K. K. Wagh Institute of Engineering Education and Research, Nashik
(An Autonomous Institute from A.Y. 2022-23)

Model Answer Set-01

End-Sem Examination-I, Winter 2025

Academic Year: 2025-2026 **Semester: I**

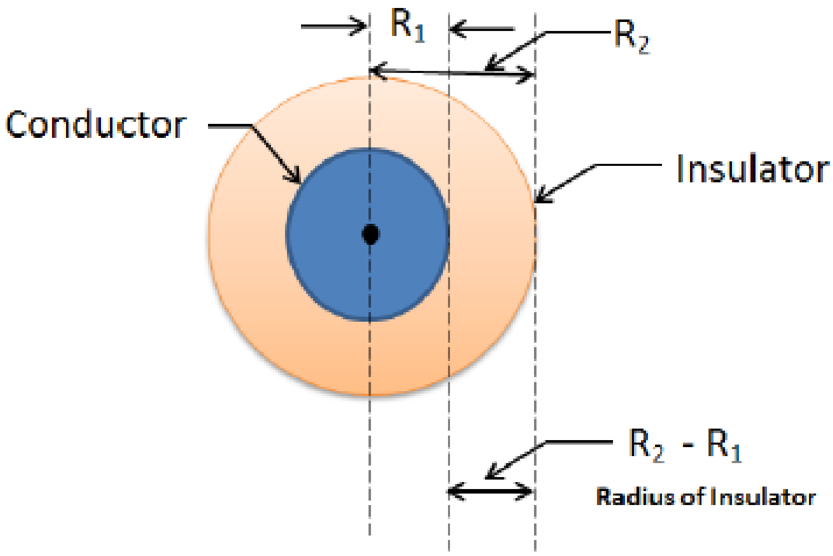
Name of Program: FY B.Tech **Pattern: 2023**

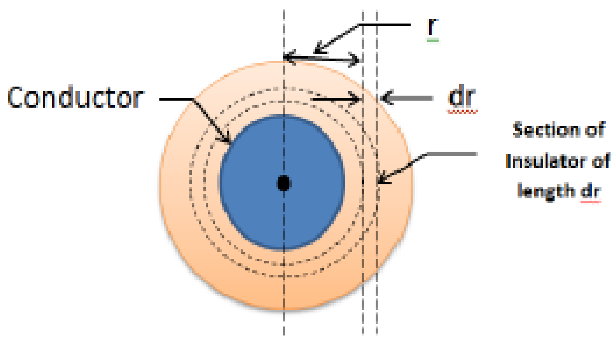
Name of Course: Fundamentals of Electrical Engineering **Course Code:** 2300105A

Branch Code: COM/ELE/ INT /ADS/ROB/CSD

Q.1 **Define insulation resistance. Derive Formula to calculate insulation resistance for single core cable** [6]

The level or degree of *insulation resistance of a cable* depends on the purpose for which the cable was designed for. Apart from saving energy from being lost or dissipated to the surrounding, one paramount reason why cables are insulated is to save us from the danger of being electrocuted.





Length = dr and cross sectional area = $2\pi r l$

$$\therefore dR_i = \rho \times \frac{length\ of\ path\ followed\ by\ leakage\ current}{Area}$$

$$\therefore\ dR_i = \rho \times \frac{dr}{2\pi r l}$$

Where $l = length\ of\ the\ cable$

The total insulation resistance R_{ins} can be obtained by integrating "dR_i" over the entire radius of the insulating material i.e. from R_1 to R_2

$$\therefore R_i = \int_{R_1}^{R_2} dR_i = \int_{R_1}^{R_2} \frac{\rho dr}{2\pi r l} = \frac{\rho}{2\pi l}\int_{R_1}^{R_2} \frac{dr}{r} = \frac{\rho}{2\pi l}[log_e r]_{R_1}^{R_2}$$

$$R_i = \frac{\rho}{2\pi l}[log_e R_2 - log_e R_1]$$

$$R_i = \frac{\rho}{2\pi l} log_e [R_2/R_1]\ \Omega$$

i.e.

