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Design & Analysis of 11 KV Distribution Transformer

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Abstract :

This research paper heed with the blueprint of Distribution Transformer utilizing with technical programming dialect name scientific laboratory. In this, user has to input given value and get accurate output in seconds of time. Paper gives overview on significant constituent of Transformer. Transformer is most essential component in power system engineering which regulates the voltage at constant frequency and power. This paper helps design employee, inflation manufacturer production and its growth. In short, it contributes effective benefit to society.

Keywords – **Transformer, Step-down, Design, Computer program equation**

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I. INTRODUCTION

Transformer is a staticpieceofelectricalapparatuswhichconvertselectricalpowerf romonecircuittoother circuit at same frequency.It can increase or decrease the voltage with corresponding decrease or increase in current keeping the power same.This transformation of energy is done due to the Faraday'slaws of Electromagnetic induction. Transformer is an important link in power system between generating station and transmission substation, between transmission sub transmission and sub transmission substation, between sub transmission substation and primary distribution substation, finally between primary distribution and the consumers.Transformers are ordered, designed (as per I.S. 2026 & I.S. 1180), manufactured, tested, transported, installed, commissioned, operated &maintained. This static device has highest efficiency as it has no rotating parts. They operate only with alternating current.According to the principle of transformer operation, it doesn't work on a DC supply since the rate of change of flux is zero. Michael Faraday built the first transformer in 1831 with single solid iron core device. He used it only to demonstrate the principle of electromagnetic
induction and did not foresee its practical uses. First single phase transformer 15 kVA 1500/300 V made by Ganz Budapest in 1883. He first used the term TRANSFORMER.

Russian engineer Mikhail Dolivo in 1889 developed the first three - phase transformer. In the year 1906, in India first timeoil immersed transformer used by hydro power plant situated at Darjeeling.

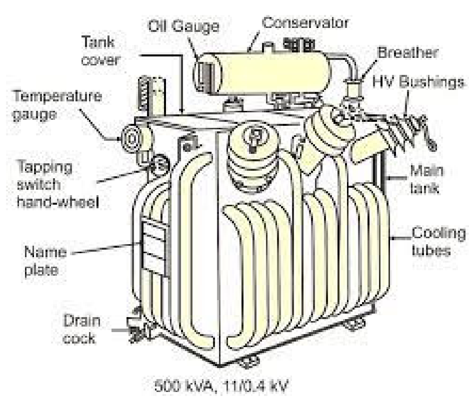

Fig. 1. Transformer overview with parts

Schematic sounds the side view of distribution transformer with all its parts II.

II. CONSTRUCTION

There is rectangular shape which is core of transformer built up of silicon steel. At rectangular length two windings are wound of copper material namely primary and secondary. Primary winding is connected to AC source and load is connected at secondary side.

A. The alternating current through the primary winding produces a continuously changing and alternating flux that surrounds the winding. As both windings are placed on same core, some portion of this alternating flux will link with the secondary winding. As this flux is continually changing in its amplitude and direction, there must be a changing flux linkage in the secondary winding.According to Faraday's law of electromagnetic induction, there will be an EMF induced in the secondary winding. If the circuit of this secondary winding is closed, then a current will flow through it.

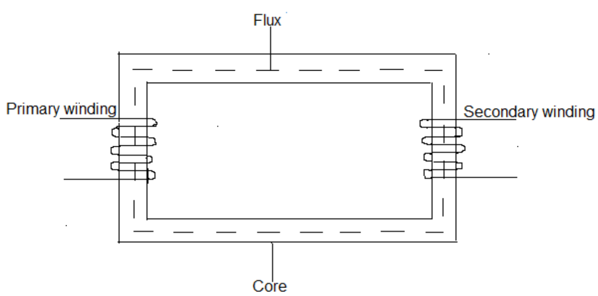

Fig. 2. Transformer construction

The EMF (E_1) is called as primary EMF and the EMF (E_2) is known as secondary EMF and being given by-

$$E_1 = -N_1 (d\phi_m/dt) V - Unit \qquad (1)$$

where, E_1 = emf induced in primary winding, N_1 = number of turns at primary side, $d\phi_m/dt$ = rate of change in flux wrt. time

$$E_2 = -N_2 (d\phi_m/dt) \quad (2)$$

where, E_2 = emf induced in secondary winding, N_2 = number of turns at secondary side

$$E_2/E_1 = N_2/N_1 \quad (3)$$

If $N_2 > N_1$, then $E_2 > E_1$, thus the transformer will be a step-up transformer and if $N_2 < N_1$, then $E_2 < E_1$, thus the transformer will be a step-down transformer.

