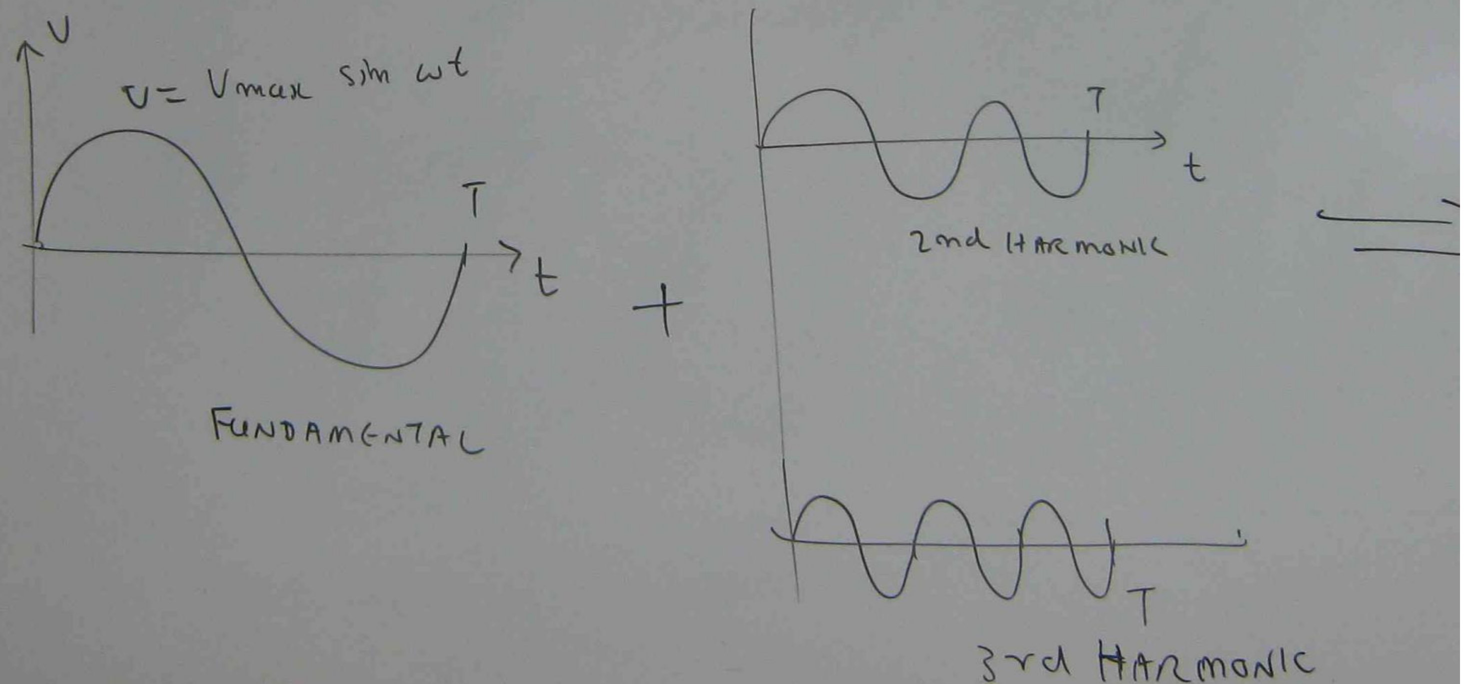
HARMONICS IN TRANSFORMERS

WHEN ELECTRICAL SUPPLY IS PROVIDED TO TRANSFORMER, THE INDUCTANCE RESISTS THE BUILDING UP OF MAGNETIC FLUX AND MAIN VOLTAGE.

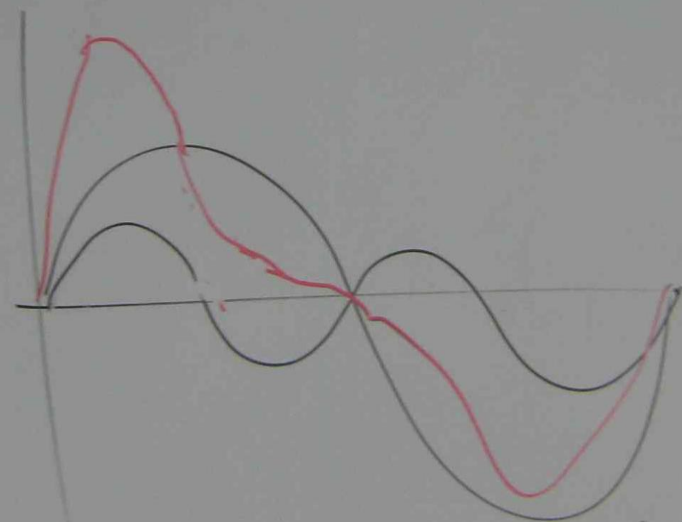
THE TRANSFORMER VOLTAGE OUTPUT CONSISTS OF THE VOLTAGES WHICH FREQUENCIES ARE HIGHER THAN FUNDAMENTAL.

DUE TO HARMONICS EFFECT, THE MAIN VOLTAGE WAVE FORM IS DISTORTED

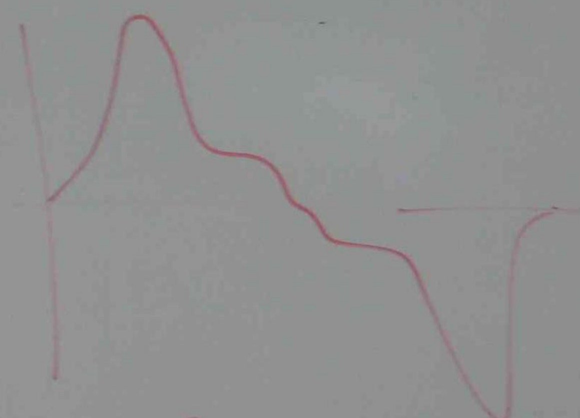


TRANSFORMER CAN DISTORT THE OUTPUT WAVE FORM. IT IS REQUIRED TO PROVIDE APPROPRIATE TRANSFORMER CORE AND WINDING DESIGN (OR) HARMONICS FILTER TO ELIMINATE THE HARMONIC.

HARMONIC WAVE CAN DEGRADE THE QUALITY OF TRANSFORMER INSULATION DIELECTRIC STRENGTH.



