Chapter 8b

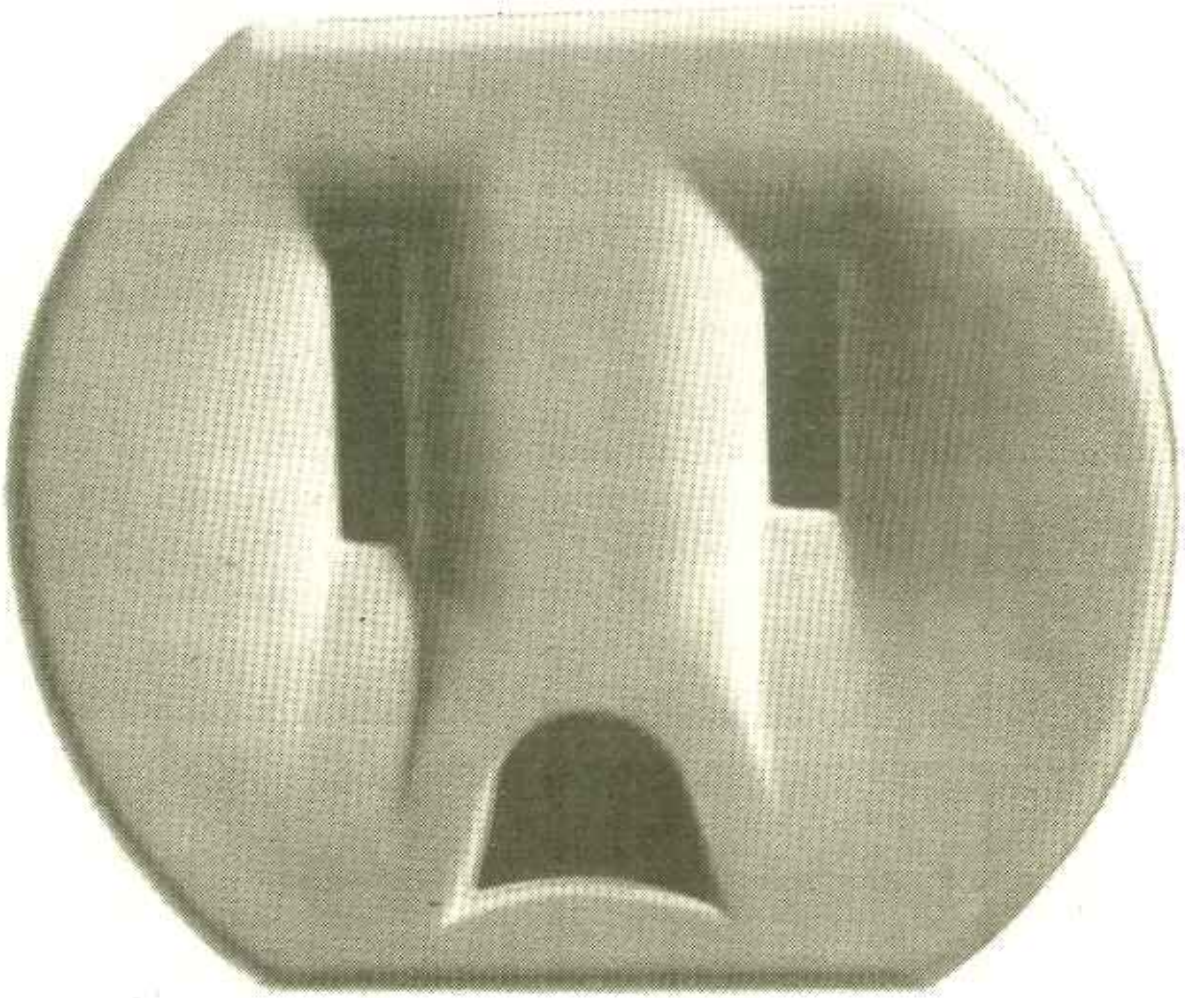
Topics:

- Talks
- Three Phase Review
  - Wye
  - Delta
- Homework
- Unbalanced Three Phase

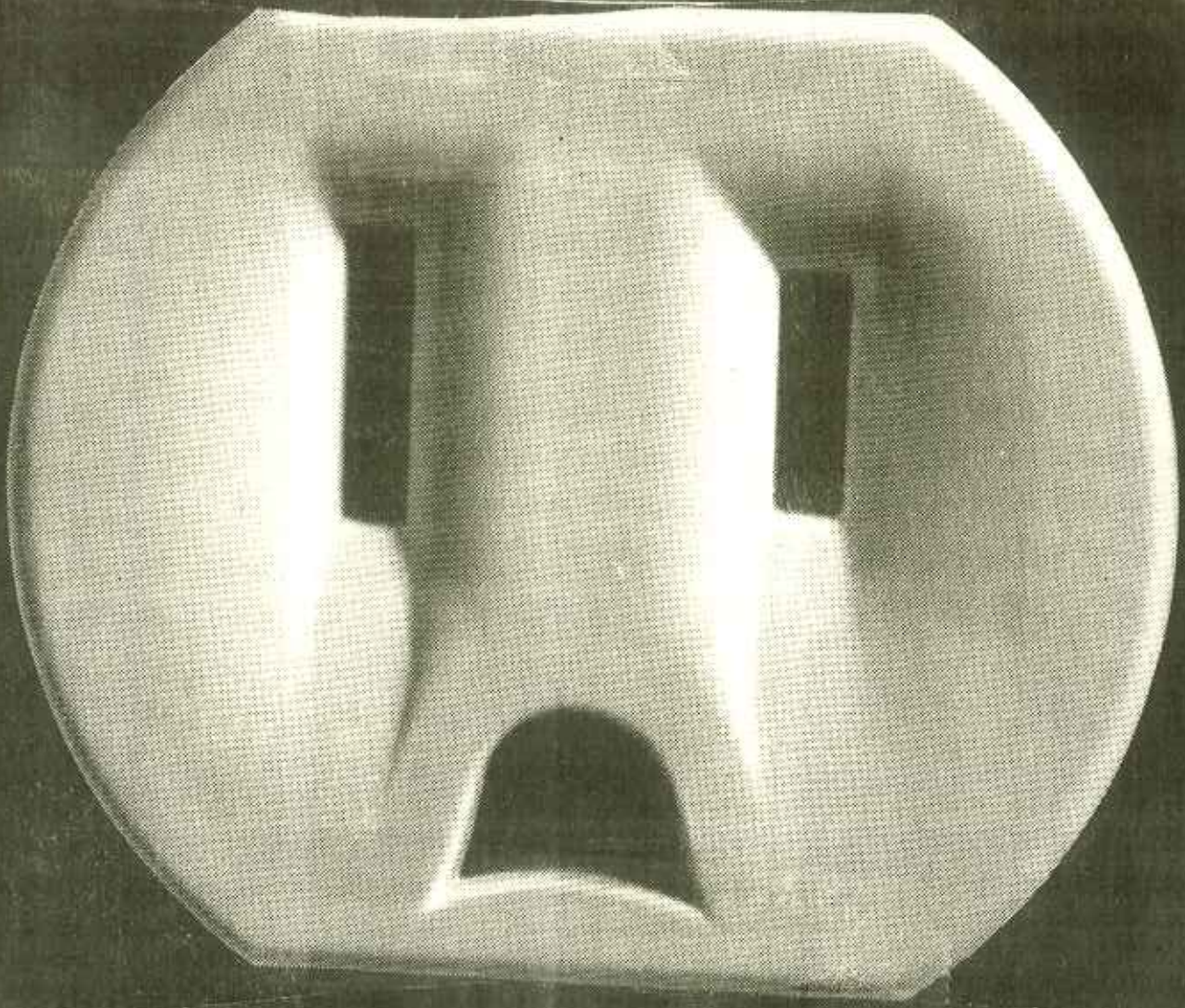
"That's my favorite story. But tonight I'd like to hear both sides."