III. DESIGN CONSTITUENT

B. Winding
C. Core
D. Resistance
E. Leakage reactance
F. Cooling

Schedule confession is given for all constituent.

Design dilemma: Rating- 25 kVA, Primary voltage- 11000 V, Secondary voltage- 433 V, Frequency- 50 Hz, 3 Phase, Connection- Delta/Star, Transformer type- Core as well as Distribution transformer, Cooling- natural oil cooled, Tapping- ±5%.

B. Winding

Low Voltage - The low-voltage winding has fewer turns of thicker, insulated wire around the core. This thicker winding is designed to handle higher currents. However, the insulation on this winding does not have to withstand the same high stress as the high-voltage winding.

Low voltage windings are -

1. Cylindrical Winding
2. Helical Winding
3. Double- Helical Winding
4. Disc Winding

In this dilemma helical winding is used. Because as per standards, it has voltage range between 400 V - 11000 V. Helical winding has also sub division (a) single helical (b) double helical and (c) multi-layer helical.

In double helical winding parallel conductors are distributed in two lateral circuits and are situated in two layers shifted in axial direction. This winding is used because it reduces eddy current loss. This is on account of reduced number of parallel conductors situated in radial direction. In short, number of conductors is directly half then single helical winding. Ratings are same for single and double helical winding but the difference is current is twice in double helical winding.

Equation used in technical code for L.V. winding.

$E_t = k\sqrt{Q}\ V$ – Unit(1)
where, E_t = voltage per turn, k = 0.45, Q = kVA rating

$T_s = [V_s/\sqrt{3}] / E_t$ (2)
where, T_s = number of turns per phase, V_s= secondary voltage

$I_s = Q \times 10^3 / [V_s/\sqrt{3}]$ A – Unit (3)
where, I_s = secondary phase current

$a_s = I_s / \S_s$ A/mm^2 – Unit (4)
where, a_s = cross sectional area, $\S_s$ = current density as 2.3

$L_{cs} = T_s \times$ condt. width mm – Unit (5)
where, L_{cs} = winding axial depth, IS 1897-1962 is use for conductor (condt.) width

$b_s = lay \times y1 + 2 \times cly$ mm – Unit (6)
where, b_s = winding radial depth, lay = number of layer as 3, y1 = modified dimension as 2.2, cly = 0.5 as cylinder thickness

$Id = dc + 2 \times lvi$ mm – Unit (7)
where, Id = inside diameter of winding, lvi = 1.5 as insulation between lv winding and core

$Od = Id + bs$ mm – Unit(8)
where, od = outside diameter of winding

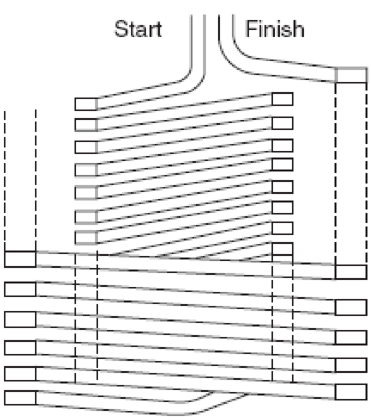

Fig. 3.Helical Winding

(b) High Voltage - The high-voltage winding is made up of many turns of relatively thin, insulated wire wound around the core. This winding is thinner than the low-voltage winding because it is designed to handle lower currents. The insulation on this winding must be able to withstand the stress of the higher voltage applied across it.

High voltage windings are –

1. Multilayer Cylindrical Winding
2. Multilayer Helical Winding
3. Crossover Winding
4. Foil Winding
5. CTC Winding

In this dilemma crossover winding is used at H.V.side. Because as per standards, it has kVA rating up to 1000, voltage range up to 33 kV, current not exceed 20 A.

This winding is divided into a number of coils in order to reduce the voltage between adjacent layers. These winding coils are axially separated by a distance of 0.5 to 1 mm with the help of washers. Voltage should not be greater than 1000 V. Complete winding consist of a number of coils connected in series. Two ends of each coil are brought out, one from inside and other from outside. This winding can be used in the same rating of cylindrical winding.