FUNDAMENTAL + 2^{nd} HARMONIC



DISTORTED WAVE

HARMONIC CAUSES DISTORTION OF WAVE FORM

↓

CORE LOSS IS INCREASED

↓

CORE LOSS $\propto$ FREQUENCY

FREQUENCY ↑ $\longrightarrow$ CORE LOSS ↑

WAVE

PHASE RELATIONSHIP

3^{rd}, 9^{th} - INPHASE WITH EACH OTHER IN EACH PHASE

5^{th}, 7^{th}, 11^{th}, 13^{th} - DISPLACED BY 120°

HARMONIC EFFECT DEPENDS ON

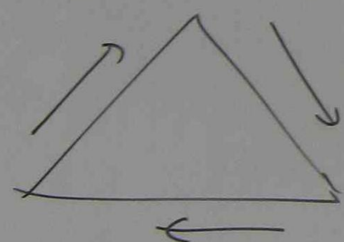
(i) WHETHER PHASES ARE MAGNETICALLY SEPARATED (OR) LINKED

(ii) WHETHER PHASES ARE ELECTRICALLY SEPARATED (OR) LINKED.

EFFECT OF TRANSFORMER CONNECTION ON HARMONIC

Δ CONNECTION

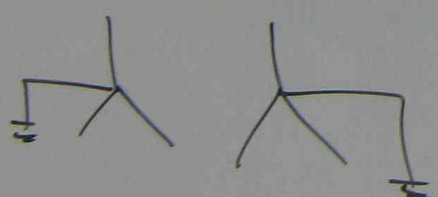
HARMONIC CURRENT CAN ONLY FLOW IN Δ CONNECTION, CAN NOT FLOW IN Y.



PATH FOR HARMONIC IN TRANSFORMER WINDING.

HARMONIC CURRENT CIRCULATES IN Δ.

NO HARMONIC CURRENT FLOWS IN TO LINE



Y | Y WITH NEUTRAL

NEUTRAL WIRE CAN CARRY HARMONIC CURRENT.

HARMONIC IMPACT ON LOAD CAN BE REDUCED.

Y Y WITHOUT NEUTROL

NO WAY TO FLOW OUT THE HARMONIC CURRENT.

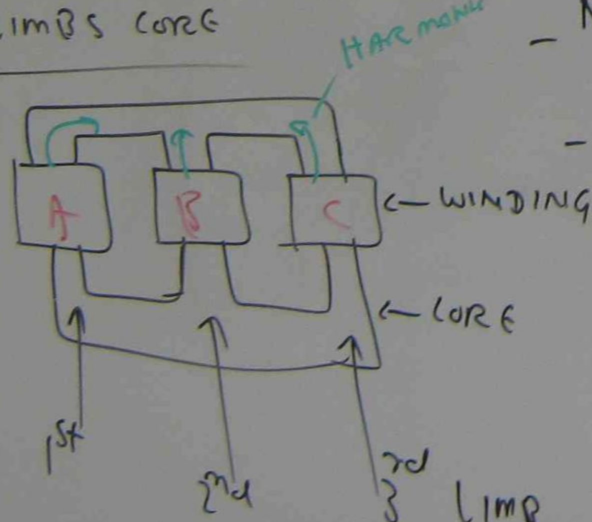
HARMONIC IS COMBINED WITH MAIN CURRENT AND MAIN CURRENT WAVE FORM IS DISTORTED.

LOAD SUFFERS THE IMPACT OF HARMONIC.

THE WAYS TO REDUCE / ELIMINATE HARMONIC IN POWER TRANSFORMERS

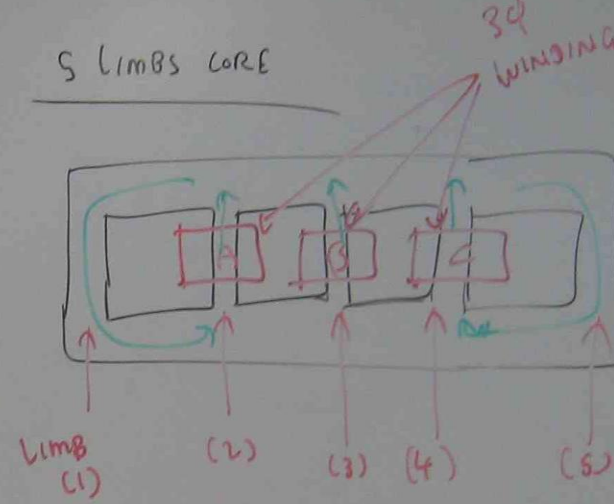
CORE DESIGN

3 LIMBS CORE



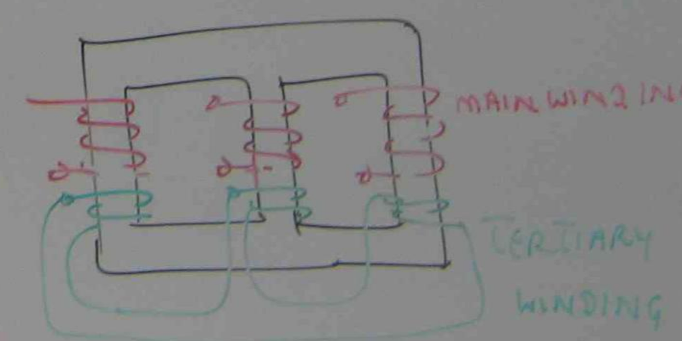
- NO-HARMONIC RETURN PATH
- HARMONIC CAN HAPPEN

5 LIMBS CORE

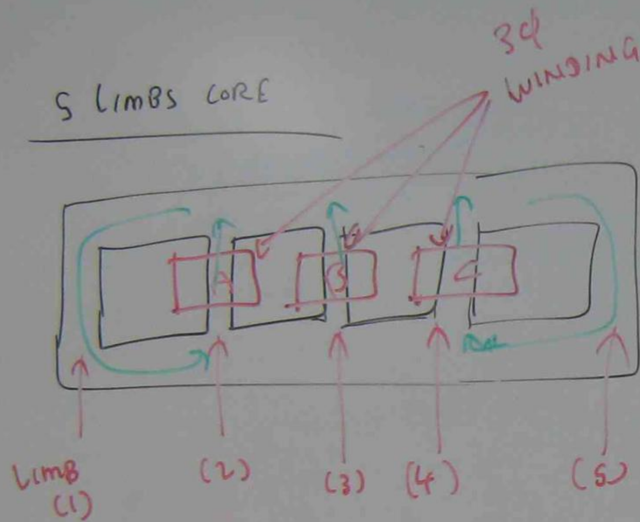


OUTER TWO LIMBS PROVIDE HARMONIC RETURN PATH.