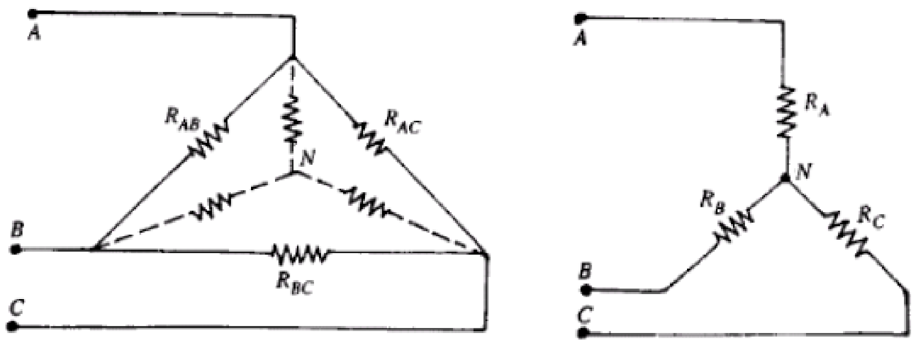
$$R_{ins} = \frac{\rho}{2\pi l}[log_e \frac{r_2}{r_1}]$$

Where,

$R_2 = Radius\ of\ the\ cable\ including\ the\ Conductor\ \&\ Insulator$

$R_1 = Radius\ of\ the\ conductor$

2 **Derive formulae to convert DELTA connected network into its STAR connected equivalent network. (6 marks)** [6]



(a) Delta Connection **(b) Star connection**

$$R_A = \frac{R_{AB}.R_{AC}}{R_{AB} + R_{BC} + R_{AC}}$$

$$R_B = \frac{R_{BC}.R_{BC}}{R_{AB} + R_{BC} + R_{AC}}$$

$$R_C = \frac{R_{AC}.R_{BC}}{R_{AB} + R_{BC} + R_{AC}}$$

Derivation (6 marks)

3 i) Define following terms in AC fundamentals with its values. [16]

1) Form Factor 2) Amplitude factor (2 Marks)

ii) An alternating current varying sinusoidally with a frequency 50Hz has RMS value of 20A. Find its value after passing through zero positive maximum.

1) 0.0025 Sec 2) 0.125 Sec (6 Marks)

Each definition - 2 x 01 Marks

1) Form Factor

The ratio of the **RMS value** to the **average value** of an AC waveform.

2) Crest Factor or Amplitude Factor Definition:

The ratio of the peak (maximum) value to the RMS value of an AC waveform.

- Frequency, $f = 50 \text{ Hz}$
- RMS current, $I_{\text{rms}} = 20 \text{ A}$

Step 1: Find maximum (peak) value of current

$$I_m = \sqrt{2}\, I_{\text{rms}} = \sqrt{2} \times 20 = 28.28 \text{ A}$$

Step 2: Write the instantaneous current equation

Since the current has **just passed through zero in the positive direction**, we take:

$$i(t) = I_m \sin(\omega t)$$

where

$$\omega = 2\pi f = 2\pi \times 50 = 100\pi \text{ rad/s}$$

So,

$$i(t) = 28.28 \sin(100\pi t)$$

(1) At $t = 0.0025$ s

$$\omega t = 100\pi \times 0.0025 = 0.25\pi = \frac{\pi}{4}$$

$$i = 28.28 \sin\left(\frac{\pi}{4}\right) = 28.28 \times 0.707 = 20 \text{ A}$$

✅ Current = 20 A

(2) At $t = 0.125$ s

$$\omega t = 100\pi \times 0.125 = 12.5\pi$$

$$\sin(12.5\pi) = \sin\left(12\pi + \frac{\pi}{2}\right) = 1$$

$$i = 28.28 \times 1 = 28.28 \text{ A}$$

✅ Current = 28.28 A

OR

b) What is meant by resonance in series R-L-C circuit connected across sinusoidal A.C. supply? Derive the equation for resonant frequency
(8 Marks)

Resonance in series R-L-C circuit 04 Marks

Derivation for resonant frequency 04 Marks

c) The voltage and current, in simple series circuit are given by V = 150 ∠30^0 Volt and I = 2∠ − 15^0 amp. If the supply frequency is 50Hz, determine, impedance, resistance, reactance and power consumed by the circuit, Draw phasor diagram. (8 marks)

