ii) Back to Back Test.

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d) Special tests are the tests required to be performed on T/F used for specific purpose only. These test are conducted only when the result of such tests are demanded by purchaser. They can be classified as follows:

i) Test to determine the noise level of T/F.
ii) Measurement of harmonics present in T/F emfs.
iii) Measurement of zero phase sequence impedance of three phase T/F.

1) Measurement of winding Resistance :-

a) (Voltmeter - Ammeter Method)

- This test aims to determine the difference in the designed value of resistance & actual value of resistance at a fixed value of temp. and to check the change in values is within permissible limit or not.
- The meaning of DC resistance is that resistance measured between two terminals of T/F wdg when DC current is made to flow through it. Its value will change if A.C. is applied across its terminals due to skin effect.

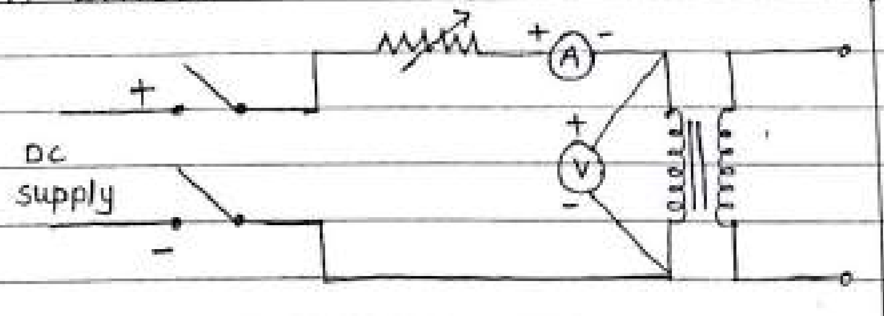


Fig- Measurement of DC Resistance.

- The simplest method of measuring DC resistance by using voltmeter, Ammeter which gives better result for moderate and high values of resistances.
- Very accurate result can be obtained in case of low resistances using wheatstone bridge or kelvin bridge method.

$$\text{Resistance}, \; R = \frac{V}{I}$$

- In same cases, test temp. will not be same at which resi value is determined during design. Hence same is required to be converted to the desired temperature value.

- In case of copper conductors it can be determined using the following relation.

$$R_{t_2} = R_{t_1} \frac{234.5 + t_2^\circ C}{234.5 + t_1^\circ C}$$

where,

R_{t_2} - resistance at $t_2^\circ C$

R_{t_1} - resistance at $t_1^\circ C$

t_2 - Temperature at which resi is required.

t_1 - Temp at the time of testing

$R_t = R_0(1+\alpha_0 t)$

$$\frac{R_2}{R_1} = \frac{1+\alpha_0 t_2}{1+\alpha_0 t_1}$$

For Cu

$$\alpha_0 = \frac{1}{234.5}$$

$$\frac{R_2}{R_1} = \frac{1+\frac{t_2}{234.5}}{1+\frac{t_1}{234.5}}$$

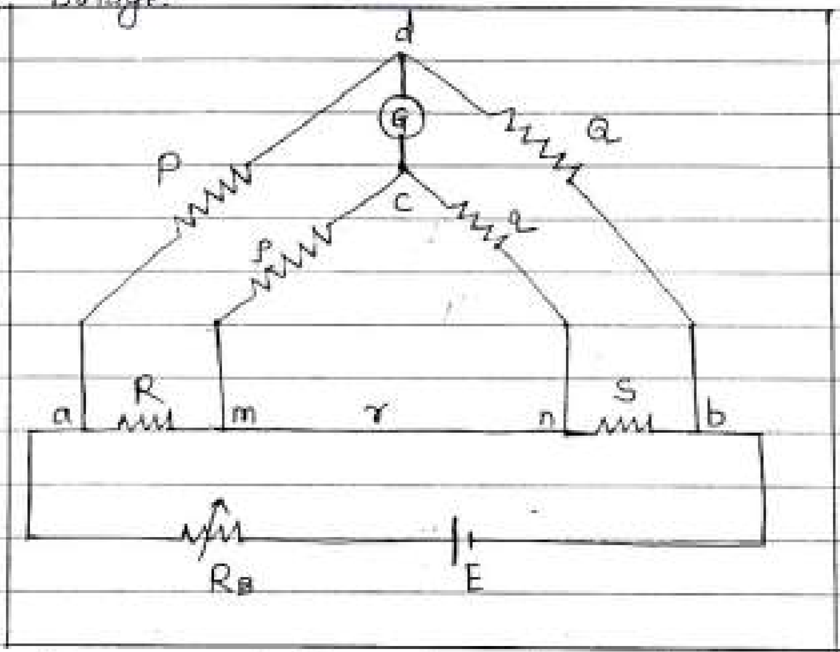
$$\frac{R_2}{R_1} = \frac{\frac{234.5+t_2}{234.5}}{\frac{234.5+t_1}{234.5}}$$