WINDING DESIGN

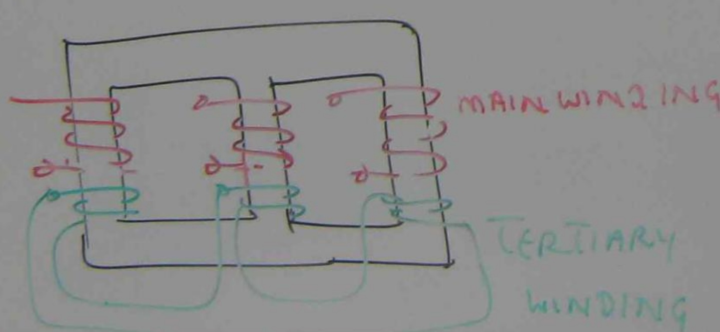


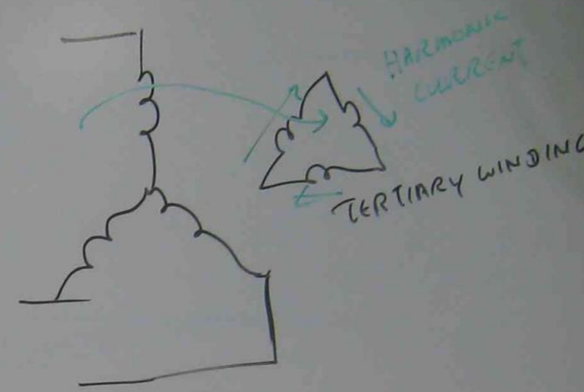
5 LIMBS CORE



OUTER TWO LIMBS PROVIDE HARMONIC RETURN PATH.

WINDING DESIGN





Δ INTERCONNECTED TERTIARY WINDING IS INCLUDED IN POWER TRANSFORMER WINDING. TERTIARY WINDING PROVIDES HARMONIC RETURN PATH SO THAT HARMONIC CURRENT CAN NOT COMBINE WITH MAIN VOLTAGE / CURRENT.

22

EFFECT OF TRANSFORMER HARMONIC

- ADDITIONAL I^2R LOSSES OCCUR
- CORE LOSS IS INCREASED
- MAGNETICALLY INTERFERENCE WITH COMMUNICATION CIRCUITS

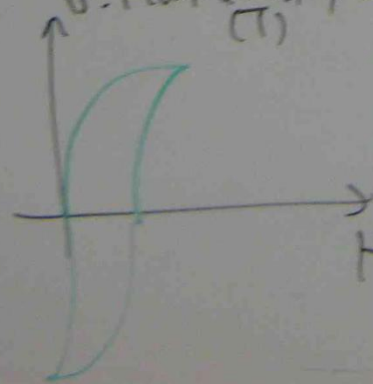
HARMONIC CAN ALSO CAUSE → (i) DECREASE IN DIELECTRIC STRENGTH
(ii) ELECTROSTATIC INTERFERENCE WITH COMMUNICATION LINES
(iii) RESONANCE OCCURS BETWEEN INDUCTANCE OF TRANSFORMER WINDING AND CAPACITANCE OF FEEDERS.

HARMONIC GENERATORS

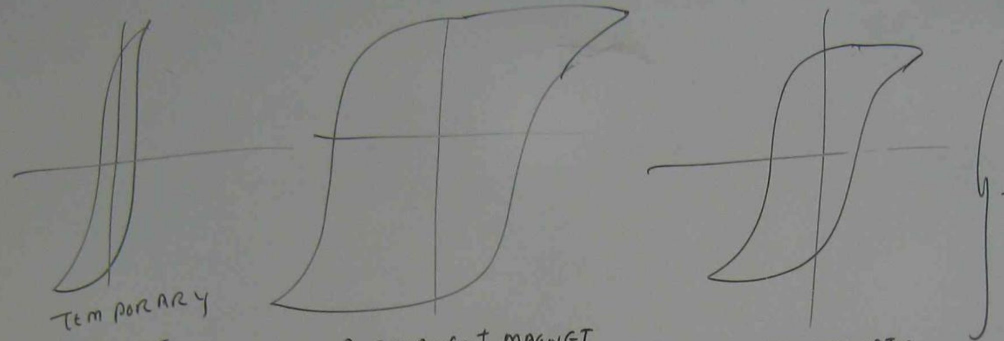
(1) HYSTERESIS EFFECT

$$B = \text{FLUX DENSITY } (T) = \frac{\phi \text{ FLUX (Wb)}}{A \text{ (CSA - } m^2)}$$

B. H CURVE



$H = \text{AMP} \times \text{TURN} = I \times N$



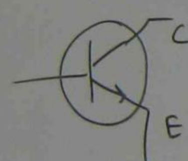
TEMPORARY MAGNET

PERMANENT MAGNET

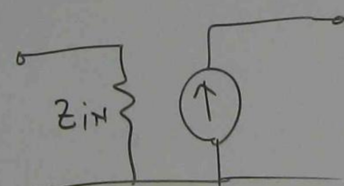
ELECTROMAGNETIC MATERIALS

→ CREATES HARMONIC

(ii) ELECTRONIC DEVICES WHICH IMPEDANCE VARY WITH APPLIED E.m.f



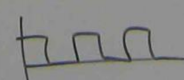
TRANSISTOR

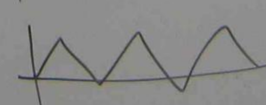


TRANSISTOR INTERNAL IMPEDANCE VARIES WITH APPLIED VOLTAGE

→ PRODUCES HARMONIC

(iii) NON SINUSOIDAL WAVE PRODUCERS

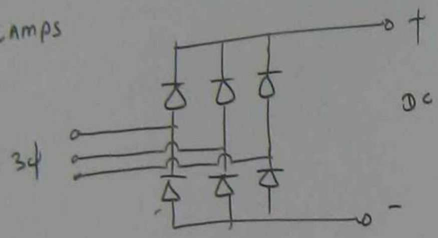
OSCILLATOR – SQUARE WAVE 

SAW TOOTH WAVE 

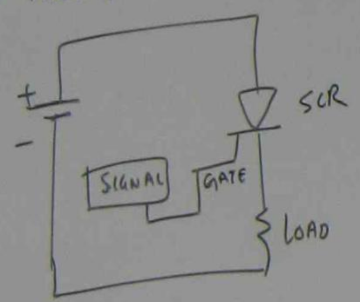
→ PRODUCES HARMONIC

OTHER DEVICES THAT PRODUCE HARMONIC

- ROTATING ELECTRICAL MACHINES
- GASEOUS DISCHARGE LAMPS
- ARC FURNACES
- RECTIFIERS



- LOAD ANGLES OF FIRING THYRISTORS



TUTORIAL (14)

Q1 IN THE FOLLOWING CONNECTIONS OF 3φ TRANSFORMER, WHICH ONE CAN CARRY HARMONIC CURRENT AND WHICH ONE CAN NOT CARRY IT?