Nuclear vs Solar vs Coal vs Wind

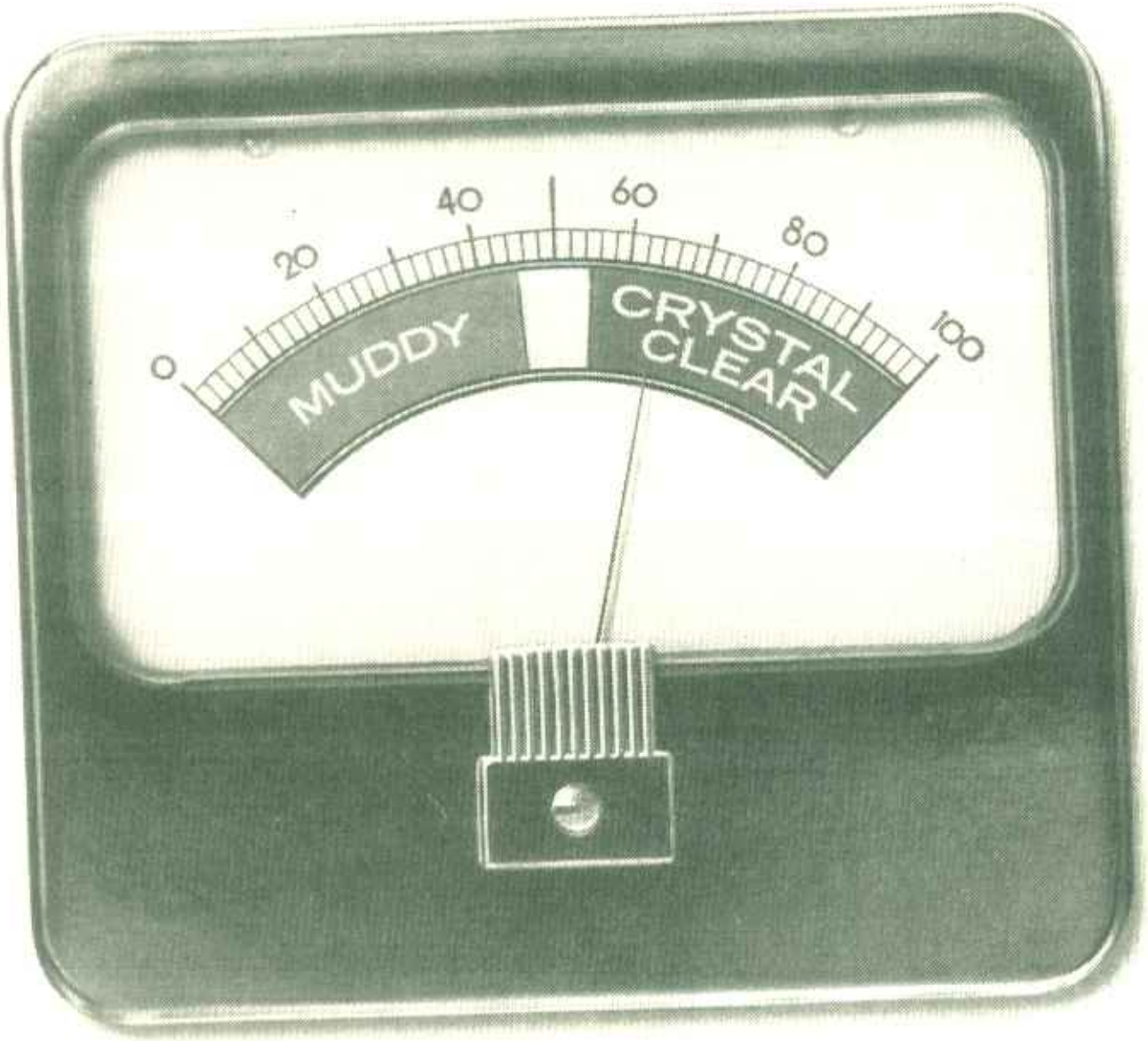
Meet Sad Socket



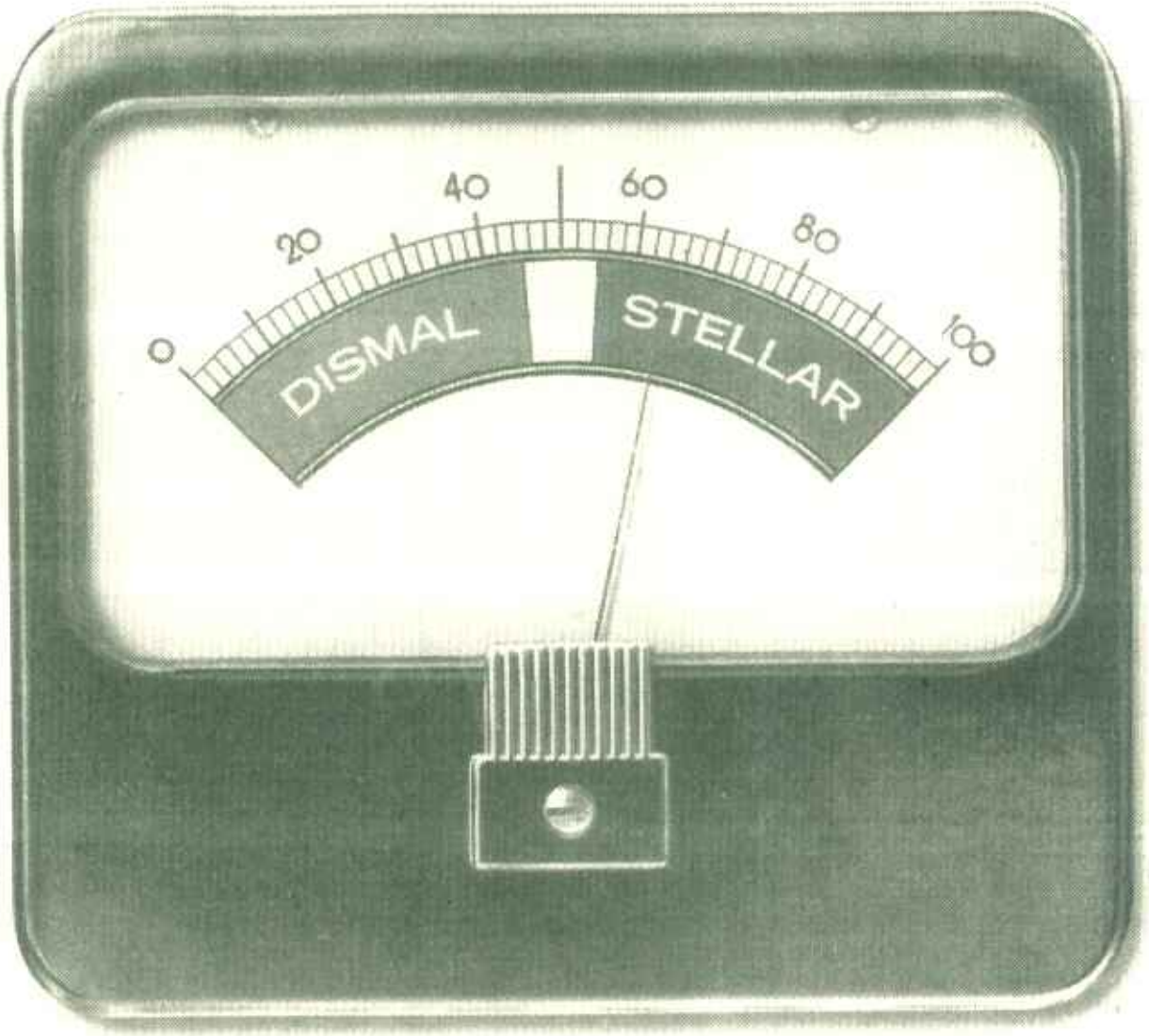
Sad Socket



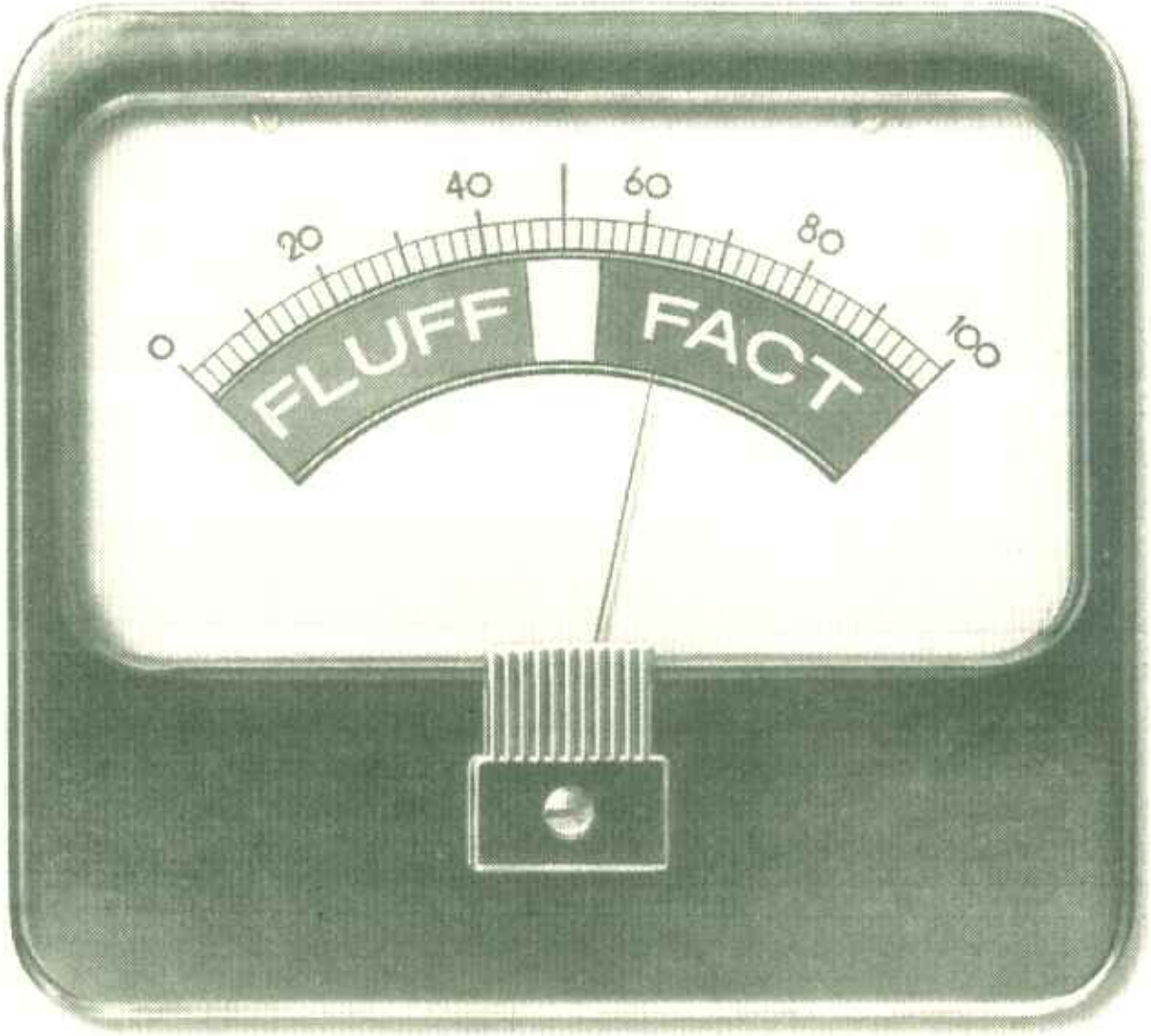
Gets Smart



CLARITY



PERFORMANCE

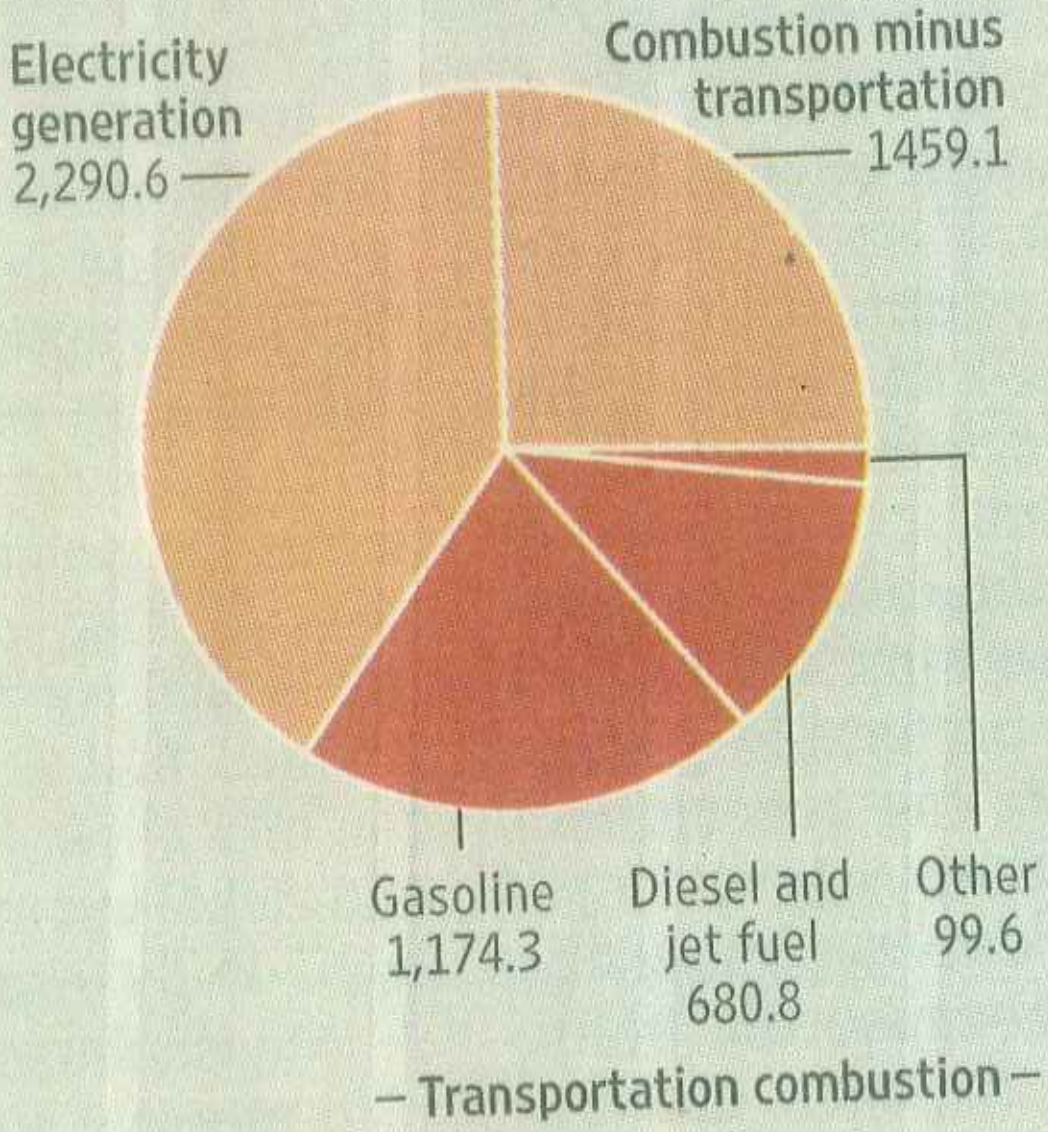


HONESTY


0
20
40
60
80
100
LOW
HIGH
RISK

Watts and Miles

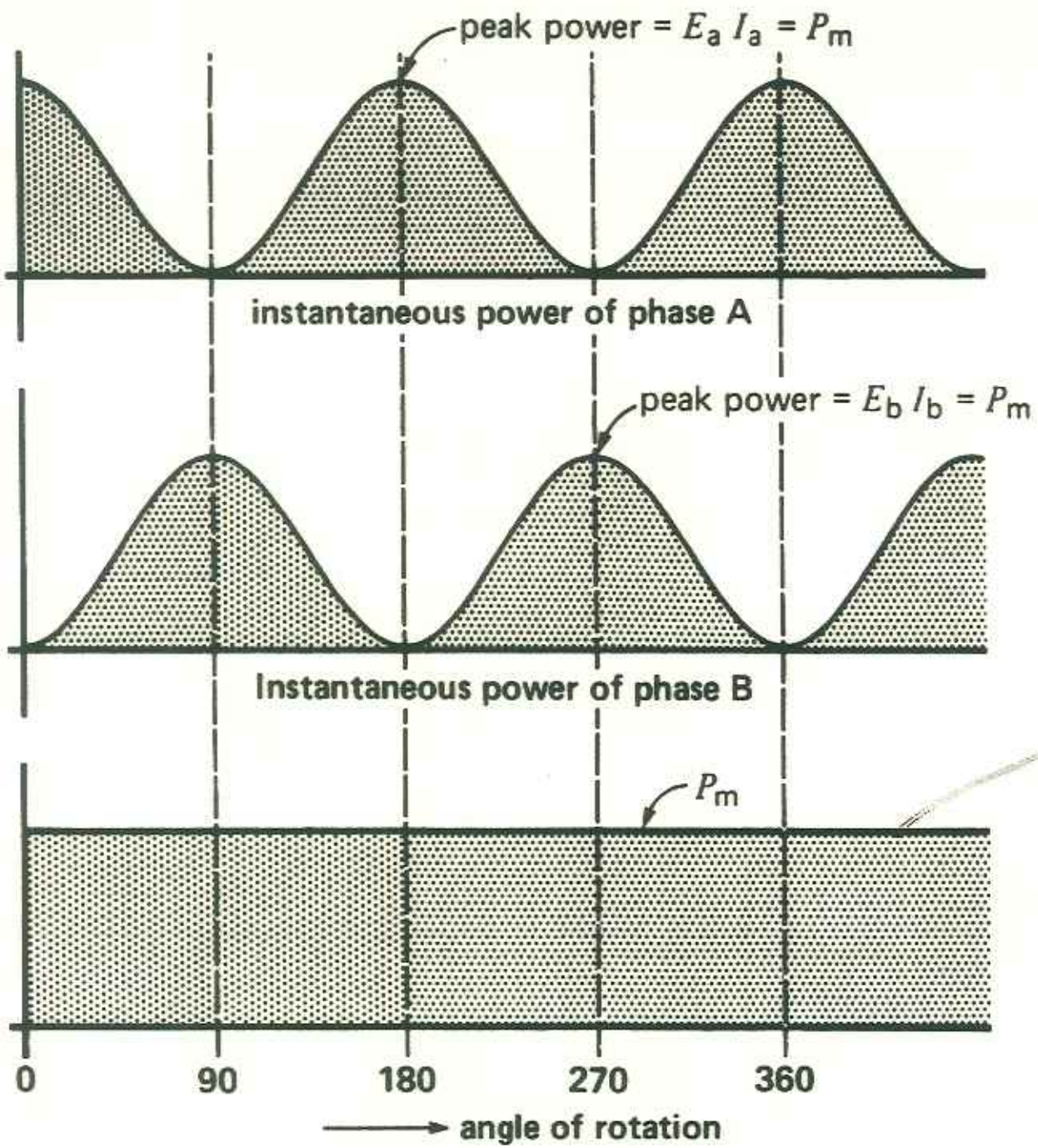