Equation used in technical code for H.V. winding.

$T_p = V_p/E_t$ (1)
where, T_p = number of turns per phase, V_p = primary voltage

$T_{p\,(new)} = 1.05 \times T_p$(2)
where, $T_{p\,(new)}$ = turn per phase when tapping is there

$I_p = Q \times 10^3 / [3 \times V_p]$ (3)
where, I_p = primary phase current

$a_p = I_p/\S_p$ A/mm^2 – Unit (4)
where, a_p = cross sectional area of primary conductor, $\S_p$ = current density in primary conductor

$d_p = \sqrt{(4 \times a_p)/\pi}$ mm – Unit (5)
where, d_p = diameter of primary conductor

$a_{p1} = (\pi \times d_{p1} \times d_{p2})/4$ mm– Unit (6)
where, a_{p1} = modified area of primary conductor, d_{p1} = std. value of diameter as 0.64, d_{p2} = std. value of insulation as 0.805

$A_d = Tncl \times d_{p2}$ mm – Unit (7)
where, A_d = axial depth of the coil, Tncl = turns per layer as 28

$$A_l = (N_c \times A_d) + (N_c \times S) \quad mm - Unit \quad (8)$$

where, A_l = axial length of the coil, N_c = Total number of coil as 8, S = space between adjacent coil as 5

$$C = (H_w \times 10^3 - A_l)/2 \quad mm - Unit(9)$$

where, C = clearance, H_w = window height as 0.3

$$R_d = (Ncl \times d_{p2}) + (Ncl - 1) \times T_i \quad mm - Unit(10)$$

where, R_d = radial depth of the coil, Ncl = number of layers as 24, T_i = insulation thickness between layers as 0.3

$$T = 5 + (0.9 \times V_p)/10^3 \quad mm - Unit \ (11)$$

where, T = insulation thickness between lv and hv winding

$$IDhv = Od + 2 \times Tmm - Unit \quad (12)$$

where, IDhv = inside diameter of hv winding

$$ODhv = IDhv + 2 \times R_d mm - Unit \quad (13)$$

where, ODhv = outside diameter of hv winding

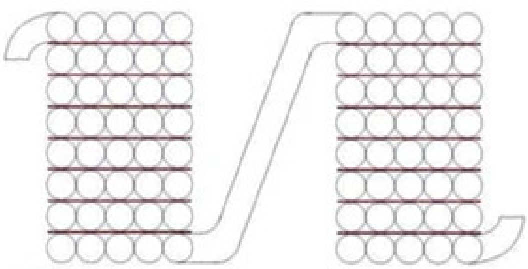

Fig. 4.Cross over Winding

Table 1: Selection of proper winding according to rating

Types of winding	Rating kVA	Voltage kV	Conductor current A	Conductor cross section mm^2
Cylindrical (circular conductor)	5000-10000 kVA	Up to 33 kV	Up to80 A	Up to30 mm^2
Cylindrical (rectangular conductor)	5000-8000 kVa	Up to6 kv	Between10-600 A	Between5-200 mm^2
Cross Over	Up to 1000 kVA	Up to33 kV	Up to40 A	Up to15 A
Helical	160-10000 kVA	Up to15 kV	Above 300 A	Above 100

C. *Core*

1. Square Core
2. Cruciform Core
3. 3- Stepped Core
4. 4- Stepped Core

In this dilemma cruciform core is used. Because it reduces circumscribing circle diameter, lesser diameter requires lesser insulation material. Addition to this length of turn is also reduced so valuation of copper is directly reduced.

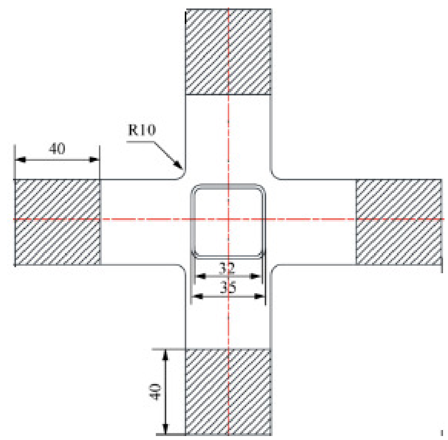

Fig. 5.Cruciform Core

Transformer core is made up of Cold Rolled Grain Oriented (CRGO) silicon steel. Cruciform core is used when circular coils are required for high voltage transformers. This core utilizes better space. Two different sizes of laminations are used in cruciform cores. As assembly of this core is complex labour cost increases directly. Lamination on core reduces eddy current loss. According to maintain mechanical strength thickness of lamination sheet must be that 0.3 mm.