D d, Y d, D y, Y Y WITHOUT NEUTRAL, Y Y WITH NEUTRAL

Q2 WHAT ARE DISADVANTAGES OF HARMONIC?

Q3 SKETCH 3rd HARMONIC FLUX

Q1 $\Delta\Delta$ (Dd) CARRY HARMONIC

$\curlywedge\Delta$ (Yd) ONLY Δ SIDE CARRIES HARMONIC

ΔY (DY)

YY WITHOUT NEUTRAL → CAN NOT CARRY HARMONIC

YY WITH NEUTRAL → NEUTRAL WIRE CARRIES HARMONIC

TUTORIAL (14)

Q1 IN THE FOLLOWING CONNECTIONS OF 3φ TRANSFORMER, WHICH ONE CAN CARRY HARMONIC CURRENT AND WHICH ONE CAN NOT CARRY IT?

Dd, Yd, Dy, YY WITHOUT NEUTRAL, YY WITH NEUTRAL

Q2 WHAT ARE DISADVANTAGES OF HARMONIC?

Q3 SKETCH 3rd HARMONIC FLUX

Q1 ΔΔ (Dd) CARRY HARMONIC

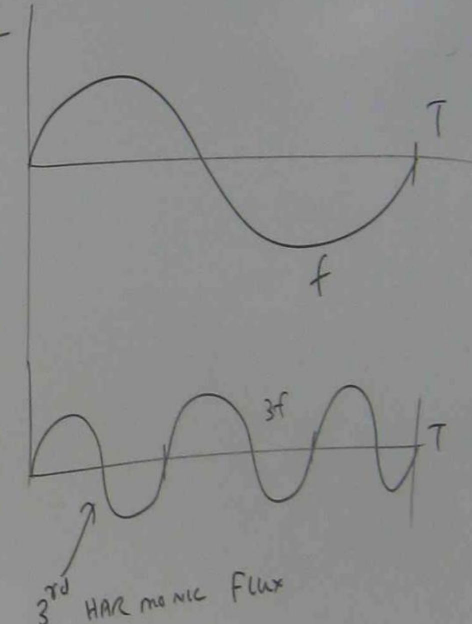
λΔ (Yd) ONLY Δ SIDE CARRIES HARMONIC

ΔY (DY)

YY WITHOUT NEUTRAL → CAN NOT CARRY HARMONIC

YY WITH NEUTRAL → NEUTRAL WIRE CARRIES HARMONIC

Q3

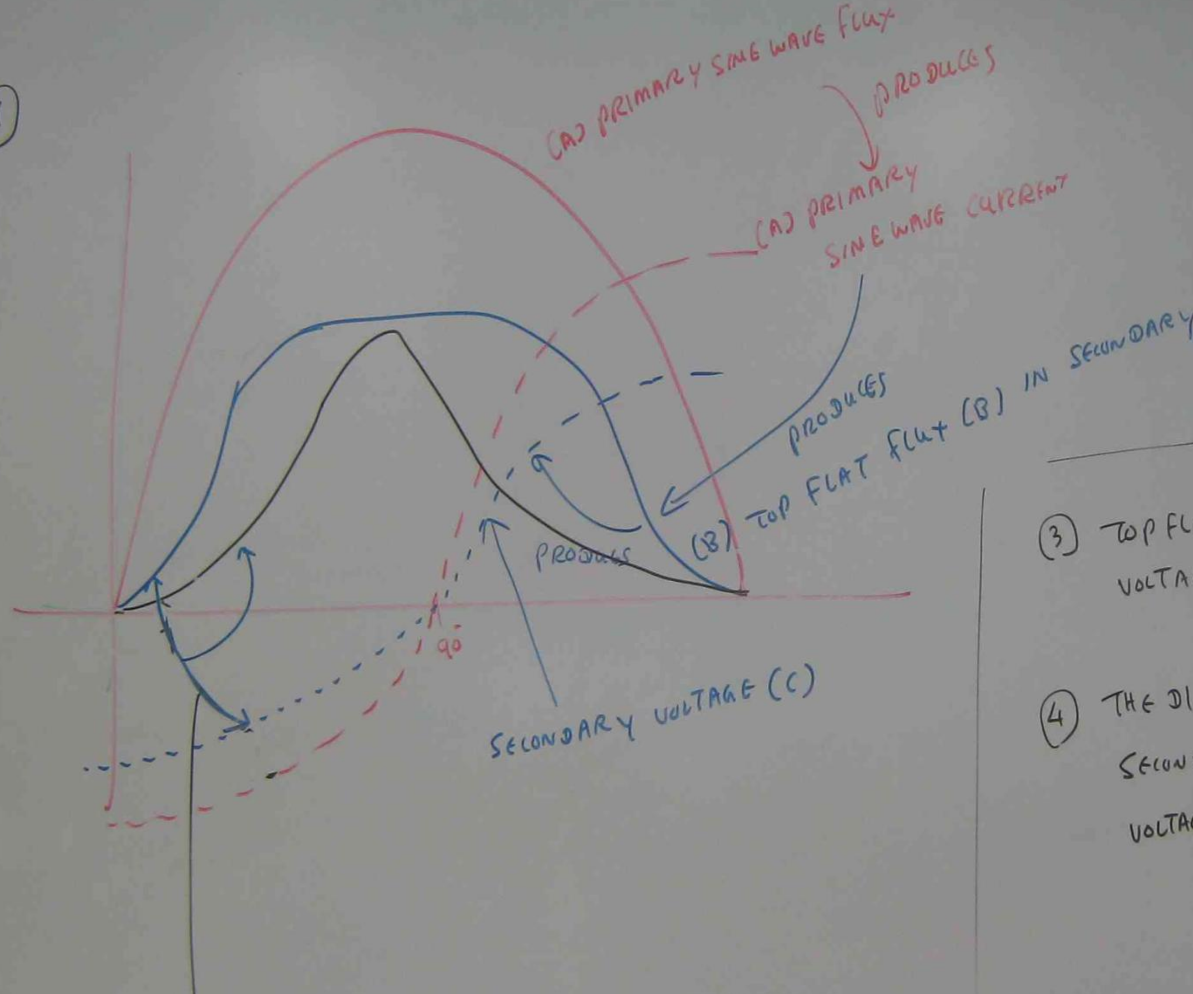


REVIEW QUESTIONS FOR SECTION (6)