U.S. carbon-dioxide emissions from fossil-fuel combustion by end-use sector, in teragrams of carbon dioxide



Note: Doesn't include U.S. territories

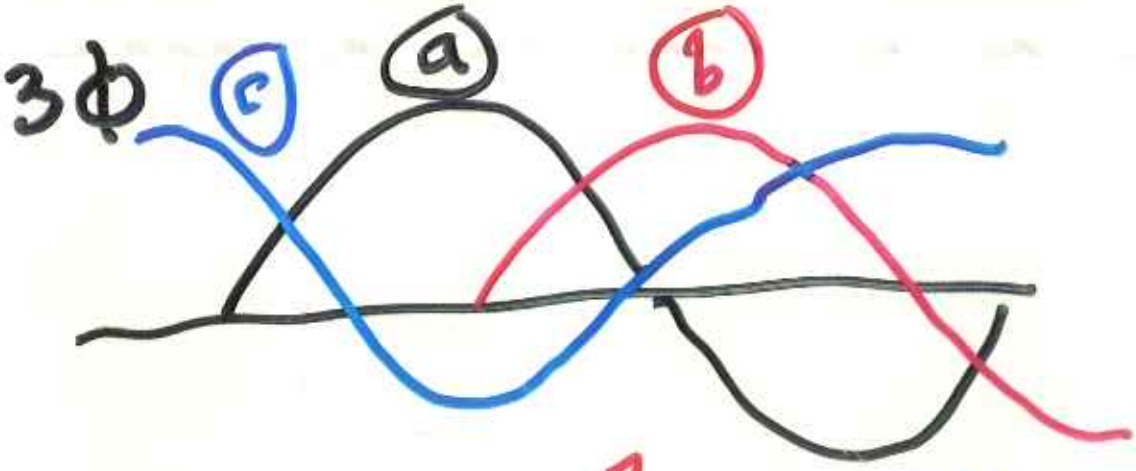
Source: Environmental Protection Agency

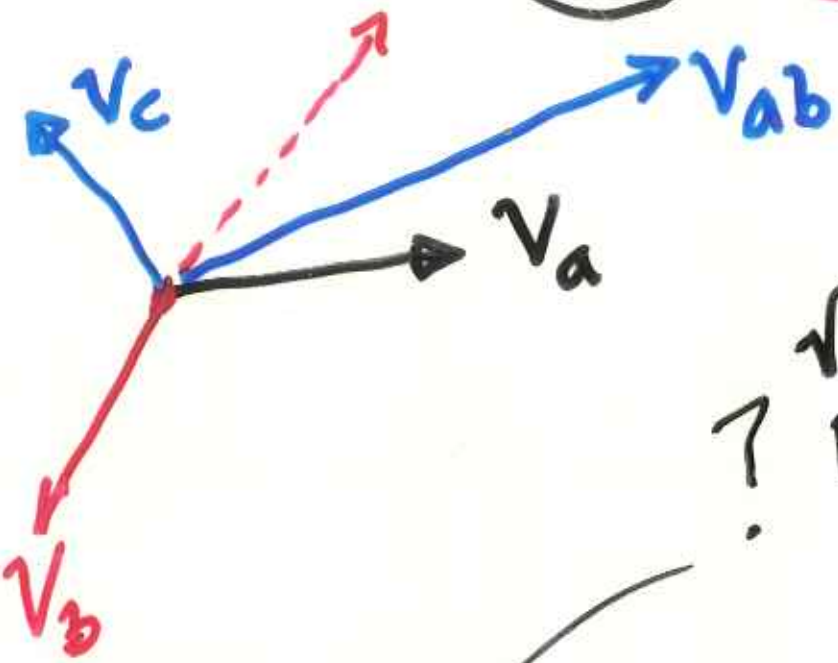
...an of pollutants ... ut



Total instantaneous power output

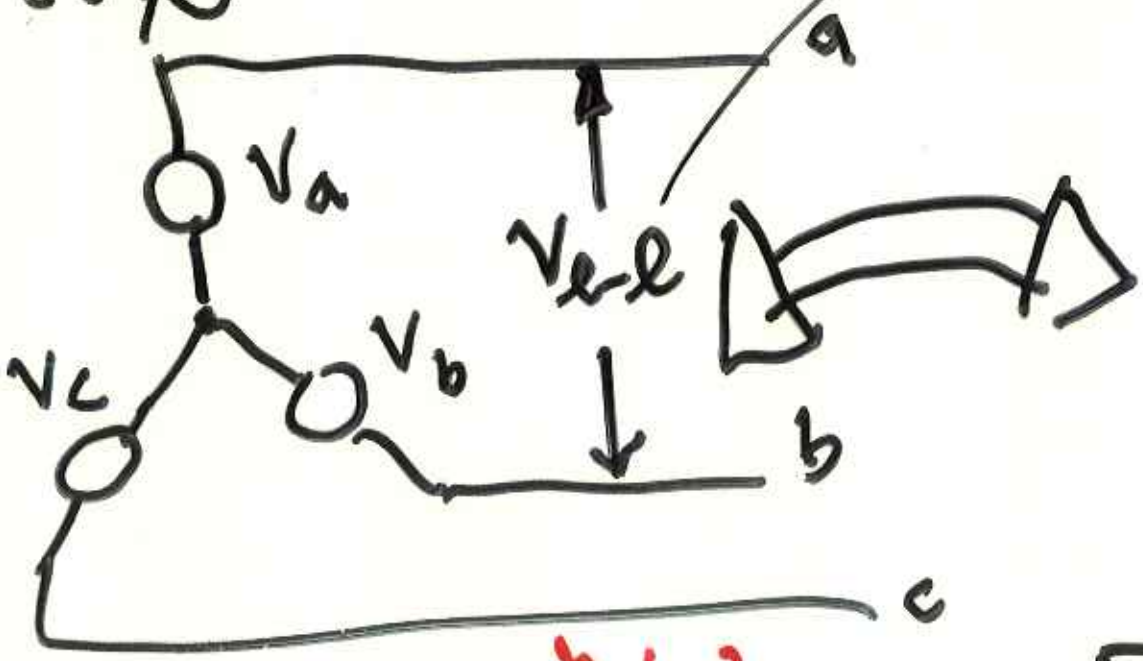
2 1Φ
90° apart
easy to
prove
why
$P \neq f(t)$