1) Impedance = 53.03 + j 53.03 Ω **02 Marks**

2) Resistance = 53.03 Ω **01 Marks**

3) Reactance = j 53.03 Ω **01 Marks**

4) Power consumed by the circuit = 212.13 Watt **02 Marks**

5) Draw phasor diagram. **02 Marks**

✅ 1. Impedance (Z):

Impedance Z is given by:

$$Z = \frac{V}{I} = \frac{150\angle 30^\circ}{2\angle -15^\circ} = 75\angle(30-(-15)) = 75\angle 45^\circ\,\Omega$$

Convert to rectangular form:

$$Z = 75\angle 45^\circ = 75(\cos 45^\circ + j\sin 45^\circ) = 75(0.707 + j0.707)$$

$$Z = 53.03 + j53.03\,\Omega$$

✅ 2. Resistance (R) and Reactance (X):

From the rectangular form of $Z = R + jX$:

- $R = 53.03\,\Omega$
- $X = 53.03\,\Omega$

✅ 3. Power Consumed (Active Power, P):

$$P = V_{\text{rms}} \cdot I_{\text{rms}} \cdot \cos(\phi)$$

✅ **3. Power Consumed (Active Power, P):**

$$P = V_{\text{rms}} \cdot I_{\text{rms}} \cdot \cos(\phi)$$

Where:

- $V_{\text{rms}} = 150\ \text{V}$
- $I_{\text{rms}} = 2\ \text{A}$
- $\phi = \angle V - \angle I = 30^\circ - (-15^\circ) = 45^\circ$

$$P = 150 \cdot 2 \cdot \cos(45^\circ) = 300 \cdot 0.7071 \approx 212.13\ \text{W}$$

OR

d) Three impedances $Z_1 = 40\angle 0^0$, $Z_2 = 20\angle 90^0$ and $Z_3 = 30\angle -90^0$ ohm are connected in series across single phase 250 V, 50 Hz supply, Calculate,
i) Total Impedance, ii) Current Drawn iii) Power Factor

iv) Power Consumed by Circuit. v) Draw Phasor Diagram (8 marks)

i) Total Impedance = $41.23\angle -14.04^\circ\ \Omega$ **01 M**
ii) Current Drawn = 6.06 A **02 M**
iii) Power Factor = 0.97 leading **01 M**

iv) Power Consumed by Circuit. = 1.47 kW **02 M**
v) Draw Phasor Diagram **02 M**

i)Total Impedance

Magnitude:

$$|Z| = \sqrt{40^2 + (-10)^2} = \sqrt{1600 + 100} = \sqrt{1700} = 41.23\ \Omega$$

Phase angle:

$$\theta = \tan^{-1}\left(\frac{-10}{40}\right) = -14.04^\circ$$

$$\boxed{Z = 41.23\angle -14.04^\circ\ \Omega}$$

(ii) Current Drawn

$$I = \frac{V}{Z} = \frac{250\angle 0^\circ}{41.23\angle -14.04^\circ}$$

$$I = 6.06\angle +14.04^\circ\ \text{A}$$

(iii) Power Factor

$$\cos\phi = \cos(14.04^\circ) = 0.97$$

Since current **leads** the voltage:

$$\boxed{\text{Power factor} = 0.97 \text{ leading}}$$

(iv) Power Consumed by the Circuit

Only resistance consumes real power.

$$P = VI\cos\phi$$

$$P = 250 \times 6.06 \times 0.97 = 1469 \text{ W (approx)}$$

Q.4

Q.4 a) Derive the relation of line & phase values of voltage and current for three phase delta connected balanced load, with phasor (8 marks) 6]

Circuit diagram 02 M
Equation of Currents 02 M
Phasor diagram 02 M
Derivation 02 M

OR

Q.4 b) Explain the technical differences between an Earth Leakage Circuit Breaker (ELCB) and a Miniature Circuit Breaker (MCB)?