$$\frac{R_2}{R_1} = \frac{234.5+t_2}{234.5+t_1}$$

$$\therefore R_2 = R_1\left(\frac{234.5+t_2}{234.5+t_1}\right)$$

b) Using Kelvin Double Bridge:-

- Very low resi. is measured accurately with kelvin double bridge.



- The ratio arm P & Q at outer side & ratio arm p & q at inner side. Galvanometer G ar is connected betⁿ the points c and d.
- In above ckt r is lead resistance & R is unknown resistance.
- When two ratio arms P & Q , p & q are becomes equal. Under balance condition there is nol current in galvanometer. Means vtg drop betⁿ a and d is equal to voltage drop betⁿ 'amc'.

If $\frac{P}{Q} = \frac{p}{q}$ $\quad \because R = \frac{P}{Q} \cdot S + \frac{rq}{p+q+r}\left[\frac{P}{Q} - \frac{p}{q}\right]$

$$R = \frac{P}{Q} \cdot S$$

- This is used to measure low resi. i.e. 0 to 1 Ω

c) Medium Resistance :-

- Medium resi. values can be very accurately measured with the help of wheatstone bridge.

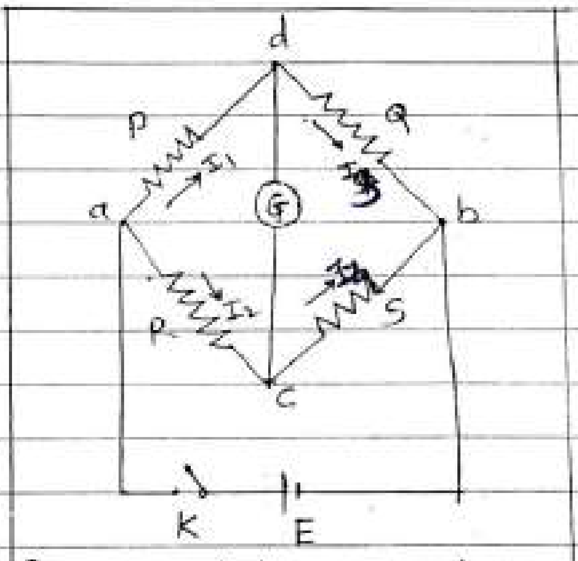


Fig. Wheatstone bridge.

- It has four resistive arms, together with vtg source & a galvanometer. The current through the galvanometer is depends on potential diff. betn points c & d.
- At balance condition, current in the galvanometer is zero.

$$I_1 P = I_2 R \quad \text{—(i)}$$

$$I_1 = I_3 = \frac{E}{P+Q} \quad \text{—(ii)}$$

$$I_2 = I_4 = \frac{E}{R+S} \quad \text{—(iii)}$$

combining (i), (ii) & (iii), $\frac{P}{P+Q} = \frac{R}{R+S}$

$$\boxed{R = \frac{P}{Q} \cdot S}$$

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*2) Test for determination of Magnetising current and core losses :- [Measurement of no load loss & magnetising current]

- In this test, generally LV wdg is connected to its rated voltage at rated frequency.
- As high voltage may not be available in the laboratory for testing purpose, this test can be carried out on transformers complete with wdg and fitted in tank with oil.
- For normal or low flux densities the reading of wattmeter will represent:
  i) core losses of the T/F
  ii) LV copper loss at no load which is negligible.
  iii) Dielectric loss very low for low voltages as it depends upon voltage.