$\sqrt{3}$ * ? leading 30°

Wye



Per phase circuit for balanced

$|V_{l-l}| = \sqrt{3}\,|V_\phi|$

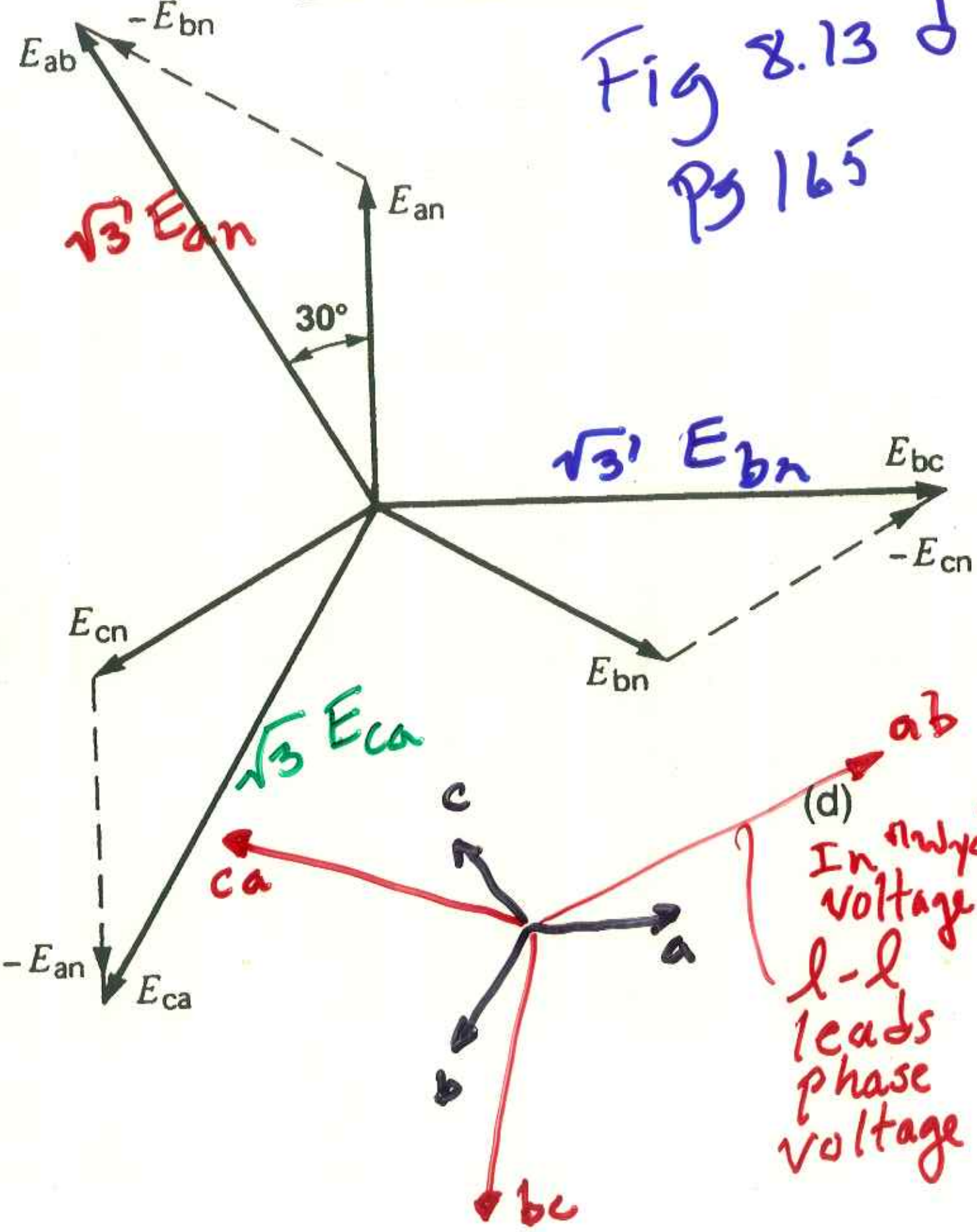
V_{ab} vs V_a who LAGS

15

Summary $\sqrt{3}$ & 30°

Fig 8.13 d

pg 165



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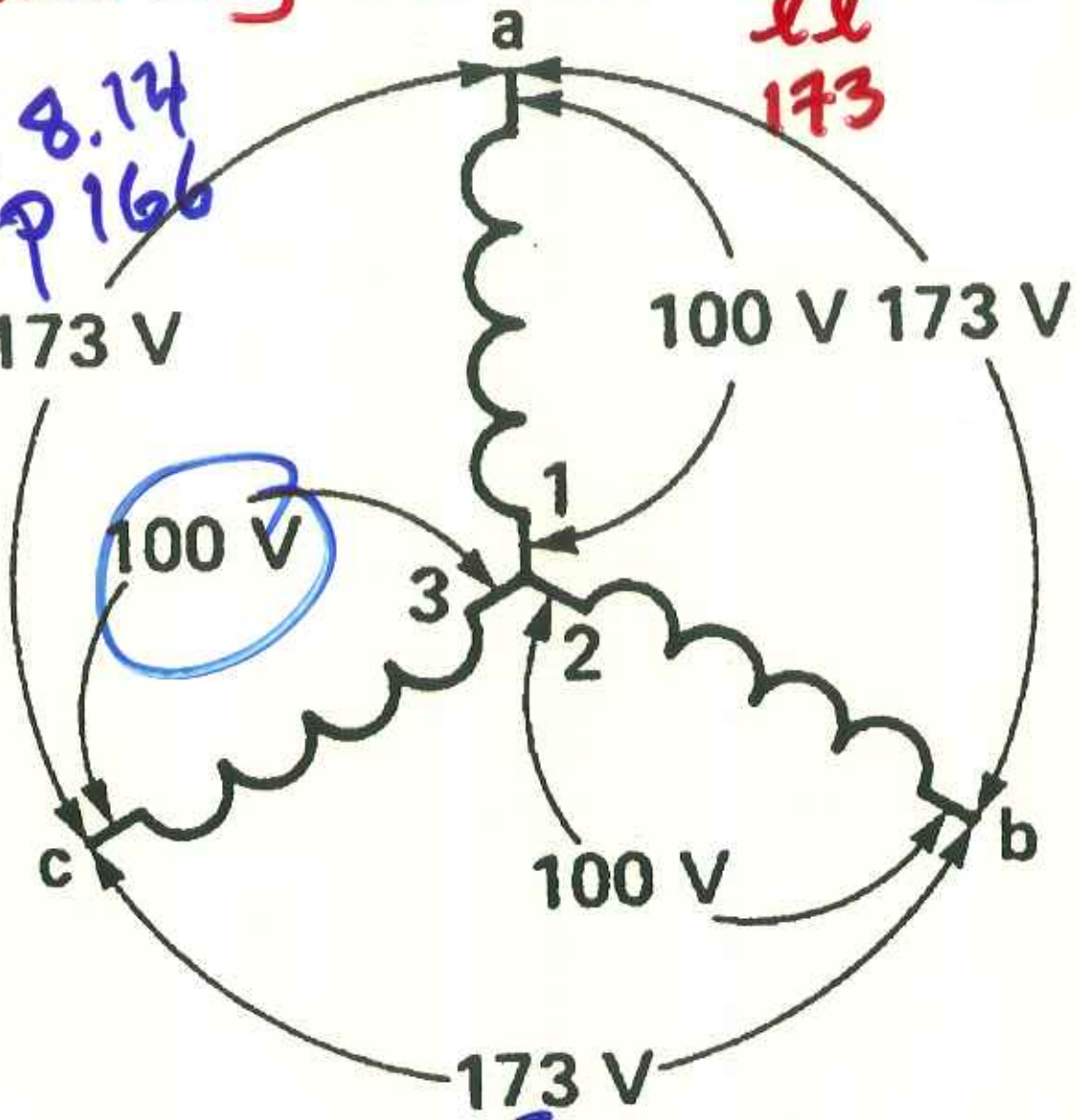
$V_{ln} = 100\ V$ on each coil

Due to "Wye" wiring among coils $E_{ll} = \sqrt{3}\, E_{coil}$

173 100

Fig 8.14 p 166



If $E_{coil} = E_{ll}/\sqrt{3}$

Common Distribution Voltages!

23.9 KV line-line $\Rightarrow$ 13.8 KV l-n

$V_{peak}(l\text{-}l) = \sqrt{2}\ 23.9 = 33.8\ KV$

Design for peak

$$Z = \sqrt{X^2 + R^2} = \sqrt{4^2 + 3^2} = 5$$

Wye phase voltage:

$$V_\phi = \frac{440}{\sqrt{3}} = 254\ V$$

Given the circuit below:

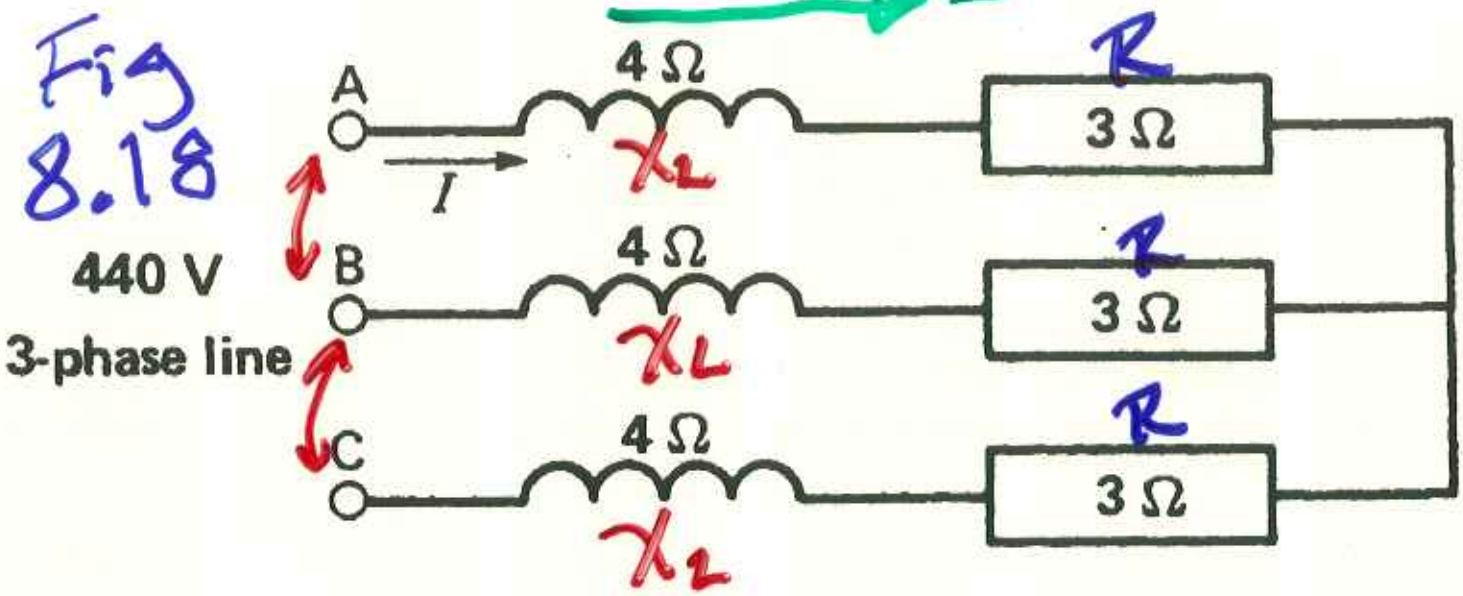
$I_{line} =$?

$I = ?$

$I = \frac{254}{151}$

$|I| = 50.8$

Fig 8.18



2.4kV ll

2400

2400

$S = 600\,kVA$

$PF = .8$ lag

$V_\phi = \frac{V_{ll}}{\sqrt{3}}$

$I_{line} = I_{phase}$

$|Z_Y|$, $|Z|$ model

8-24

a. $I = \frac{600\,000}{2400 \times \sqrt{3}} = 144\,A$ $\quad |Z_Y| = \frac{2400}{\sqrt{3} \times 144} = 9.6\,\Omega$

Find 1 of 2: X R

b. $P = 600 \times 0.8 = 480\,kW = 160\,kW$ per phase

$Q = 600 \times 0.6 = 360\,kvar = 120\,kvar$ per phase

$I^2 X = 120\,000 \quad \therefore X = \frac{120\,000}{144^2} = 5.79\,\Omega$

$I^2 R = 160\,000 \quad R = 160\,000/144^2 = 7.72\,\Omega$

$V_\phi = \frac{2400}{\sqrt{3}}$ $\quad |Z_{ln}|$ 2400 $\quad \boxed{Z}$

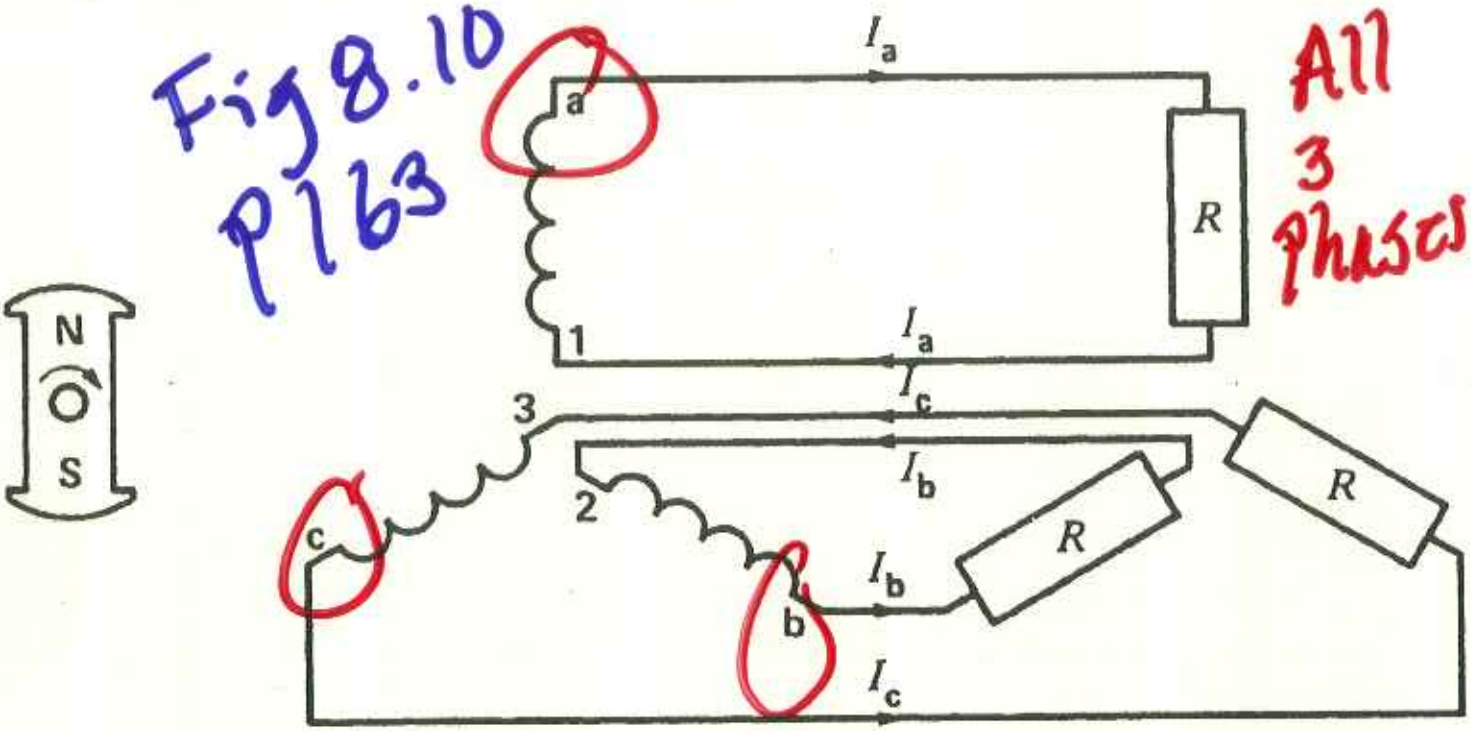
$\angle Z_{ln}$ + or − value

$\angle .6$

⑨ 3Φ Wiring

It 1st appears to have a 3 resistor load we need ? wires

Fig 8.10 p163



All 3 phases

Wires cost $. CAN we do a better wiring job ??? Use less wire?