Differences Any 06 Point = 08 Marks

Feature	ELCB (Earth Leakage Circuit Breaker)	MCB (Miniature Circuit Breaker)
Purpose	Detects and interrupts **leakage current to earth**	Protects against **overload and short circuit**
Senses	**Leakage current** (earth fault)	**Overcurrent** (exceeds rated current)
Trip Condition	Trips when leakage current exceeds safe limit (e.g., 30 mA)	Trips when current exceeds rated limit for too long
Internal Sensing Mechanism	Uses a differential transformer to detect imbalance	Uses thermal (bimetallic strip) and magnetic mechanisms

Typical Rating Units	Rated in **mA** or **A** (sensitivity to leakage)	Rated in **Amps** (load current capacity)
Response Speed	Very fast for leakage (within milliseconds)	Fast for short circuit, slower for overload
Main Use	Prevents **electric shocks and fire hazards**	Protects **wiring and appliances** from overcurrent
Earth Wire Dependency	Works with proper **earthing**	Independent of earth wire
Symbol on Devices	Often marked with **ΔI** or "test" button	Marked with current rating like B16, C10 etc.
Common Locations	Bathrooms, outdoor units, wet areas	Distribution boards for lighting, sockets, etc.

Q.4 c) A balance Delta connected load of $45\angle 36.86^\circ$ per phase is connected to a Three phase 440 volt supply. Calculate i)Phase current ii)line current iii)Power Factor iv)Active Power v)Reactive Power vi)Total Volt amperes vii) Draw Phasor Diagram

◆ (i) Phase Voltage in Delta Connection

In a delta connection:

$$V_{\text{phase}} = V_L = 440\ \text{V}$$

◆ (ii) Phase Current (I_p):

$$I_{\text{phase}} = \frac{V_{\text{phase}}}{Z_\Delta} = \frac{440}{45\angle 36.86^\circ}$$

$$= 9.78\angle -36.86^\circ\ \text{A}$$

◆ (iii) Line Current (I_L):

In a delta connection:

$$I_L = \sqrt{3} \cdot I_{\text{phase}} = \sqrt{3} \cdot 9.78 = 1.732 \cdot 9.78 \approx \boxed{16.94\ \text{A}}$$

- (iv) **Power Factor (pf):**

$$\text{pf} = \cos(\theta_Z) = \cos(36.86^\circ) \approx \boxed{0.8\,\text{lagging}}$$

- (v) **Active Power (P):**

For a three-phase system:

$$P = \sqrt{3} \cdot V_L \cdot I_L \cdot \cos(\theta)$$

$$P = \sqrt{3} \cdot 440 \cdot 16.94 \cdot 0.8 \approx 10330\ \text{W} = \boxed{10.33\,\text{kW}}$$

- (vi) **Reactive Power (Q):**

$$Q = \sqrt{3} \cdot V_L \cdot I_L \cdot \sin(\theta)$$

$$Q = \sqrt{3} \cdot 440 \cdot 16.94 \cdot \sin(36.86^\circ) = 1.732 \cdot 440 \cdot 16.94 \cdot 0.6 \approx \boxed{7915\ \text{VAR}} = 7.92\,\text{kVAR}$$

- (vii) **Apparent Power (S):**

$$S = \sqrt{3} \cdot V_L \cdot I_L = 1.732 \cdot 440 \cdot 16.94 \approx \boxed{12916\ \text{VA}} = 12.92\,\text{kVA}$$

OR

Q.4 d) A balance Star connected load of (40 - j 25) Ω/phase is connected to a three phase 415 v, 50 Hz supply Calculate i) Phase and Line current ii) Phase voltage iii) Power Factor iv)Active Power v) Reactive Power vi) Total Volt amperes vii) Draw Phasor Diagram

(8 marks)

(i) Impedance	=	**4717 ∠-32 ° Ω**	**01 M**
(ii) Line voltage	=	**415 V**	**01 M**
(iii) phase voltage	=	**239.6 V**	**01 M**
(iv) Line and phase current	=	**5.08 ∠ 32 ° Amp**	**01 M**
(v) Power Factor	=	**0.848 Leading**	**01 M**
(v) Active and reactive power	=	**3.10 KW & 1.94 KVAR**	**02 M**
(vi) Draw Phasor Diagram	=		**01 M**

1) Phase Impedance (magnitude & angle)

$$|Z_{ph}| = \sqrt{40^2 + 25^2} = \sqrt{2225} = 47.17\ \Omega$$

$$\phi = \tan^{-1}\left(\frac{-25}{40}\right) = -32^\circ$$

$$\boxed{Z_{ph} = 47.17\angle -32^\circ\ \Omega}$$

2) Phase Voltage

For star connection:

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{415}{\sqrt{3}} = 239.6\ \text{V}$$

$$\boxed{V_{ph} = 239.6\ \text{V}}$$

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3) Phase Current

$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{239.6\angle 0^\circ}{47.17\angle -32^\circ}$$

$$I_{ph} = 5.08\angle +32^\circ\ \text{A}$$

$$\boxed{I_{ph} = 5.08\ \text{A (leading)}}$$

4) Line Current

For star connection:

$$I_L = I_{ph}$$

$$\boxed{I_L = 5.08\ \text{A}}$$

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5) Power Factor

$$\cos\phi = \cos 32^\circ = 0.848$$

Since current leads voltage:

$$\boxed{\text{Power factor} = 0.848\ \text{leading}}$$

6) Active Power (Real Power)

$$P = \sqrt{3} V_L I_L \cos\phi$$

$$P = \sqrt{3} \times 415 \times 5.08 \times 0.848$$

$$\boxed{P \approx 3.10\,\text{kW}}$$

7) Reactive Power

$$Q = \sqrt{3} V_L I_L \sin\phi$$

$$\sin 32^\circ = 0.530$$

$$Q = \sqrt{3} \times 415 \times 5.08 \times 0.530$$

$$\boxed{Q \approx 1.94\,\text{kVAr (capacitive)}}$$

8) Total Apparent Power (Volt-Amperes)

$$S = \sqrt{3} V_L I_L$$

$$S = \sqrt{3} \times 415 \times 5.08$$

$$\boxed{S \approx 3.65\,\text{kVA}}$$

Q.5 a) What are the different types of losses in a transformer? Also, discuss the methods used to minimize these losses to improve efficiency. (8 marks) [16]

Losses in Transformer 02 M
Parts in which losses are taking Place 03 M
How to reduce Losses 03 M

Losses in a Transformer
A transformer is not 100% efficient. Various losses occur during its operation, which can be broadly classified into **core (iron) losses** and **copper losses.**
1. Iron (Core) Losses
These occur in the **transformer core** due to alternating magnetic flux.

a) Hysteresis Loss

Cause: Due to reversal of magnetic domains in the core material.
Location: In the **iron core**.
reduction:
Use **high-grade silicon steel** or **CRGO steel** core.
Use materials with **low hysteresis coefficient**.

b) Eddy Current Loss

Cause: Circulating currents induced in the core due to changing magnetic flux.
Location: In the **iron core**.
Reduction:
Use **thin laminated core** sheets.
Insulate laminations from each other to restrict current paths.

🔷 **2. Copper Losses**

These occur in the **winding conductors** due to the flow of load current.

Cause: I^2R losses in primary and secondary windings.
Location: In **copper windings**.
Reduction:

Use **thicker conductors** with **low resistance**.
Optimize **winding design** to reduce length and resistance.
Use **proper cooling** to avoid resistance increase due to temperature.

◆ **3. Stray Losses**

Cause: Leakage flux inducing eddy currents in tank walls, clamps, and structural parts.
Location: In **metal parts around windings and core**.
Reduction:

Proper **shielding** and core design.
Use of **non-magnetic materials** for supports and clamps.

◆ **4. Dielectric Loss**

Cause: Leakage current through insulation material.
Location: In **insulating oil and solid insulation**.
Reduction:

Use **high-quality insulation materials**.
Regular maintenance of oil and insulation.

OR

b) Mention Advantages and Disadvantages of Stepper motor (8 marks)

Advantages of Stepper motor = **04 M**

Disadvantages of Stepper motor = **04 M**

✅ Advantages of Stepper Motor:

1. **Precise Position Control:**
   - Moves in accurate and fixed angular steps, ideal for digital control.
2. **No Feedback Required:**
   - Often used in open-loop systems—no need for encoders or feedback sensors.
3. **Good Low-Speed Torque:**
   - Provides high torque at low speeds, useful in robotics and CNC machines.
4. **Simple to Control:**
   - Easily controlled using digital pulses from a microcontroller or driver.
5. **Reliability and Durability:**
   - No brushes; less wear and tear, leading to longer lifespan.
6. **Quick Response to Starting and Stopping:**
   - Can start, stop, and reverse quickly without needing ramping.