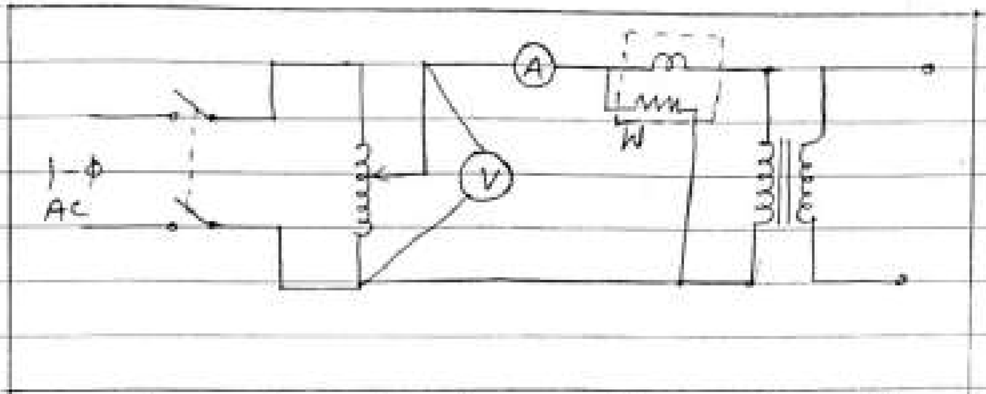
- Neglecting other losses which are very small, the wattmeter reading represent core losses.

- If W_0 - wattmeter reading on no load
  I_0 - Ammeter reading
  V_0 - Rated vtg applied in o.c. test
  $\frac{W_0}{V_0} = I_W$, no load component of current supplying core losses.

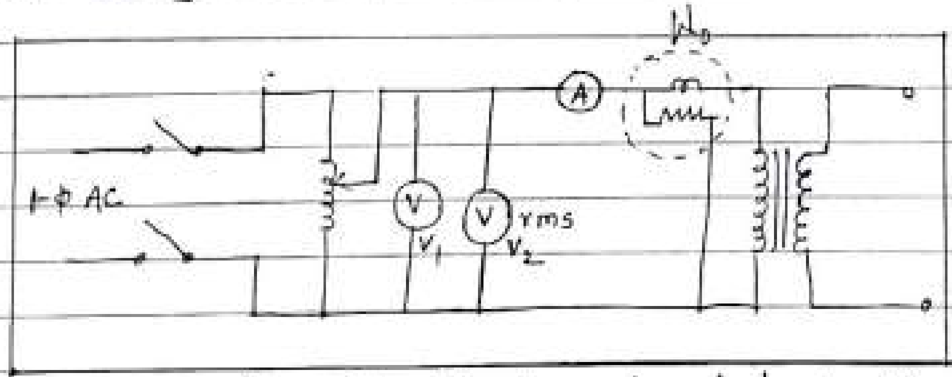
  $\sqrt{(I_0^2 - I_W^2)} = I_\mu$ - magnetising component of current which set up desired flux in the T/F core.

- When higher values of flux density are used the saturation effect may cause harmonic emf.

- The eddy current loss which is a function of waveform of flux density depending upon induced emf.



- The reading of wattmeter used in above fig will not give correct value of core loss under this condition.
- For obtaining more accurate reading of core losses under such a condition, a rectifier type voltmeter measuring avg value of vtg, ~~but~~ & its dial records rms value & another voltmeter measuring & records directly rms ~~voltage are connected.~~ value.



- If W_0 - reading of wattmeter at rated vtg V_2
  V_1 - reading of rectifier type voltmeter.
  V_2 - rms vtg recording voltmeter.

Then corrected core loss can be calculated as

$$W_c = \frac{W_o}{P_1 + KP_2}$$

where,

W_c - corrected value of core loss

W_o - wattmeter reading at rated rms vtg.

$$K = \left(\frac{V_2}{V_1}\right)^2$$

- P_1 & P_2 are const. whose value for flux density used in the T/F are as follows:

$$P_1 = \frac{\text{Hysteresis loss}}{\text{Total Iron loss}}$$

$$P_2 = \frac{\text{Eddy current loss}}{\text{Total Iron loss}}$$

$P_1 = 0.5$ & $P_2 = 0.5$ for oriented steel laminations.