$\sum i = ?$

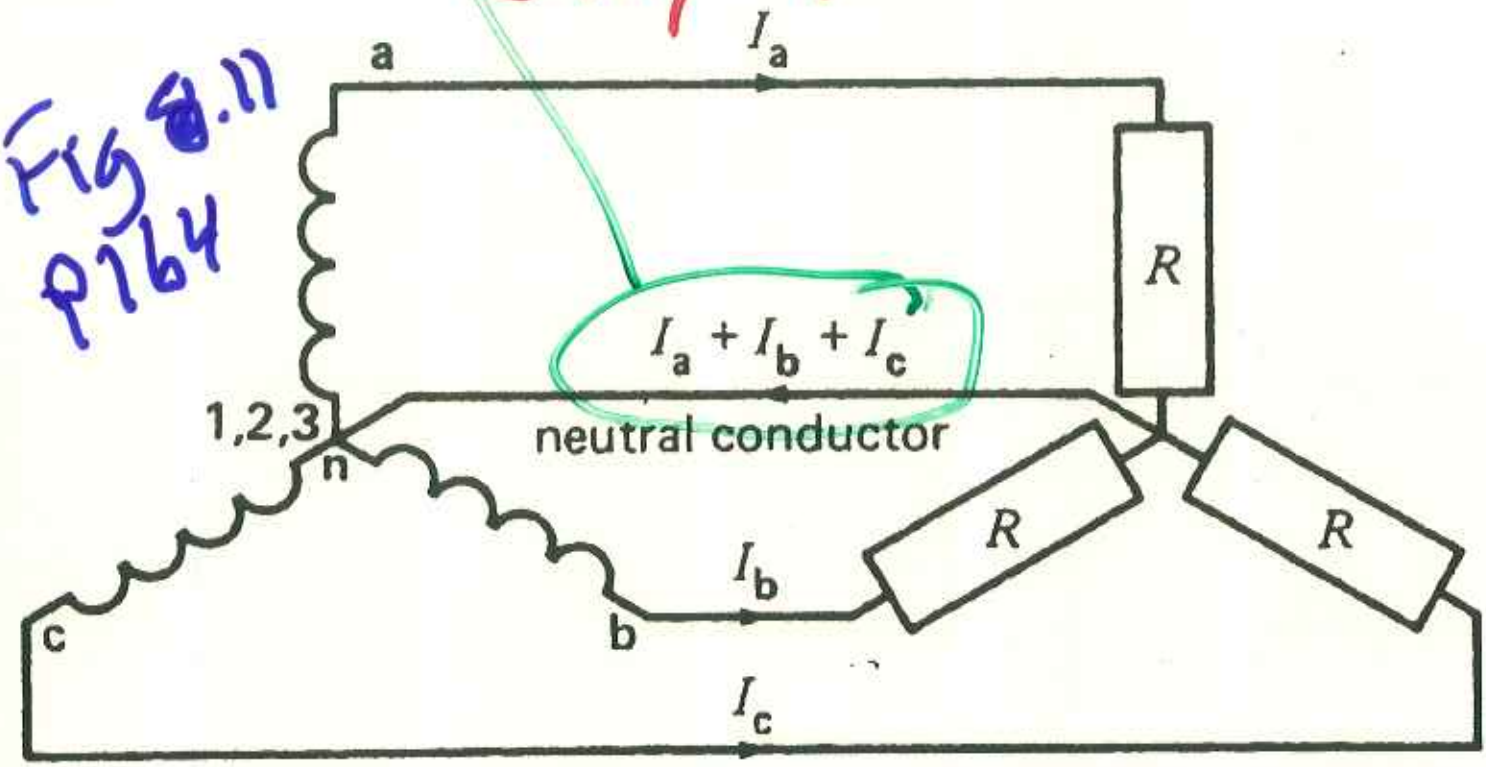
3ϕ 3W Kills

Could we even use a smaller area wire to save more $?

After all $\Sigma i = 0$

Only 4 wires not 6

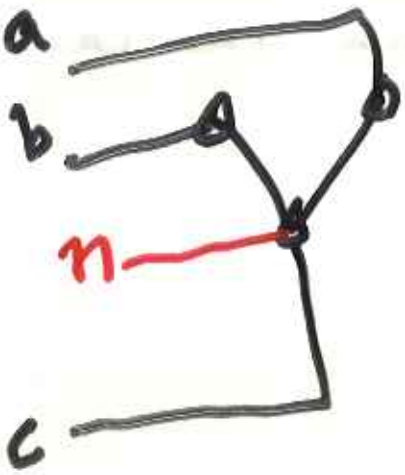
Fig 8.11 p164



What about

- unbalanced 3ϕ i
- Harmonic Currents

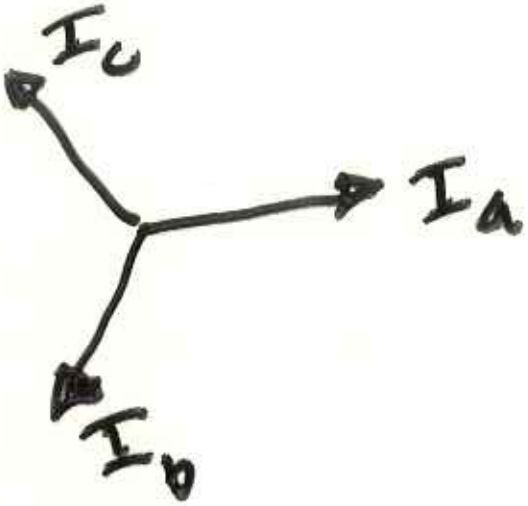
i_{3W} (neutral) = ?



$I_n = ?$

mains 3 ϕ balanced

$\Rightarrow$ What



What about harmonics at 3ω

$I_n(3\omega) = ?$

Σi @ node convention

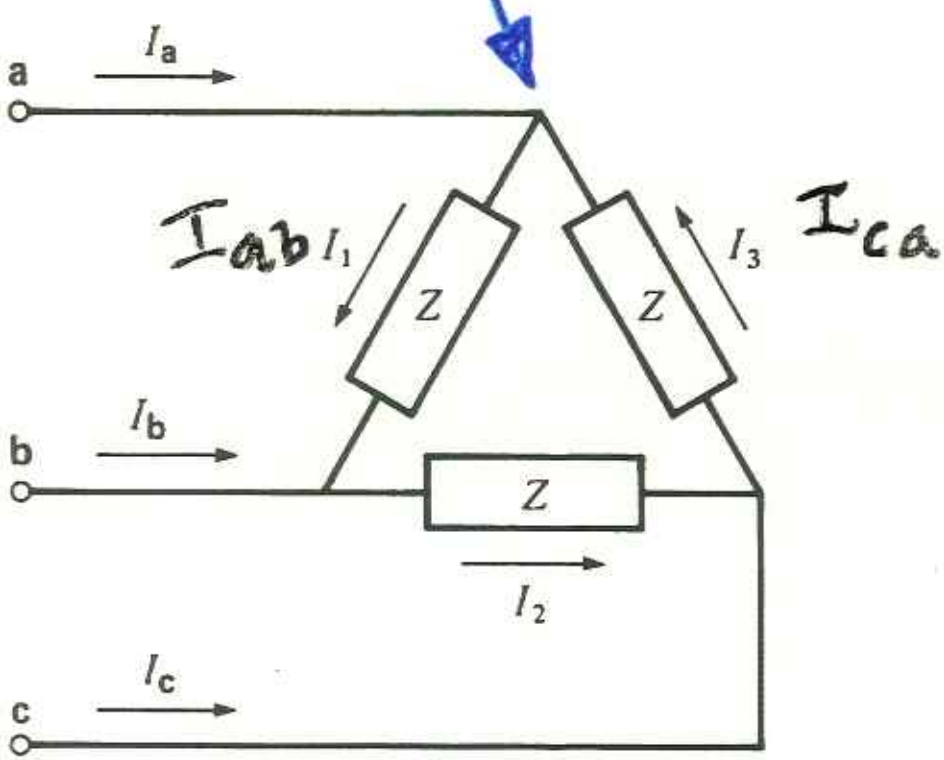
i into node is (+)

I_1, I_3 are phase current

@ node a $\quad I_a + I_3 - I_1 = 0$

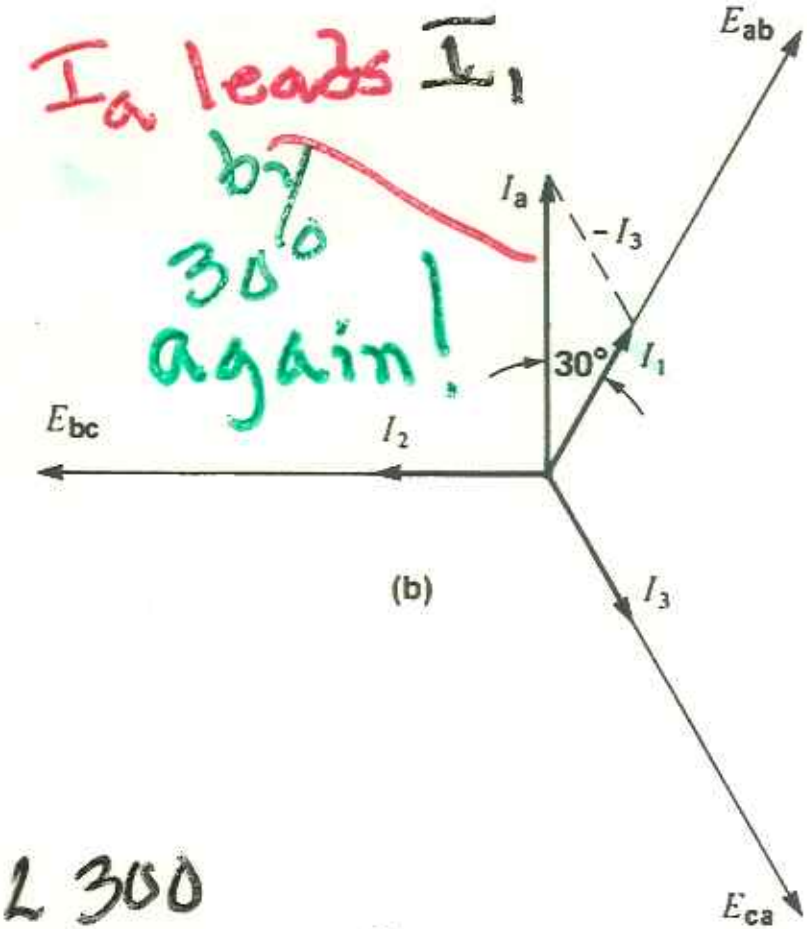
$I_a = I_1 - I_3$

I_a is line current



(a)

I_a leads I_1 by 30° again!



(b)

If $I_1 \angle 60$

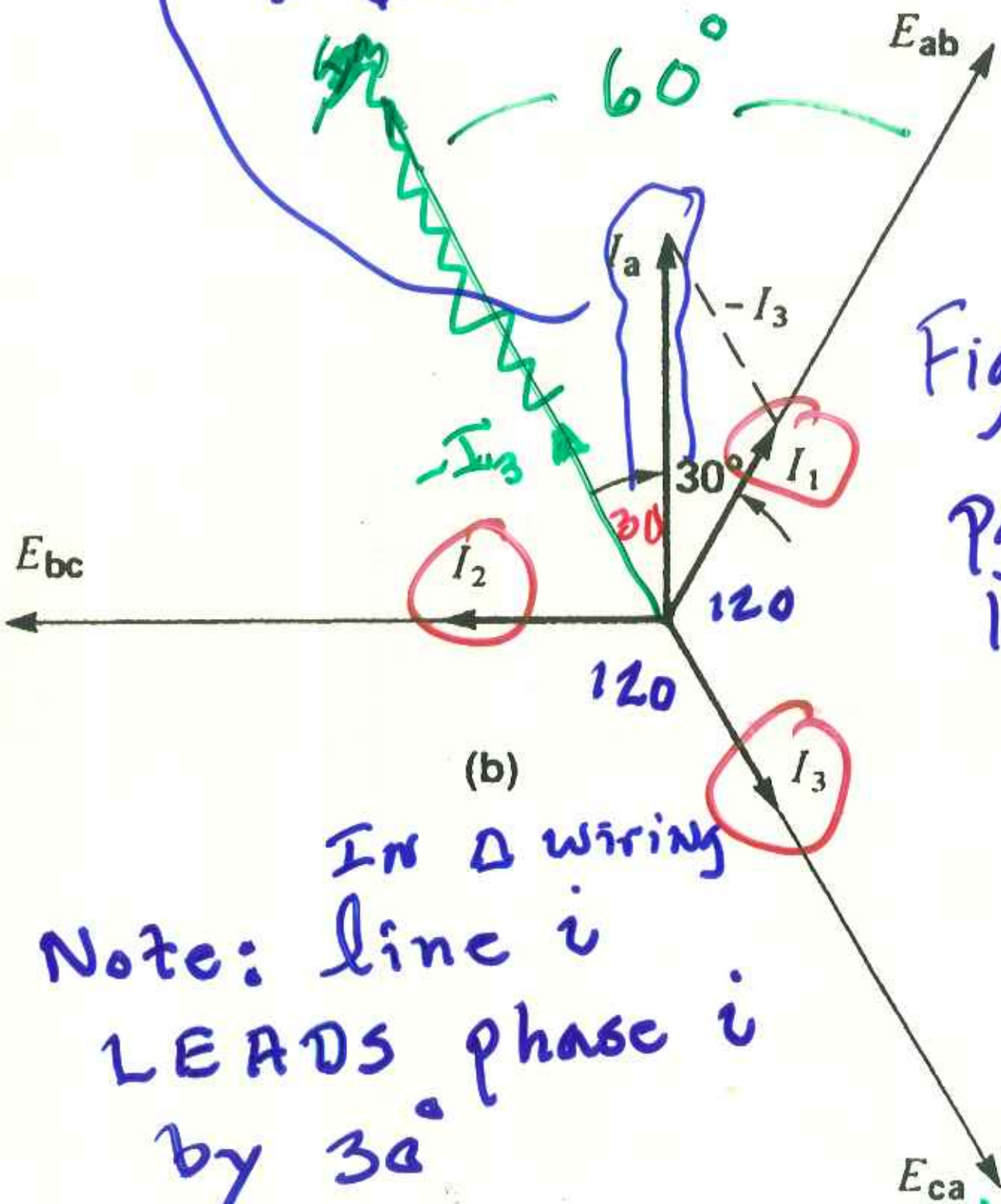
Then $I_2 \angle 180$, $I_3 \angle 300$

$|\text{line current}| = \sqrt{3}\,|I_\phi|$ Again!