Equation used in technical code for transformer core.

$$PHIm = E_t / (4.44 \times f) \quad Wb - Unit \ (14)$$

where, PHIm = flux in the core

$$A_i = PHIm / B_m \ m^2 - Unit(15)$$

where, A_i = net iron area, B_m = 1 as flux density

$$Ag_i = A_i / K_i \ m^2 - Unit \quad (16)$$

where, Ag_i = gross iron area, K_i = 0.9 as stacking factor

$$d = \sqrt{(A_i / ct)} \quad m - Unit \quad (17)$$

where, d = core diameter, ct = 0.56 as core type

$$K_w = 8 / (30+V_p) \quad (18)$$

where, K_w = window space factor

$$Ww = \sqrt{(Aw/ratio1)} \quad m - Unit \quad (19)$$

where,W_w = window width, ratio1 = 2.5 as height to width ratio

$$H_w = ratio1 \times W_w \quad m - Unit \quad (20)$$

where, Hw = window height

$$D = W_w + d \quad m - Unit \quad (21)$$

where, D = distance between adjacent core

D. *Resistance*

According to IS standards resistivity of material for hv winding and lv winding is 0.021 ohm meter.

Purpose of measuring the resistance is (i) I^2R loss calculation, (ii) winding temperature calculation at the end of temperature rise, (iii) benchmark for assessing possible damages in the field. Transformer winding is made of copper or aluminum, and the resistivity of copper and aluminum is 1.68 x10^{-8} and 2.65 x10^{-8} both in ohm – m. The resistance of the conductor is proportional to the length of the wire, and resistivity, and inversely proportional to the cross-section area.

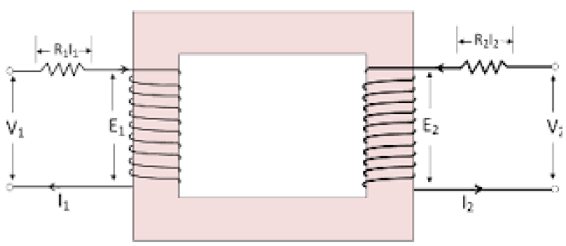

Fig. 6.Transformer Resistance

Equation used in technical code for transformer resistance.

$$Dpm = (IDhv + ODhv) / 2 \quad mm - Unit(22)$$

where, Dpm = hv winding mean diameter

$$Lmtp = (\pi \times Dpm) / 1000 \quad mm - Unit \quad (23)$$

where, Lmtp = hv winding length of mean turn

$$R_p = (T_p \times Lmtp \times rop) / a_p ohm - Unit \quad (24)$$

where, R_p = hv winding resistance, rop = resistivity of material for hv winding

$$Dsm = (Id + Od) / 2 \quad mm - Unit \quad (25)$$

where, Dsm = lv winding mean diameter

$$Lmts = (\pi \times Dsm) / 1000 \quad mm - Unit (26)$$

where, Lmts = lv winding length of mean turn

$$R_s = (T_s \times Lmts \times ros) / a_s \quad ohm - Unit (27)$$

where, Rs = lv winding resistance, ros = resistivity of material for lv winding

$$Ref = R_p + (T_p^2/T_s^2) \times R_s \, ohm - Unit(28)$$

where, Ref = primary side referred resistance

$$ep = (I_p \times Ref) / V_p \quad ohm - Unit (29)$$

where, ep = per unit resistance

$$P_c = I_p^2R_p + I_s^2R_s \quad watt - Unit (30)$$

where, Pc = total copper loss

E. *Leakage Reactance*

According to IS standards leakage reactance of transformer is between 4% - 20% of base rating.

The magnetic leakage takes place in every transformer which causes leakage reactance. Leakage field is mainly packed into the space between the winding that is into the duct and runs parallel with the core for nearly the full length of the coils.