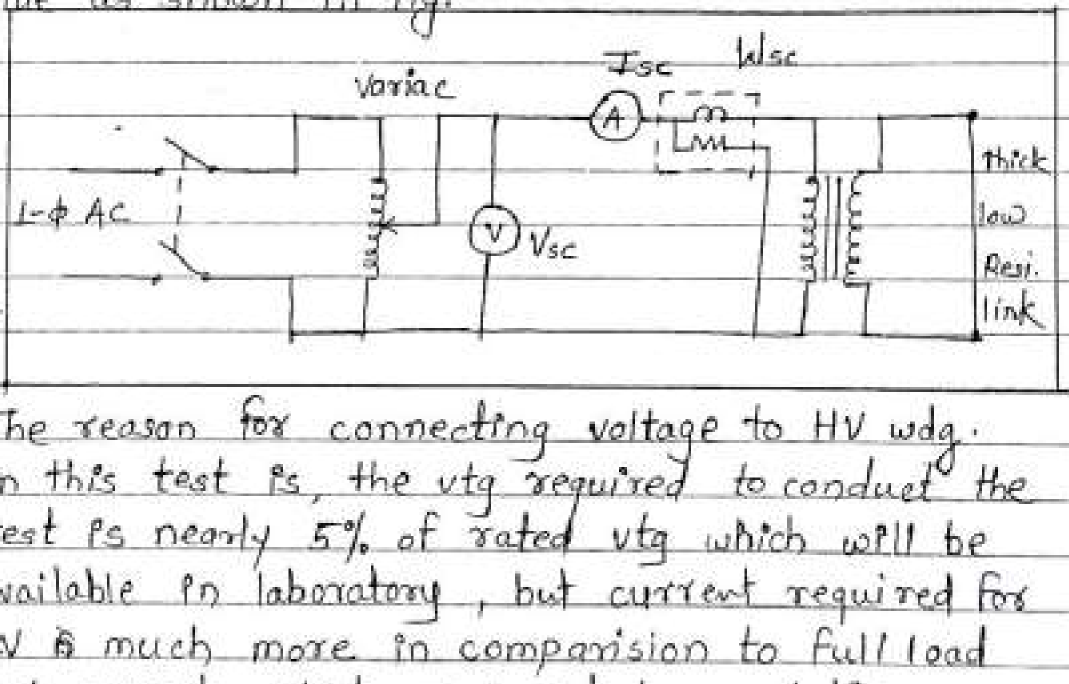
$P_1 = 0.7$ & $P_2 = 0.3$ for non-oriented steel laminations.

- The aim of the test is to determine the percentage variation of magnetising current, no load current & core loss from designed values. Also to check these values are within the specified limit or not.

* 3) Impedance and Copper losses (load losses) :-

- In this test, equivalent impedance, equivalent resistance & equivalent reactance of the T/F refered to measuring side can be determined. At the same time if full load current is circulated through the T/F wdg, full load copper loss can also be determined.

- In this test, transformer H.V. wdg is (generally) connected to variable vtg source & L.V. is short circuited by thick low resi. wire, a wattmeter, voltmeter, ammeter being connected on H.V. side as shown in fig.



- The reason for connecting voltage to HV wdg. in this test is, the vtg required to conduct the test is nearly 5% of rated vtg which will be available in laboratory, but current required for LV is much more in comparision to full load H.V. current which may not be available or may cause disturbance to distribution system at the time of testing
- Generally current flowing through H.V. wdg is adjusted to its full load value

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- At this time the reading of wattmeter indicate indicates full load copper loss. Iron losses being negligible.
- The vtg applied under this condition say Vsc is called as impedance voltage or impedance voltage drop as this voltage is utilised in a drop across the impedance of T/F wdg & no vtg is available across the short circuited L.V. winding.

- If I_{sc} = full load current of H.V. wdg, W_{sc} is full load copper loss at test temp. & V_{sc} represent impedance voltage at test temperature.

W_c at 75°C (full load Cu loss at 75°C)

$$= W_{sc} \times \frac{234.5 + 75}{234.5 + \text{Test temp in } ^\circ C}$$

Equivalent impedance at test temperature say

$$Z_1 = \frac{V_{sc}}{I_{sc}}$$

Equivalent resistance at test temperature say R_1,

$$R_1 = \frac{W_{sc}}{I_{sc}^2}$$

Equivalent Reactance say X_1,

$$X_1 = \sqrt{Z_1^2 - R_1^2}$$

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- This test is mainly performed to determine how much variation is there in designed value of copper losses, impedance voltage & whether it is within the permissible limits as specified by ISS (Indian standard specifications)
- The test result can be used to determine the efficiency of T/F by loss summation method and regulation calculation.