18

$|I_a| = I_1 - I_3 = \sqrt{3}\,|I_\phi|$

$= 2 I_\phi \cos 30$



(b)

Fig 8.15 b

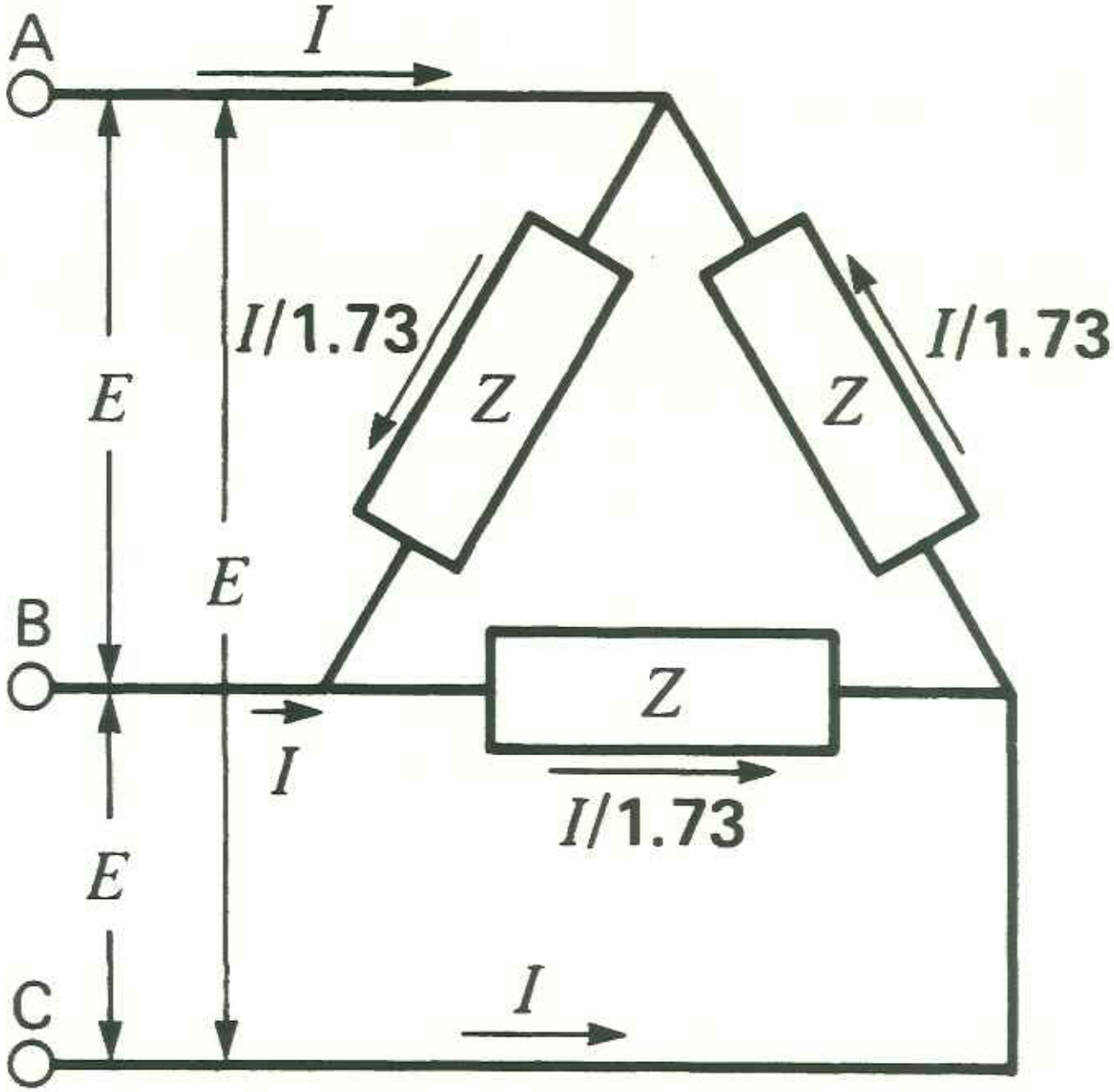
Pg 167

In Δ wiring

Note: line i LEADS phase i by 30°

I_a leads I_1

line i leads phase i


A
B
C
I
I/1.73
I/1.73
I/1.73
E
E
E
Z
Z
Z
I
I

Σi convention : in is positive

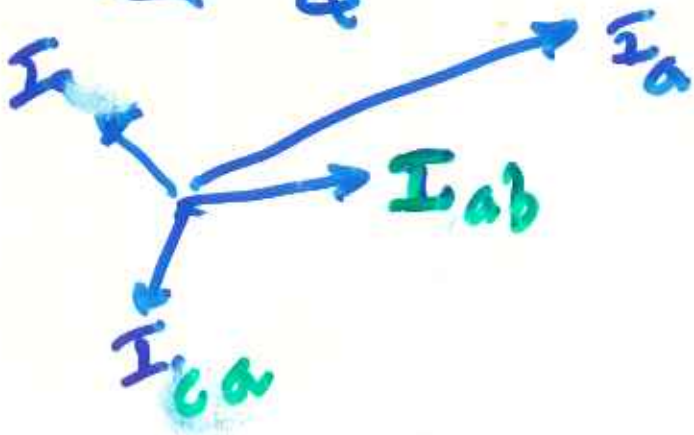
$$I_a + I_{ca} - I_{ab} = 0$$

Impedances connected in delta

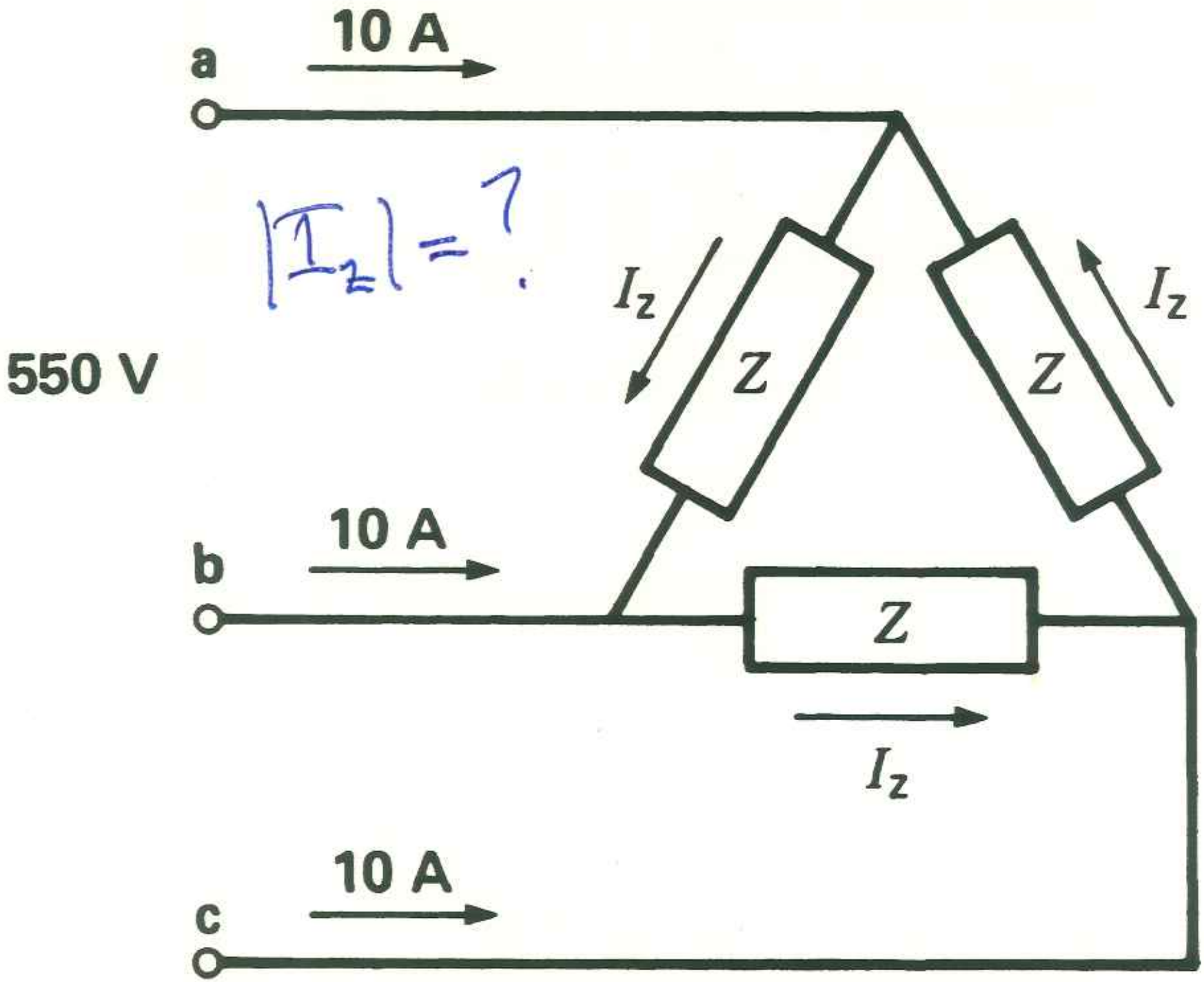
$$I_a \equiv I_{ab} - I_{ca}$$

- The current in each element is equal to the line current I divided by $\sqrt{3}$.
- The voltage across each element is equal to the line voltage E.
- The voltages across the elements are 120° out of phase.
- The currents in the elements are 120° out of phase.