(1) WITH THE AID OF SIMPLE WAVE FORM EXPLAIN THE FORMATION OF HARMONIC IN THE SECONDARY OF TRANSFORMER

(2) SKETCH THE EFFECT OF ODD HARMONIC ON SECONDARY VOLTAGE OF A TRANSFORMER

(3) SKETCH THE EFFECT OF EVEN HARMONIC ON SECONDARY VOLTAGE OF TRANSFORMER



1. PRIMARY SINE WAVE FLUX (A) PRODUCES PRIMARY SINE WAVE CURRENT (A)
2. PRIMARY SINE WAVE CURRENT (A) PRODUCES TOP FLAT FLUX IN SECONDARY (B)
3. TOP FLAT FLUX IN SECONDARY PRODUCES SECONDARY VOLTAGE (C)
4. THE DIFFERENCE BETWEEN PRIMARY AND SECONDARY FLUXES PRODUCE HARMONIC OUTPUT VOLTAGE.

TOTAL OUTPUT VOLTAGE IS PRODUCED BY PRIMARY & SECONDARY VOLTAGE

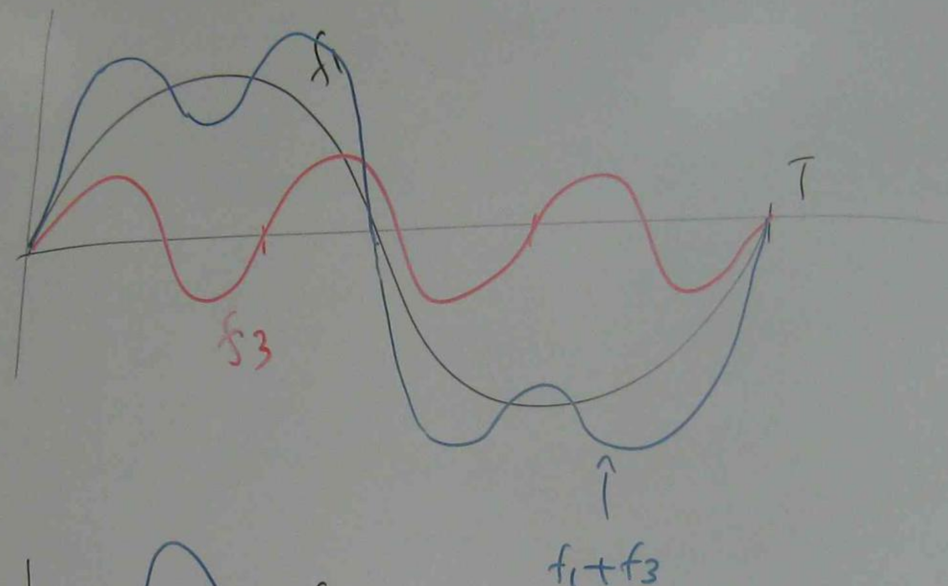
ER

ONIC

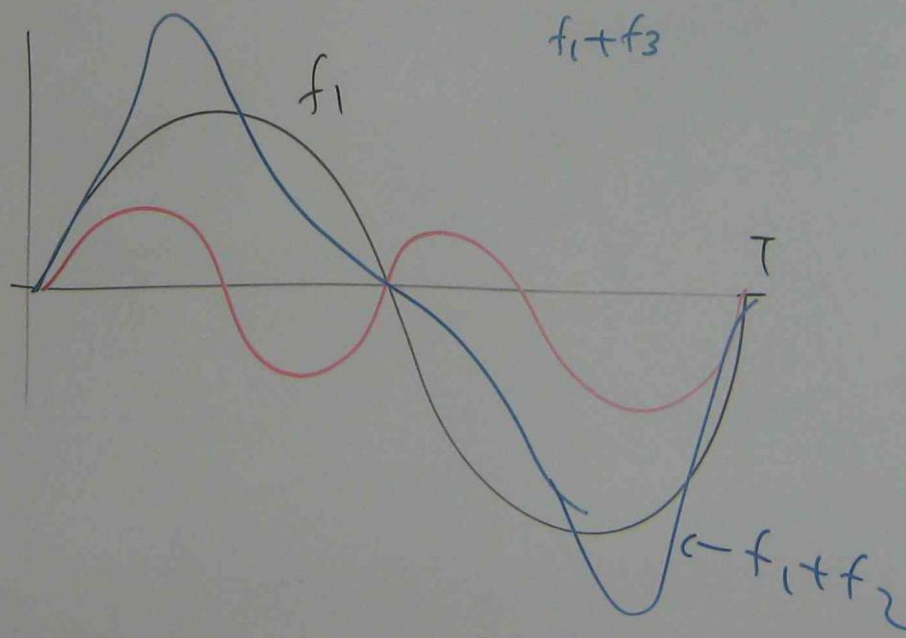
RMONIC

SFORMER

2



3



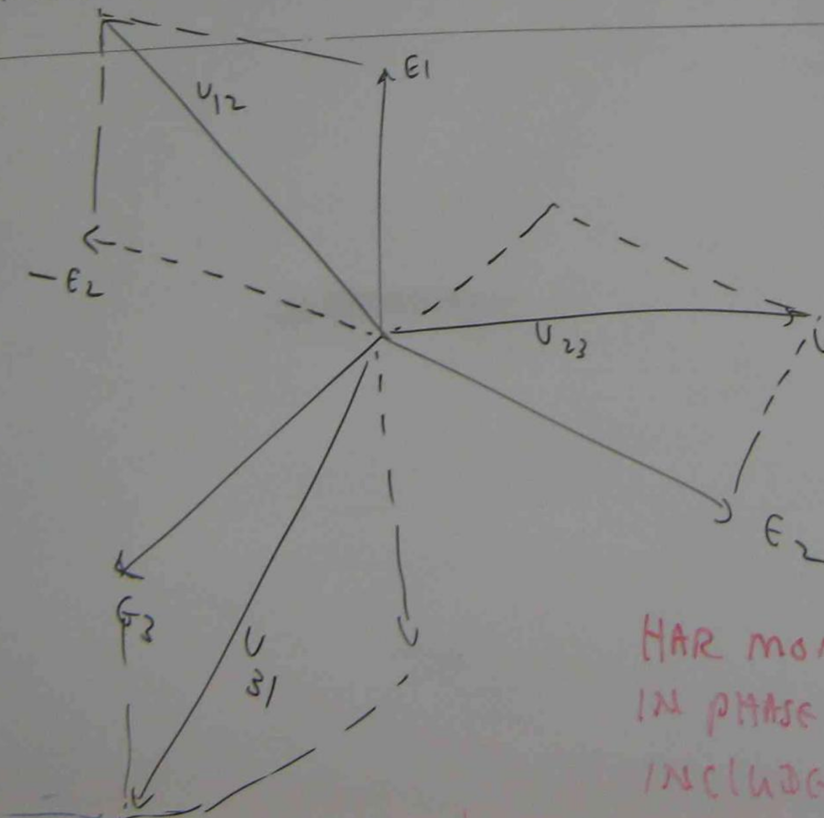
Q4 EXPLAIN THE EFFECT OF THREE WIRE STAR CONNECTION ON THIRD HARMONIC

Q5 EXPLAIN THE EFFECT OF FOUR WIRE STAR CONNECTION ON THIRD HARMONIC

Q6 EXPLAIN THE EFFECT OF DELTA CONNECTION ON THIRD HARMONIC

Q7 EXPLAIN THE EFFECT OF CORE TYPE AND SHELL TYPE MAGNETIC CIRCUITS ON THIRD HARMONIC

Q4



E_1, E_2, E_3 = PHASE VOLTAGES

V_{12}, V_{23}, V_{31} = LINE VOLTAGE

$V_{12} = E_1 - E_2$

$V_{23} = E_2 - E_3$

$V_{31} = E_3 - E_1$

HARMONIC CAN ONLY INCLUDE IN PHASE VOLTAGES. IT CAN NOT INCLUDE IN LINE VOLTAGE

COMBINED 3rd HARMO

$V_1 = E_1 +$

$V_2 = E_2 +$

$V_1 = E_1 +$

$V_2 = E_2 +$

$V_{12} = V_1 - V_2 = (E_1 -$

$= (E_1 + E$

$= (E_1 +$

$= E_1 +$

$= E_1 -$

... ON THIRD HARMONIC

... ON THIRD HARMONIC

...RD HARMONIC

...IC TYPE MAGNETIC

E_1, E_2, E_3 = PHASE VOLTAGES

V_{12}, V_{23}, V_{31} = LINE VOLTAGE

$V_{12} = E_1 - E_2$

$V_{23} = E_2 - E_3$

E_2 $V_{31} = E_3 - E_1$

...MONIC CAN ONLY INCLUDE ...SE VOLTAGES. IT CAN NOT ...BE IN LINE VOLTAGE