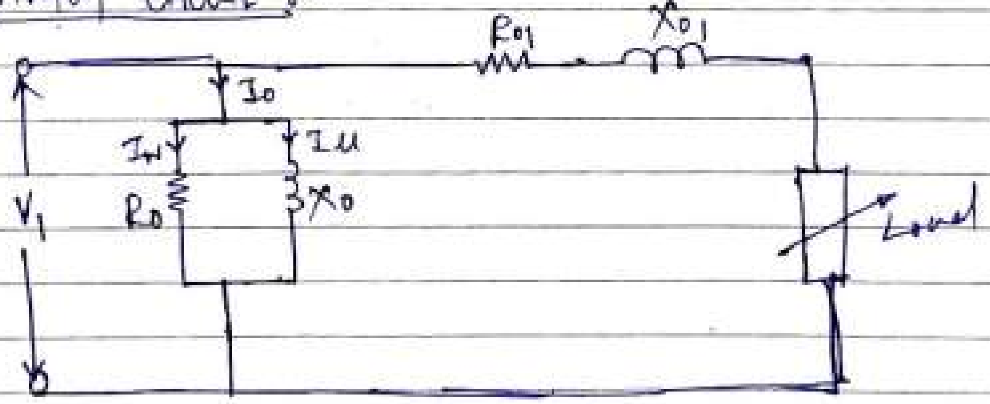
Determination of regulation :-

$$\%\ \text{Voltage Regulation} = \frac{I_1 [R_{01} \cos\phi \pm X_{01} \sin\phi]}{V_1} \times 100$$

Where, $I_1 = I_{sc}$ = full load primary current
V_1 = Primary rated voltage

$$\%\ \text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{iron loss} + \text{Cu loss}}$$

Equivalent Circuit :-



* 4) Insulation Resistance Test :-

- Insulation resistance depends upon the winding temp. Its value reduces by 50% if the winding temp. increased by 10 to 15°c.
- The value of insulation resi. is measured for determining moisture absorbed by the windings, insufficient insulation betn windings or effect of atmospheric pollution on windings etc.
- There is no any hard and fast rule giving insulation resistance values for T/F winding but a generalised rule may be followed as 2MΩ (Two Mega ohm) per KV.
- Insulation resi. test is carried out with meggers of suitable voltage rating as specified in table. The test should be immediately conducted after the heat run test on T/F.
- The insulation resistance is measured between T/F wdg and core, betn T/F wdgs.
- During the test handle of the megger should be moved at a const speed otherwise it will gives misleading results.
- In case of high vtg and KVA rating T/F a motor driven megger is used to obtain correct results. A high value of insulation resistance does not mean high value of dielectric strength. For eg. if there is a small air gap in betn windings it will show high insulation resistance but will puncture when few kilovolts are applied across the wdgs.
- Insulation which has wrinkles or damaged mechanically will show high insulation resistance but will fail at a very vtg applied across it.

voltage of wdg	Minimum Insulation Resi. in Mega-ohms	Voltage of Megger
400 V	2	500 V
11 KV	50	1000 V
33 KV	150	2500 V
132 KV	500	2500 V.

* 5> High voltage Tests :-

- Insulation resistance measured by megger does not give clear idea about strength of insulation, i.e. it will whether withstand the high vtges because of switching surges or not. for determining this, high vtg tests are conducted on the T/F.
- High vtg tests can be conducted in the following ways i> Power freq. High vtg test
ii> Induced overvoltage withstand test.

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*Induced overvoltage withstand test :-

- The aim of this test the insulation between turns, insulation betn coils & terminals.
- In this, test, a voltage equal to twice the rated voltage of any one winding i.e. either H.V. or L.V. is applied. It will cause high voltage to be induced in the other winding.
- To avoid the excessive magnetising or no-load current, the vtg is applied from a seperate alternator so that freq. of test voltage can be adjusted to twice the normal freq.
- The test is carried out in a similar manner as above means the voltage applied to start is not more than $1/3^{rd}$ test value then it is brought to the value; maintained for 60 seconds for test frequencies upto twice the normal then reduced to less than $1/3^{rd}$ test value before switching off.
- If the test freq. is other than, upto twice the normal frequency the duration of test is given by the following relation,

$$\text{Duration of test in sec.} = 60 \times \frac{\text{twice the rated Freq.}}{\text{Test freq.}}$$

- For induced type T/F, test vtg is equal to twice the highest system vtg + 1000 volt; subjected to a minimum of 2000 volt.

e.g. In case of 11 KV T/F, highest system vtg is 12 KV therefore test vtg will be $12 \times 2 + 1 = 25$ KV. This test is also called flash test.