$\angle I_\phi$ wrt $\angle I_{line}$



line leads phase


10 A
a
$|I_z| = ?$
550 V
I_z
Z
Z
I_z
10 A
b
Z
I_z
10 A
c

19 Given: V_{ll} and I_L for Delta

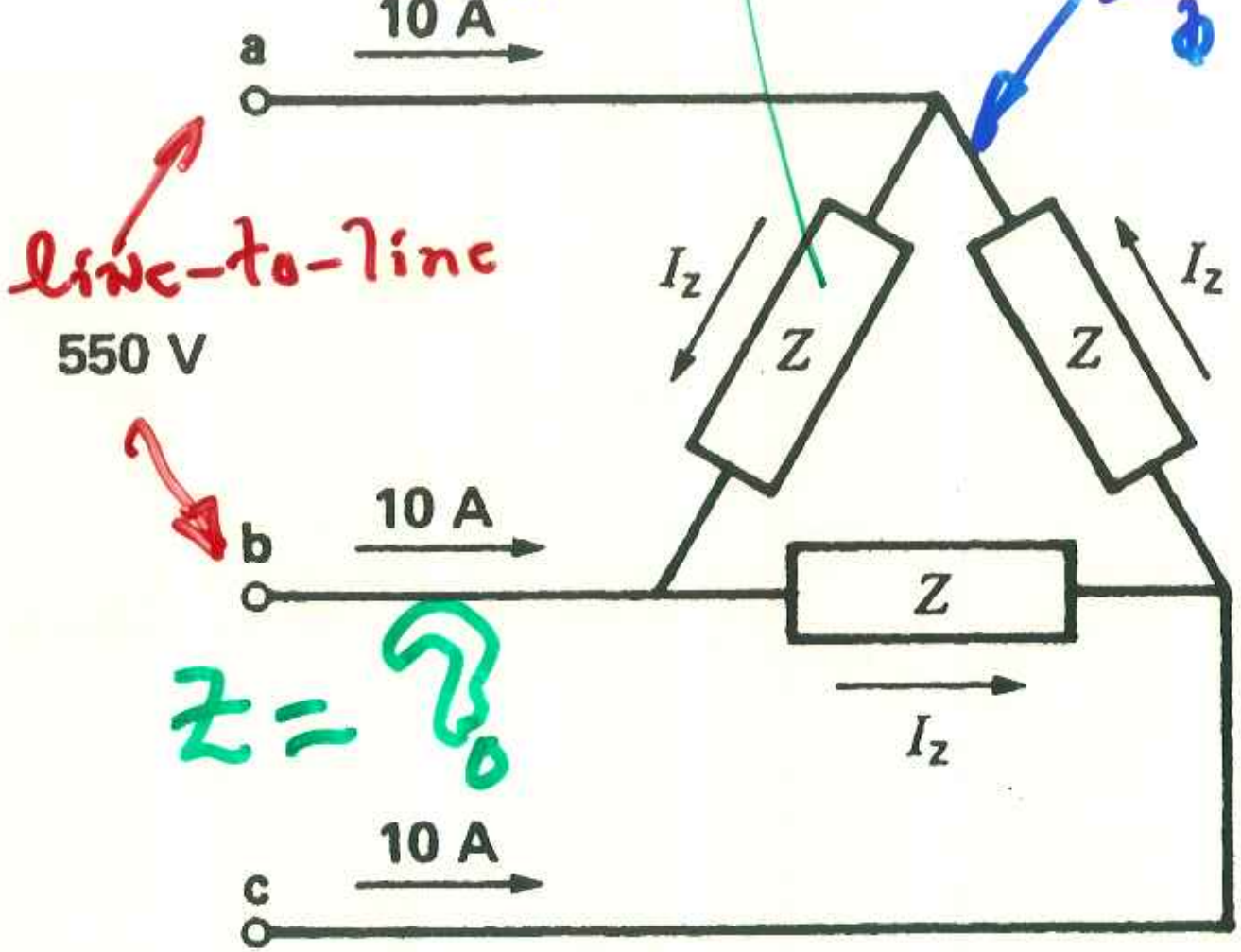
$Z = ?$

Fig 8.15c
pg 168

$$Z = \frac{V_{l-l}}{I_\phi}$$

I_{line}

$I_\phi = \frac{I_l}{\sqrt{3}}$



$Z = ?$

$$Z = \frac{550\,(rms)}{\frac{10}{\sqrt{3}}} = 95\,\Omega$$

$I_\phi \neq I_{line}$

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Δ Connected Caps

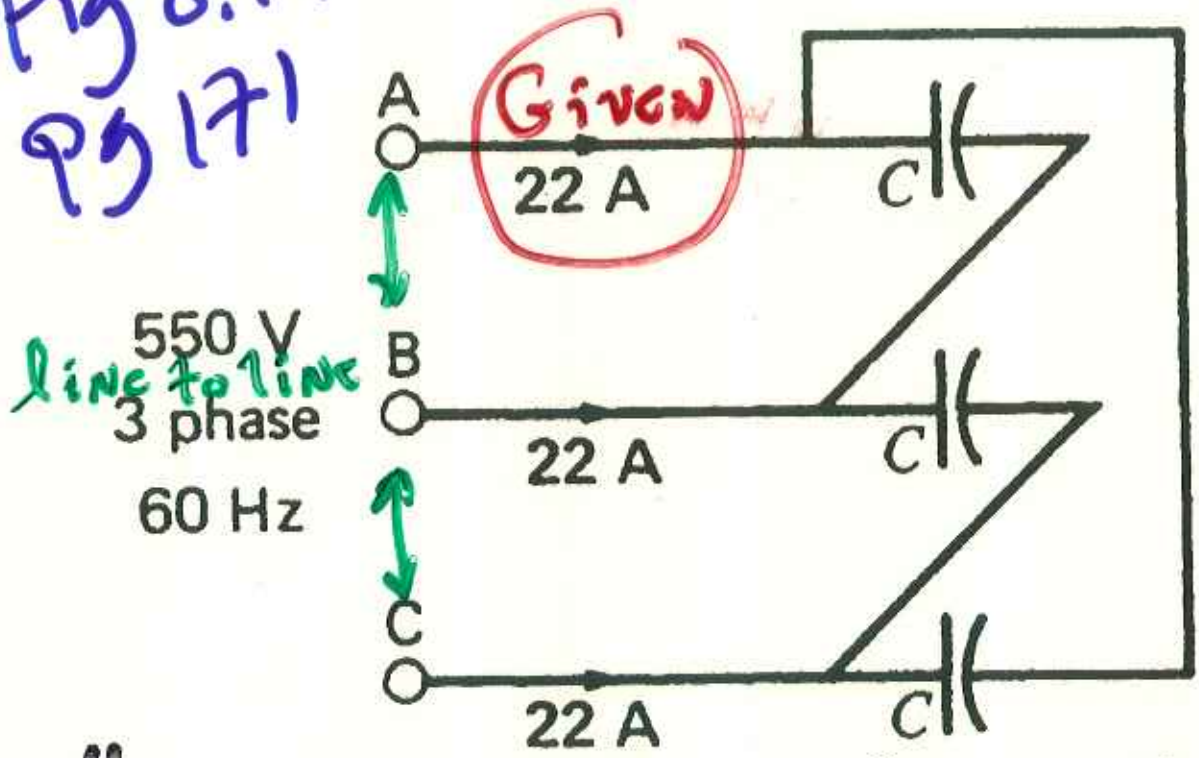
Value of C for measured I_L — Given I_{line}

$$I_C(\text{each } C) = \frac{22}{\sqrt{3}} = \underbrace{12.7}_{|I_\phi|}$$

$$X_C = \frac{550^{-V_C}}{12.7} = 43.3\,\Omega$$

@ f_{mains}

Fig 8.19 pg 171



"C" value for f = 60 Hz mains

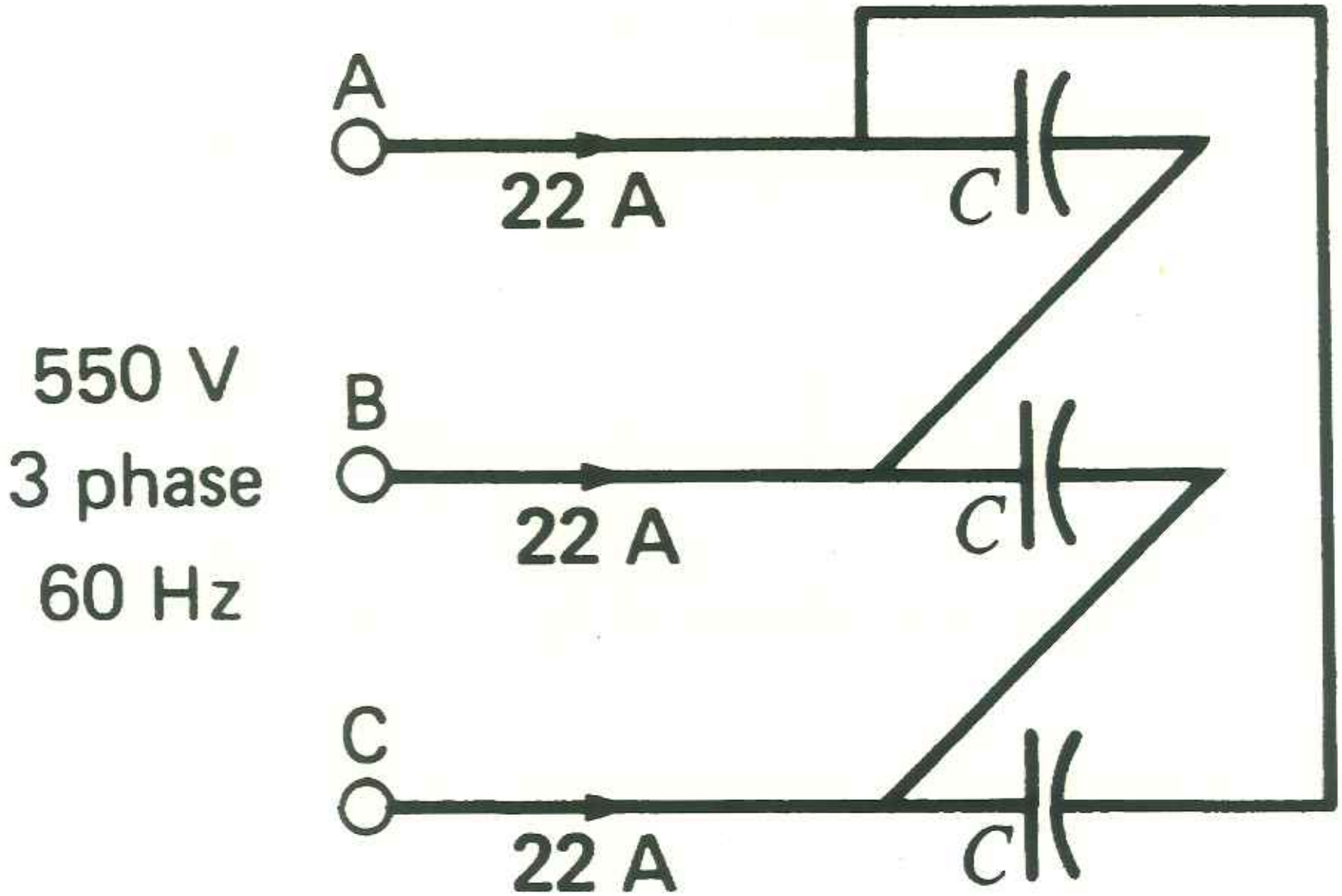
$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(60)(43.3)}$$