COMBINED 3^{rd} HARMONIC

$V_1 = E_1 + E_{3^{rd}\ \text{harmonic}}\ (ph_1)$

$V_2 = E_2 + E_{3^{rd}\ \text{harmonic}}\ (ph\ 2)$

$E_{3rd\ ph1} = E_{3max} \sin 3\omega t \longrightarrow$ PHASE 1

$E_{3^{rd}\ \text{harmonic}\ ph\ 2} = E_{3max} \sin 3(\omega t - 120) \longrightarrow$ PHASE 2

$\sin(A-B) = \sin A \cos B - \cos A \sin B$

$V_1 = E_1 + E_{3max} \sin 3\omega t$

$V_2 = E_2 + E_{3max} \sin 3(\omega t - 120) = E_2 + E_{3max} \sin(3\omega t - 360)$

$V_{12} = V_1 - V_2 = \left(E_1 + E_{3max} \sin 3\omega t\right) - \left[E_2 + E_{3max} \sin(3\omega t - 360)\right]$

$= \left(E_1 + E_{3max} \sin 3\omega t\right) - \left(E_2 + E_{3max}\left(\sin 3\omega t \underbrace{\cos 360}_{1} - \cos 3\omega t \underbrace{\sin 360}_{0}\right)\right)$

$= \left(E_1 + E_{3max} \sin 3\omega t\right) - \left(E_2 + E_{3max} \sin 3\omega t\right)$

$= E_1 + \cancel{E_{3max} \sin 3\omega t} - E_2 - \cancel{E_{3max} \sin 3\omega t})$

$= E_1 - E_2$

Q5

THIRE HARMONIC VOLTAGES EXIST IN THE PHASE, BUT CAN NOT EXIST IN THE LINE VOLTAGE.

THE THIRD HARMONIC CURRENTS FLOW IN THE PHASES AND THE LINES AND RETURIN IN THE FOURTH WIRE

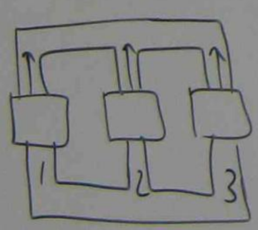
Q6

THE THIRD HARMONIC VOLTAGES IN THE 3 PHASES ARE IN SERIES AROUND DELTA AND THEY CAUSE A THIRD HARMONIC CURRENT TO CIRCULATE.

IT IS NOT POSSIBLE TO MEASURE THE THIRD HARMONIC VOLTAGE WHILE THE DELTA IS CLOSED AS IT CAUSES THE THIRD HARMONIC CURRENT TO FLOW IN THE PHASES. NO THIRD HARMONIC CURRENT EXISTS IN LINES BUT IT EXISTS IN PHASES

Q7

CORE TYPE

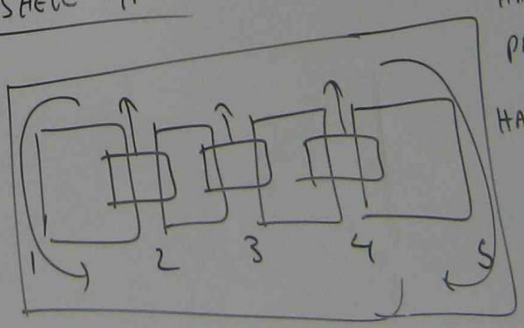


3 LIMBS

THERE IS NO HARMONIC RETURN PATH.

HARMONIC WILL INCLUDES IN LINE CURRENTS.

SHELL TYPE



5 LIMBS

HARMONIC RETURN PATH IS PROVIDED.