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* Separate Source Voltage Withstand Test (Power freq^n):-

- This test is made with the help of 1 ϕ AC vtg of sinusoidal waveforms as far as possible & at a freq^n not less than 80% of rated freq^n.
- The test is started at a vtg. not greater than 1/3rd of test vtg. & is rapidly increased to test vtg value.
- The full test vtg is applied for 60 sec. bet^n winding under test & all terminals of remaining winding, core, frame & tank of T/F connected together to earth.
- At the end of test, the vtg is rapidly reduced to less than 1/3rd of test vtg. & they supply is switched off.
- The peak value of vtg. is measured with the help of digital peak voltmeter associated with capacitive vtg. divider. The test vtg is then $\frac{\text{Peak value}}{\sqrt{2}}$. The test vtg that should be applied is obtained from previous table.

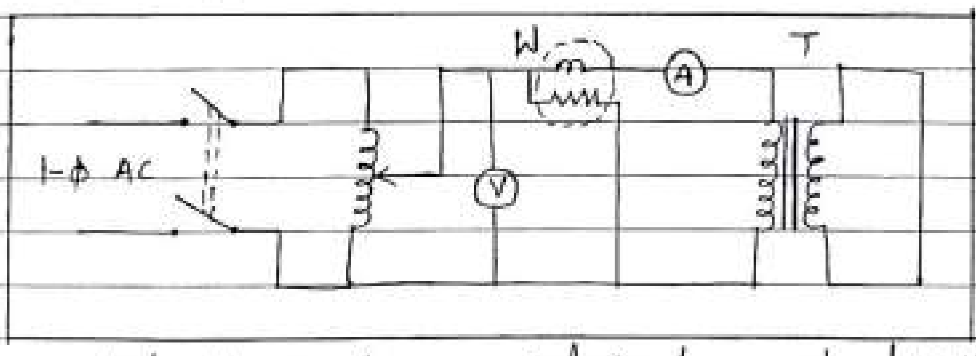
* Type Test :-

Temperature rise Test :-

- The aim of the test is to measure the rise in temp when the transformer will be its full load & to see whether rise in temperature is as per designed value or not; whether it is within permissible limit or not. If found that the temp rise is much more as compared to designed value, the reasons for this temp rise should be determined & necessary modifications should be done to obtain the correct result.

1) Short circuit Test :-

- This test is carried out on power freq. T/Fs.
- In this test short circuit vtg is adjusted in such a way that wattmeter will record the total losses of T/F on full load i.e. No-load losses excluding small no-load Cu loss & full load copper losses including stray load losses etc.



- The applied vtg is then maintained const. till the steady state temp. condition is reached; which will recorded by const. reading of thermometer used for recording oil or core temp. or in case of the high capacity power T/f thermometer used for recording winding temperatures. The supply is then switched off.