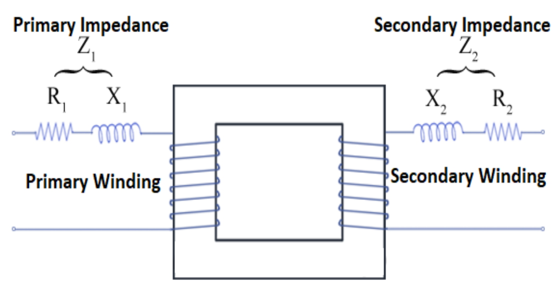

Fig. 7.Transformer Leakage Reactance

The transformer draws more current to produce the same amount of flux to nullify the effect of leakage flux. Moreover, the percentage impedance of the transformer also increases with an increase in the leakage flux.

Equation used in technical code for transformer leakage resistance.

$Dm = (Id + ODhv) / 2$ ***mm – Unit*** ***(31)***where,
Dm = winding mean diameter

$Lmt = (\pi \times Dm) / 1000$ ***m – Unit*** ***(32)***
where, Lmt = length of mean turn of winding

$Lc = (Lcp + Lcs) / 2$ ***mm – Unit*** ***(33)***
where, Lc = mean axial length of winding

$X_p = (2\pi fmuo \times Tp^2 Lmt(T+(ba)/3)/Lc$ ***ohm – Unit*** ***(34)***
where, Xp = leakage reactance referred to hv, muo = magnetic permeability as $4\pi \times 10^{-12}$, ba = bp+bs

$epx = (I_p \times X_p) / V_p$ ***(35)***
where, epx = per unit leakage reactance

$epi = \sqrt{(ep^2)} + (epx^2)$ ***(36)***
where, epi = per unit impedance

F. *Cooling*

As per IS standards oil density is 0.89 gm/cc at 29.5C Tube diameter is generally 50 mm and space between tube is 75 mm. Air, Gas, Synthetic oil, Mineral oil, Solid insulation, Water is the cooling medium in transformer.

Natural and force are the method of cooling. Small transformers have cooling tubes on vertical side, but large transformers require separate banks of cooling tubes. Vertical cooling ducts are along the direction of laminations and hence can be easily provided. Horizontal ducts are across the laminations and therefore require special punching of core

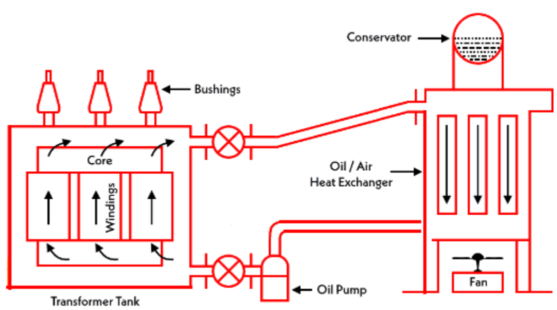

Fig. 8.Transformer Cooling

Equation used in technical code for transformer resistance.

$T_w = (2 \times D_d) + D + (2 \times C_w)$ ***m – Unit (37)***
where, T_w = tank width, D_d = 0.47 as distance between center to adjacent limbs, C_w = 0.07 as clearance width between winding and tank

$T_l = D + (2 \times C_l)$ ***m – Unit*** ***(38)***
where, T_l = tank length, C_l = 0.09 as clearance length between winding and tank

$H_o = Rs+B+D_o$ ***m – Unit*** ***(39)***
where, H_o = oil level height from tank bottom, B = 0.05 as base value, D_o = oil dimension

$T_h = H_o+D_o$ ***m – Unit*** ***(40)***
where, T_h = tank height

$D_s = 2 \times (T_l + T_w) \times T_h$ ***m^2 – Unit*** ***(41)***
where, D_s = plain tank dissipating surface

$T_l = I_l+P_c$ ***watt – Unit*** ***(42)***
where, T_l = transformer loss, I_l = core loss

$Q_p = ((T_l \times 10^3)/(D_s \times 35))-12.5/8.8$ ***(43)***
where, Q_p = simplification

$T_A = Q_p + T_l$ ***m^2 – Unit*** ***(44)***
where, T_A = tube area

$Q_r = \pi \times B \times L_t$ ***(45)***
where, Q_r = simplification

$N_t = T_A/Q_r$ ***(46)***
where, N_t = number of tube

IV. *CONCLUSION*

This is the best method for designing any transformer as per requirement. Design engineer get 100% accurate result at any time. As, we are living in developing country various rating and design are used based on technical and economical reason. If engineer due manual calculation that result to slower production > error chances >decrement in vendor capital > brings pessimist effect to employee's life > time consuming. To eliminate all this detriment smart technical coding dialect is must essential.

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