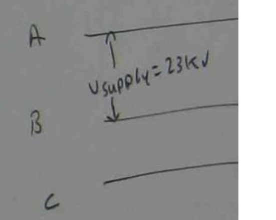
HARMONIC WILL ONLY CIRCULATE IN CORE. IT WILL NOT FLOW OUT

Q8

A 100 MVA 3

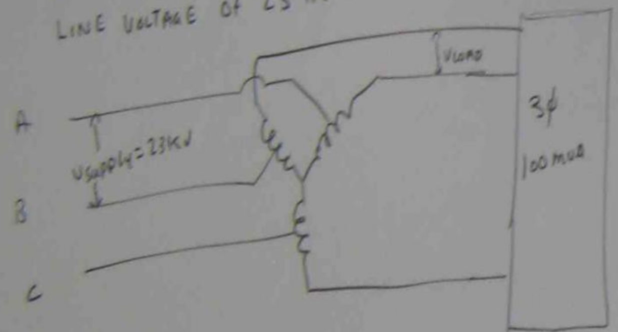
AUTO TRANSFORME

LINE VOLTAGE



(a)

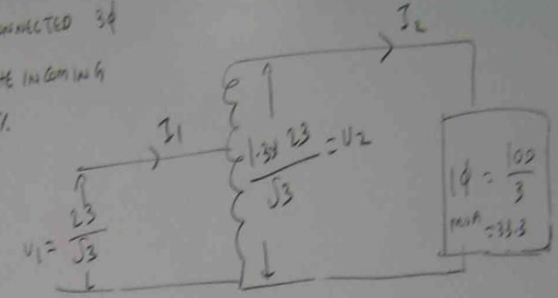
Q8 A 100 MVA 3ϕ LOAD IS TO BE SUPPLIED BY A STAR CONNECTED 3ϕ AUTO TRANSFORMER WHOSE CONNECTIONS ARE SHOWN BELOW. THE INCOMING LINE VOLTAGE OF 23 KV IS TO BE BOOSTED BY 30%



(a) CALCULATE THE CURRENTS IN THE AUTO TRANSFORMER WINDINGS

(b) CALCULATE APPARENT POWER RATING OF AUTO TRANSFORMER.

...RMONIC RETURN
...ATH IS PROVIDED.
...RMONIC WILL ONLY
CIRCULATE IN
CORE. IT WILL NOT
FLOW OUT



$V_1 = \frac{23}{\sqrt{3}} = 13.27$ KV

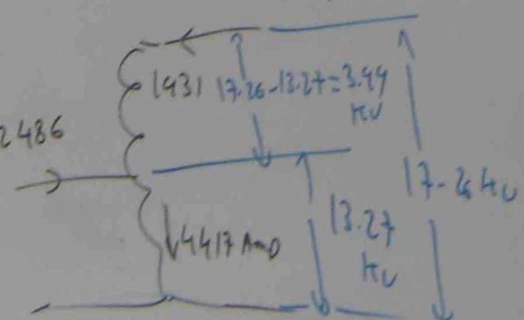
$V_2 = 1.3 \times \frac{23}{\sqrt{3}} = 17.26$ KV

$$I = \frac{V.A}{VOLTAGE}$$

$$I = \frac{MVA \times 10^3}{KVA/Ph}$$

$$I_2 = \frac{33.33 \times 10^3}{17.26} = 1931 \text{ Amp.}$$

$$I_1 = \frac{33.33 \times 10^3}{13.27} = 2486 \text{ Amp.}$$



$$\text{TOTAL POWER} = \frac{1931 \times 3.99}{1000} + \frac{13.27 \times 4417}{1000}$$

$$= 66.3 \text{ MVA}/Ph$$

$$3\phi = 66.3 \times 3 = 198 \text{ MVA}$$

REVIEW QUESTIONS

1. SKETCH CORE TYPE AND SHELL TYPE 3ϕ TRANSFORMER

2. WHAT ARE MAJOR INSULATION AND MINOR INSULATION

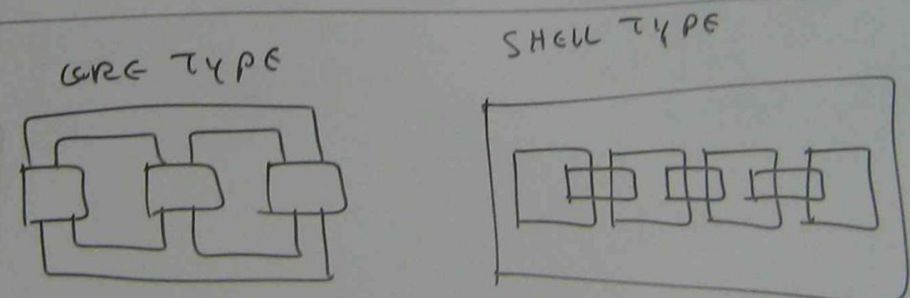
3. CALCULATE IRON CORE FLUX DENSITY AND RMS MAGNETIZING CURRENT FOR THE FOLLOWING SINGLE PHASE TRANSFORMER

   $N_p = 400$, $E_p = 3000$ V RMS, $f = 60$ Hz

   CORE C.S.A = 200 sq cm, CORE LENGTH = 230 cm

   AIR GAP = 0.4 mm $\mu_r = 1900$

1.



2. MAJOR INSULATION – INSULATION BETWEEN WINDING AND CORE

   INSULATION BETWEEN HV AND L.V WINDING

   MINOR INSULATION – INSULATION BETWEEN TRANSFORMER TURNS

③ $E_p = 4.44\ \phi\ f\ N$

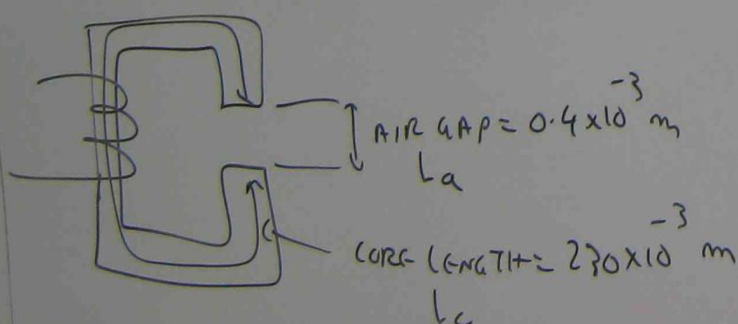
$3000 = 4.44 \times \phi \times 60 \times 400$

$\phi = \dfrac{3000}{4.44 \times 60 \times 400}$

$= 0.0282\ wb$

FLUX DENSITY $B = \dfrac{\phi}{A} = \dfrac{0.0282}{200 \times (10^{-2})^2} = 1.41\ T$

$H = \dfrac{B}{\mu_0 \mu_r}$



$\boxed{\sum HL = N \times I}$

$H_{air} \times L_{air} + H_{CORE} \times L_{CORE} = N \times I$

$\dfrac{B}{\mu_0 \times \mu_{r\,AIR}} \times L_{air} + \dfrac{B}{\mu_0\, \mu_{r\,IRON}} \times L_{CORE} = 400 \times I$

$\dfrac{1.41}{4\pi \times 10^{-7} \times 1} \times 0.4 \times 10^{-3} + \dfrac{1.41}{4\pi \times 10^{-7} \times 1900} \times 230 \times 10^{-3} = 400 \times I$

$I = I_{MAX} = 4.52$ Amp

$I_{rms} = \dfrac{I_{MAX}}{\sqrt{2}} = \dfrac{4.52}{1.4142} = 3.2$ Amp.