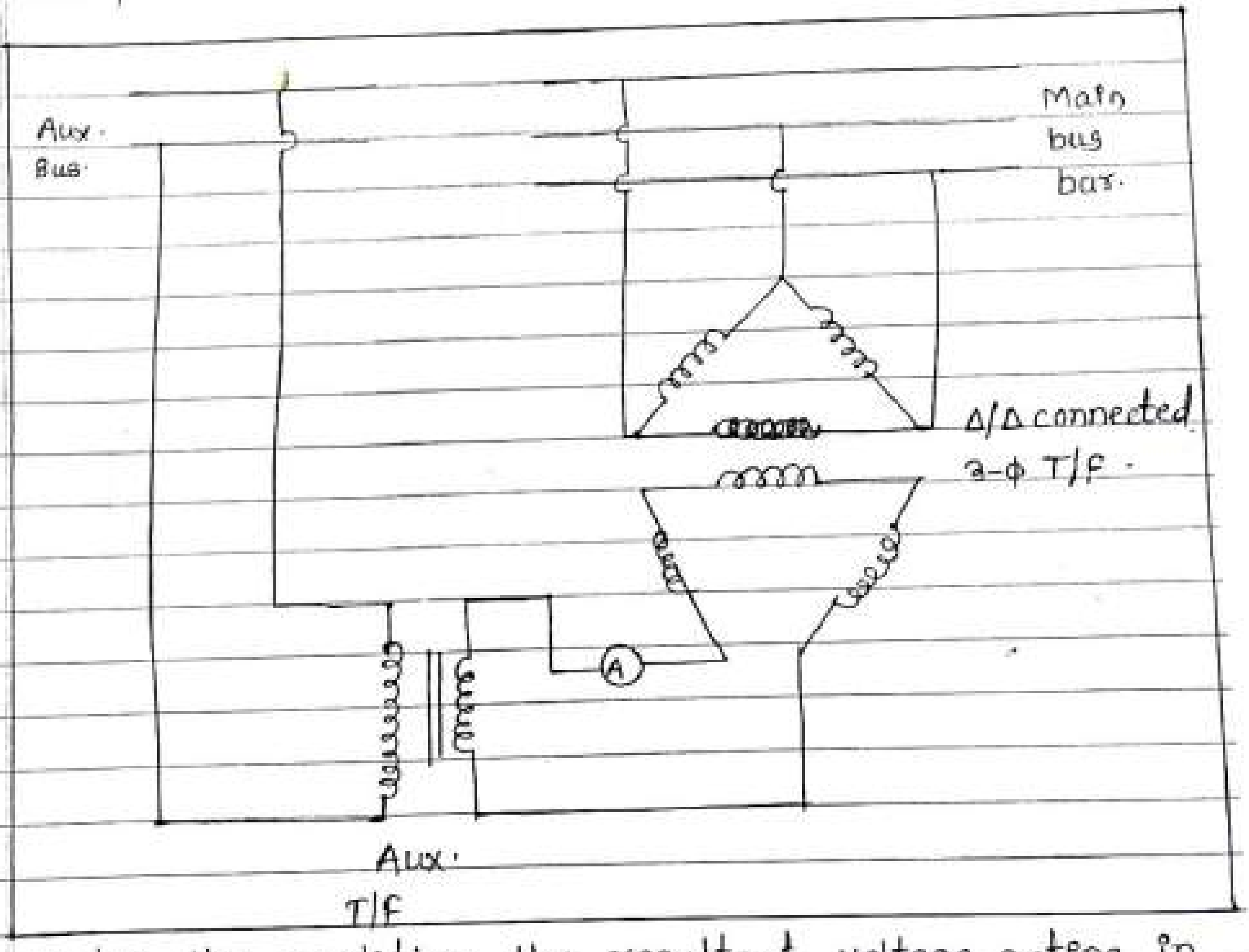
- The wdg resi is measured accurately at once. then initial value of resistance & final value of resistance the rise in temp. can be calculated,

$$\boxed{R_{t_2} = R_{t_1} \times \frac{234.5 + t_2}{234.5 + t_1}}$$

t_1 — ambient temp.
t_2 — final temp of wdg.
R_{t_2} — resi at t_2°C
R_{t_1} — resi at t_1°C.

ii) Open Delta Method :-

- This method is applicable in case of a Delta/Delta connected transformers. When a balanced three phase vtg is applied to the prim. winding of a Delta/Delta connected ~~secondary~~ T/F.



- Under this condition the resultant voltage acting in the closed delta is zero, Hence no circulating current will flow in the circuit.
- To make the current to circulate in secondary as well as primary above circuit diagram is shown.
- A small vtg is introduced in the secondary by connecting secondary of Aux. T/F in series as shown in fig.

- The vtg applied to the prim. of Aux T/F is adjusted in such a way that full load current circulates through three phase T/F secondary as recorded by ammeter A.
- It well cause full load current to circulate through T/F primary also. Hence full load working condition is developed i.e. iron losses at normal flux density drawn from mains & full load copper losses drawn from aux. bus.
- This condition is maintained till final steady state temp. is developed. The temp. rise can be determined by similar manner by resistance measurement test.