❌ Disadvantages of Stepper Motor:

1. **Loses Torque at High Speed:**
   - Torque drops significantly as speed increases.
2. **Resonance and Vibration:**
   - Can cause instability or noise if not damped properly.
3. **Not Energy Efficient:**
   - Draws full current even when idle or under no load.
4. **Can Miss Steps:**
   - Without feedback, it can lose synchronization under load, affecting accuracy.
5. **Limited High-Speed Performance:**
   - Not ideal for applications requiring very high rotational speeds.
6. **Heat Generation:**
   - Can become hot during extended operation due to constant current draw.

c) A Transformer is rated at 270 KVA, at full load its copper losses is 2.5 KW and its iron losses is 1850 Watt. Calculate i) Efficiency at 70 % of full load,0.8 power factor. ii)Efficiency at 80%of full load at 0.75 power factor iii) Efficiency at full load, unity power factor (8 marks)

(1) Efficiency at 70% full load, 0.8 power factor = 98.01 % 03 M
(2) Efficiency at 80% full load, 0.75 power factor = 97.91 % 03 M
(3) **Efficiency at full load, unity power factor = 98.41 % 02 M**

(i) Efficiency at 70% full load, 0.8 power factor

Output power

$$P_{out} = 0.7 \times 270 \times 0.8 = 151.2\ \text{kW}$$

Copper loss at 70% load

$$P_{cu} = (0.7)^2 \times 2.5 = 0.49 \times 2.5 = 1.225\ \text{kW}$$

Total losses

$$P_{loss} = 1.225 + 1.85 = 3.075\ \text{kW}$$

Efficiency

$$\eta = \frac{151.2}{151.2 + 3.075} = 0.9801$$

$$\boxed{\eta = 98.01\%}$$

(ii) Efficiency at 80% full load, 0.75 power factor

Output power

$$P_{out} = 0.8 \times 270 \times 0.75 = 162\ \text{kW}$$

Copper loss at 80% load

$$P_{cu} = (0.8)^2 \times 2.5 = 0.64 \times 2.5 = 1.6\ \text{kW}$$

Total losses

$$P_{loss} = 1.6 + 1.85 = 3.45\ \text{kW}$$

Efficiency

$$\eta = \frac{162}{162 + 3.45} = 0.9791$$

$$\boxed{\eta = 97.91\%}$$

(iii) Efficiency at full load, unity power factor

Output power

$$P_{out} = 270 \times 1 = 270\ \text{kW}$$

Total losses at full load

$$P_{loss} = 2.5 + 1.85 = 4.35\ \text{kW}$$

Efficiency

$$\eta = \frac{270}{270 + 4.35} = 0.9841$$

$$\boxed{\eta = 98.41\%}$$

d) A 3000V/200V,50Hz, single phase transformer is built on a core having an effective cross sectional area of 120cm^2 and 80 turns on the secondary winding. Calculate 1) The value of maximum flux density, 2) The number of turns on the HV winding (8 marks)

1) The value of maximum flux density = 0.938 Tesla **04 M**
2) The number of turns on the HV winding = **1200 Turns** **04 M**

1) Maximum Flux Density (B_m):

We use the **transformer EMF equation:**

$$V = 4.44 \cdot f \cdot N \cdot \phi_{\max}$$

Rearranged for **maximum flux:**

$$\phi_{\max} = \frac{V}{4.44 \cdot f \cdot N}$$

Now substitute for the **secondary side:**

$$\phi_{\max} = \frac{200}{4.44 \cdot 50 \cdot 80} = \frac{200}{17760} \approx 0.01126\,\mathrm{Wb}$$

Now use:

$$B_{\max} = \frac{\phi_{\max}}{A} = \frac{0.01126}{0.012} \approx 0.938\,\mathrm{T}$$

✅ **Maximum Flux Density = 0.938 Tesla**

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2) Number of Turns on HV Winding (N_1):

Use the transformer **turns ratio:**

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow N_1 = N_2 \cdot \frac{V_1}{V_2} = 80 \cdot \frac{3000}{200} = 80 \cdot 15 = 1200\,\text{turns}$$

✅ **Number of Turns on HV Winding = 1200 turns**