REVIEW QUESTIONS

1. SKETCH CORE TYPE AND SHELL TYPE 3φ TRANSFORMER

2. WHAT ARE MAJOR INSULATION AND MINOR INSULATION

3. CALCULATE IRON CORE FLUX DENSITY AND RMS MAGNETIZING CURRENT FOR THE FOLLOWING SINGLE PHASE TRANSFORMER

$N_p = 400$, $E_p = 3000$ V RMS, $f = 60$ HZ

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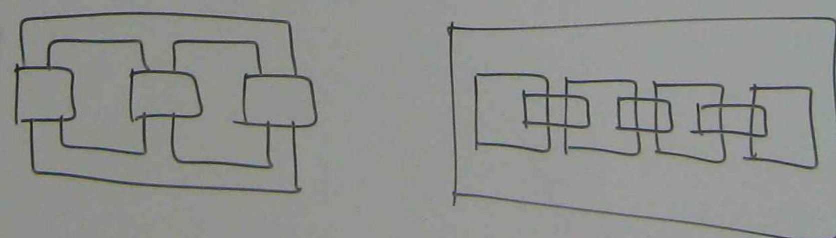
AIR GAP = 0.4 mm $\mu_r = 1900$

---

1. CORE TYPE SHELL TYPE



2. MAJOR INSULATION - INSULATION BETWEEN WINDING AND CORE

INSULATION BETWEEN HV AND L.V WINDING

MINOR INSULATION - INSULATION BETWEEN TRANSFORMER TURNS

(3) $E_p = 4.44\ \phi f N$

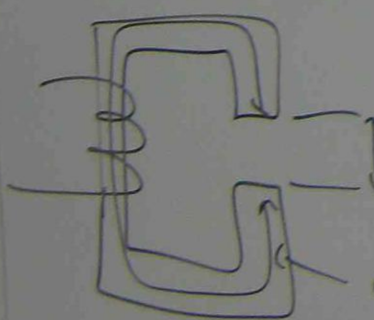
$3000 = 4.44 \times \phi \times 60 \times 400$

$\phi = \dfrac{3000}{4.44 \times 60 \times 400}$

$= 0.0282\ wb$

FLUX DENSITY $B = \dfrac{\phi}{A} = \dfrac{0.0282}{200 \times (10^{-2})^2} = 1.41\ T$

$H = \dfrac{B}{\mu_0 \mu_r}$



AIR GAP $= 0.4 \times 10^{-3}$ m

L_a

CORE LENGTH $= 230 \times 10^{-2}$ m

l_c

$\boxed{\sum HL = N \times I}$

$H_{air} \times L_{air} + H_{CORE} \times L_{CORE} = N \times I$

$\dfrac{B}{\mu_0 \times \mu_{r_{AIR}}} \times L_{air} + \dfrac{B}{\mu_0 \mu_{r_{IRON}}} \times L_{CORE} = 400 \times I$

$\dfrac{1.41}{4\pi \times 10^{-7} \times 1} \times 0.4 \times 10^{-3} + \dfrac{1.41}{4\pi \times 10^{-7} \times 1900} \times 230 \times 10^{-2} = 400 \times I$

$I = I_{MAX} = 4.52$ Amp

$I_{rms} = \dfrac{I_{MAX}}{\sqrt{2}} = \dfrac{4.52}{1.4142} = 3.2$ Amp.

(4) FIND ALL DAY EFFICIENCY OF THE FOLLOWING TRANSFORMER

200 KVA, 1φ IRON LOSS = 700W, FULL LOAD COPPER LOSS = 900 W

24 HR LOAD CYCLE

TIME	POWER FACTOR	OUT PUT
8 hr	pf 0.9 LAGGING	180 WATT
5 hr	pf 0.8 LAGGING	100 KVA
4 hr	30 KVA & 20 KW	
3 r	ENERGIZED WITH NO LOAD	
THE REST OF TIME	DE ENERGIZED	

TIME	LOAD RATIO	PF	LOAD	HR	KWH	$(\text{LOAD RATIO})^2 \times$ COPPER LOSS $\times$ HR	IRON LOSS $\times$ HR	TOTAL INPUT
8	$\frac{180/PF}{200} = \frac{180/0.9}{200} = 1$	0.9	180	8	1440 W-HR = 1.44 KWH	$(1)^2 \times 900 \times 8$ = 7200 wh = 7.2 kwh	700 x 8 = 5600 = 5.6 kwh	14.24 kwh
5 hr	$\frac{100/PF}{200} = \frac{100/.8}{200} = 0.625$	0.8	100 x 0.8 = 80 kw	5	400 kwh	$(0.625)^2 \times 900 \times 5$ = 1.757	700 x 5 = 3500 = 3.5 kwh	405.25 kwh
4 hr	$\frac{30}{200} = 0.15$		20	4	80 kwh	$(0.15)^2 \times 900 \times 4$ = 0.081	700 x 4 = 2800 = 2.8 kwh	82.881 kwh
3 hr			0			0	700 x 3 = 2100 = 2.1 kwh	2.1 kwh
				TOTAL O/P	481.44 kwh		TOTAL I/P	504.37 kwh

ALLDA

EFFICIE

	$(\text{LOAD RATIO})^2 \times$ COPPER LOSS $\times$ HR	IRON LOSS $\times$ HR	TOTAL INPUT
0 W-HR kWH	$(1)^2 \times 900 \times 8$ = 7200 wh = 7.2 kwh	$700 \times 8 = 5600$ = 5.6 kwh	14.24 kwh
kwh	$(0.625)^2 \times 900 \times 5$ = 1.757	$700 \times 5 = 3500$ = 3.5 kwh	405.25 kwh
kwh	$(0.15)^2 \times 900 \times 4$ = 0.081	$700 \times 4 = 2800$ = 2.8 kwh	82.881 kwh
	0	$700 \times 3 = 2100$ = 2.1 kwh	2.1 kwh
44 h		TOTAL I/P	504.37 kwh

$$\text{ALLDAY EFFICIENCY} = \frac{\text{o/p kwh}}{\text{I/p kwh}} \times 100$$

$$= \frac{481.44}{504.37} \times 100$$

$$= 95.45\%$$