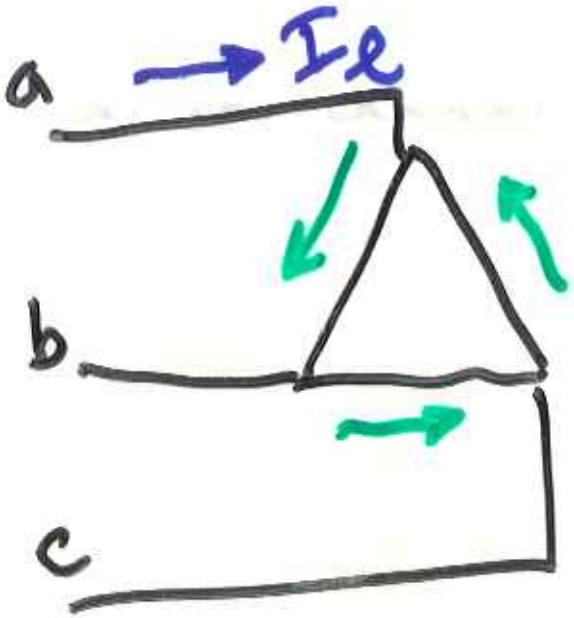
$$= 61.3\,\mu F$$

☺

X_C ↑ or ↓

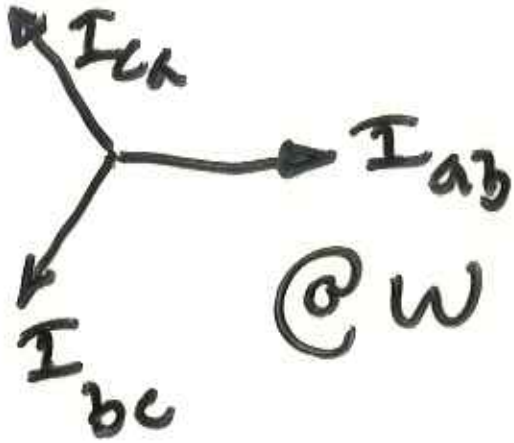
f change from 60 → 50 Hz


A
22 A
C
550 V
3 phase
60 Hz
B
22 A
C
C
22 A
C



I_ϕ has harmonics say @ 3w

$I_\ell(3w) = ?$

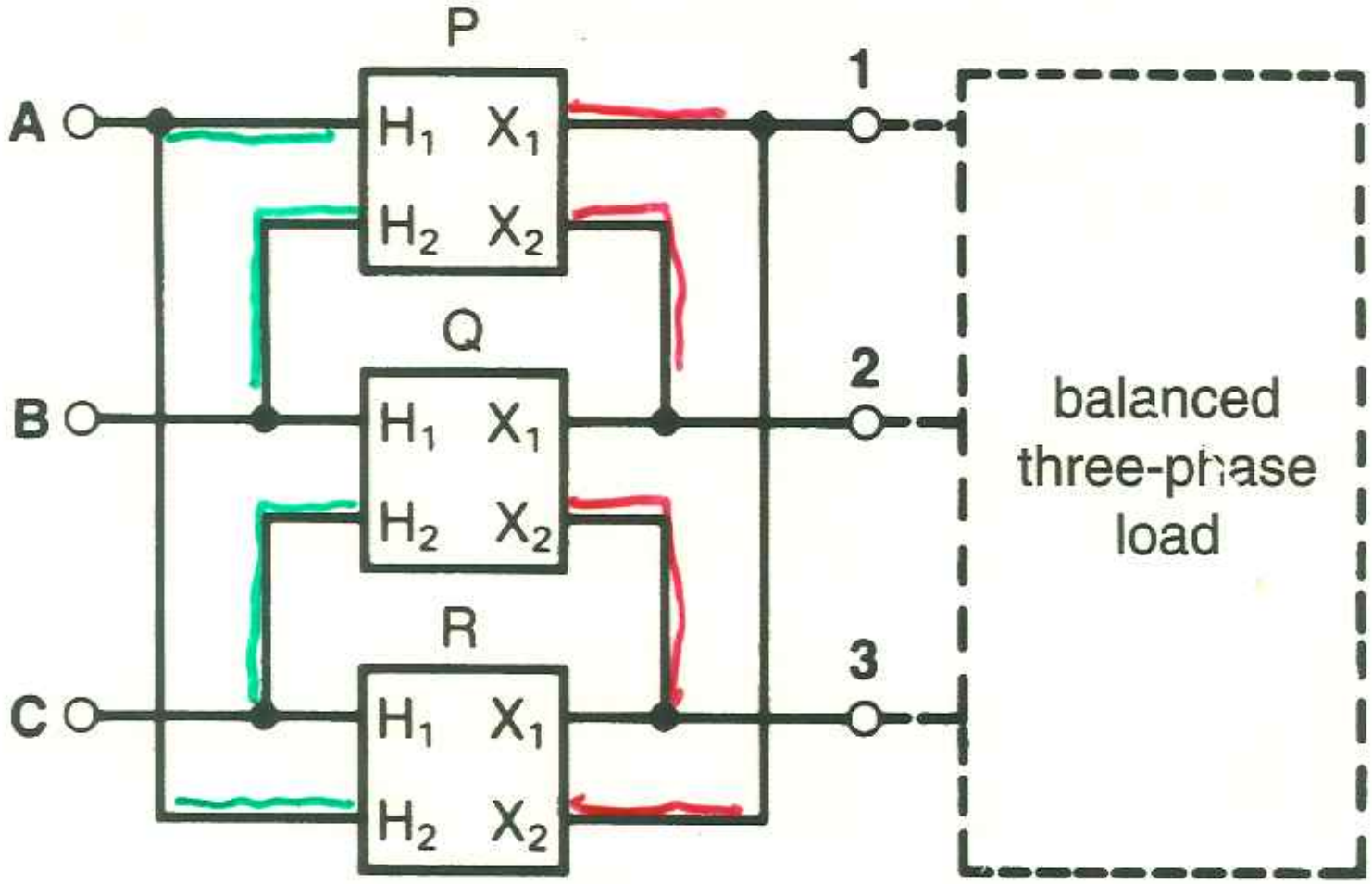


@ w

Δ acts as a harmonic

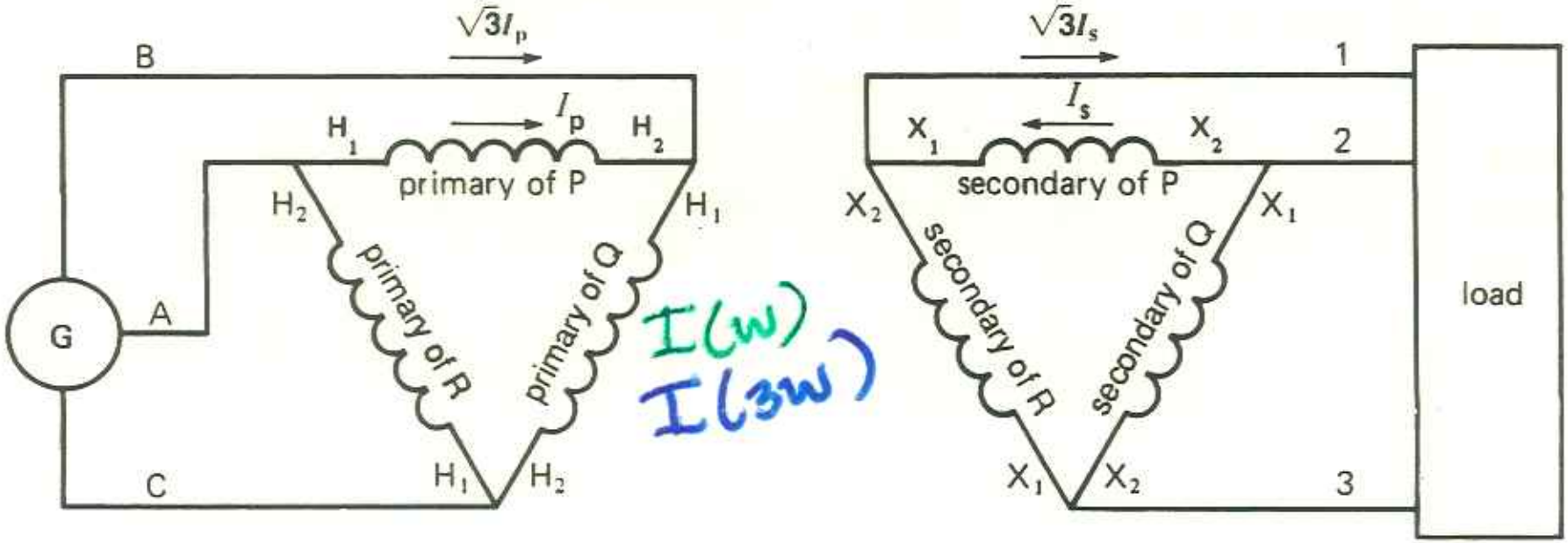
P Δ S Δ

Trf H Coils Primary wired as ?



Trf X Coils Secondary wired as ?

I → ?

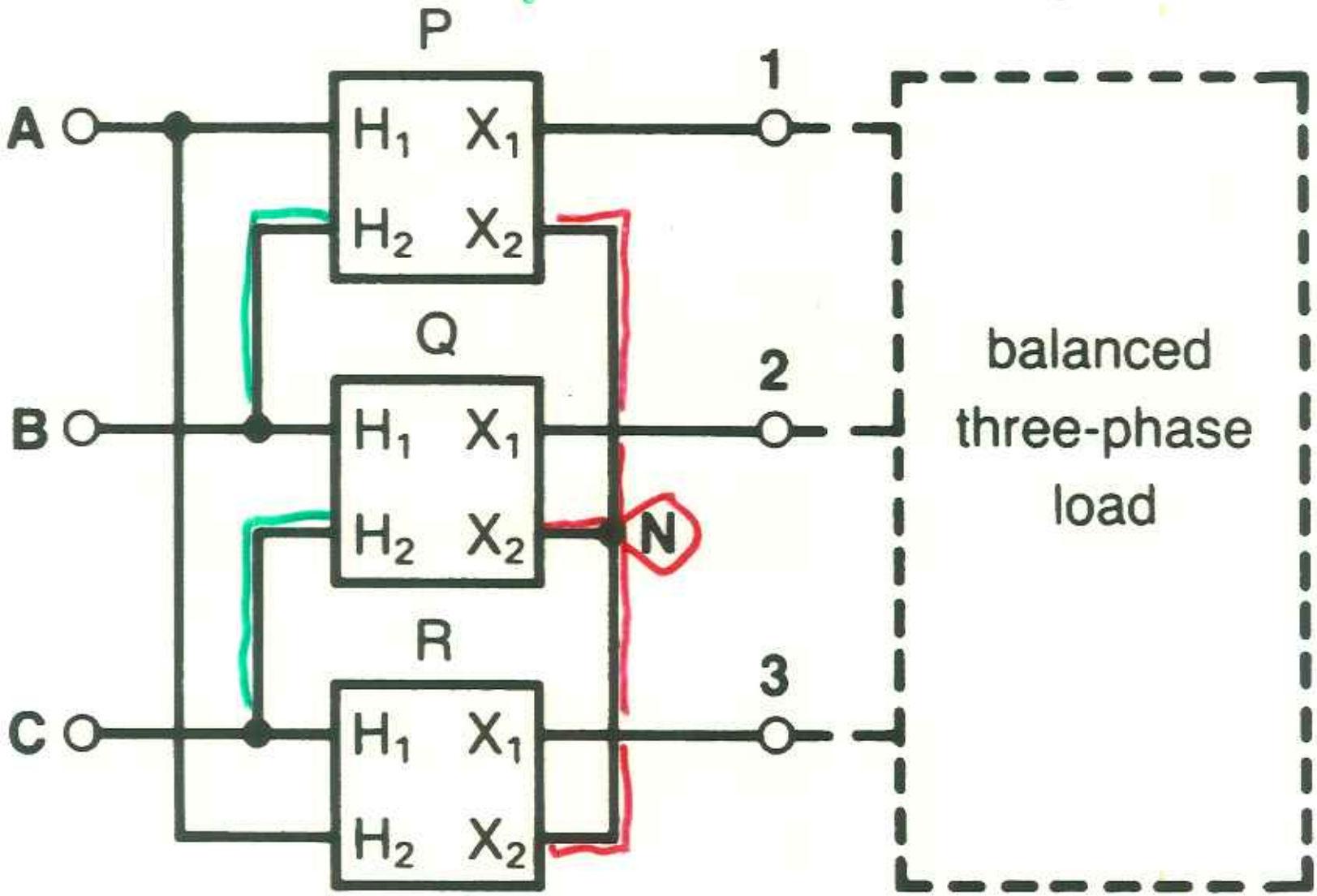


I(w)
I(3w)

Layout wiring "like phasors"

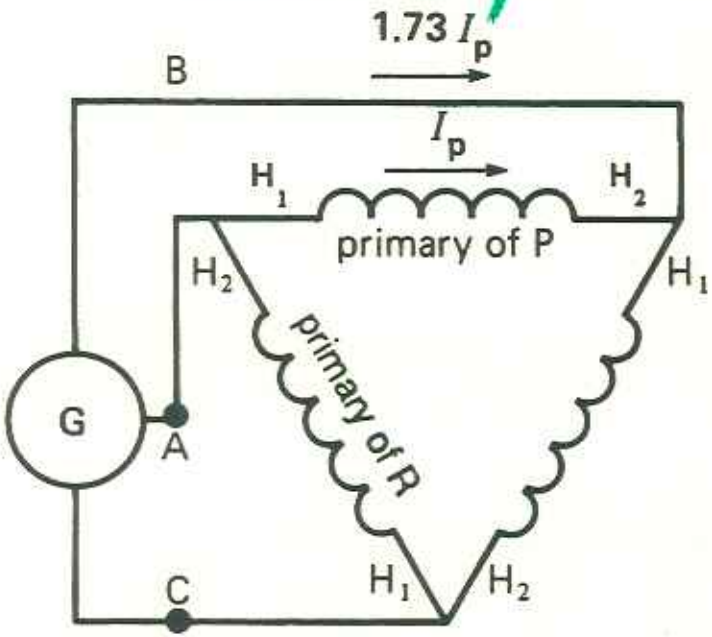
P Δ S Y

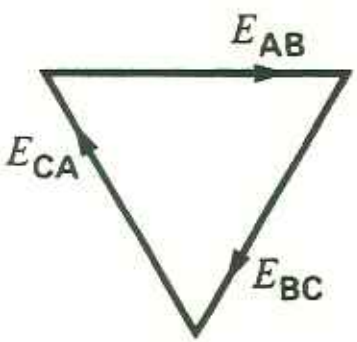
Primary wired as ?



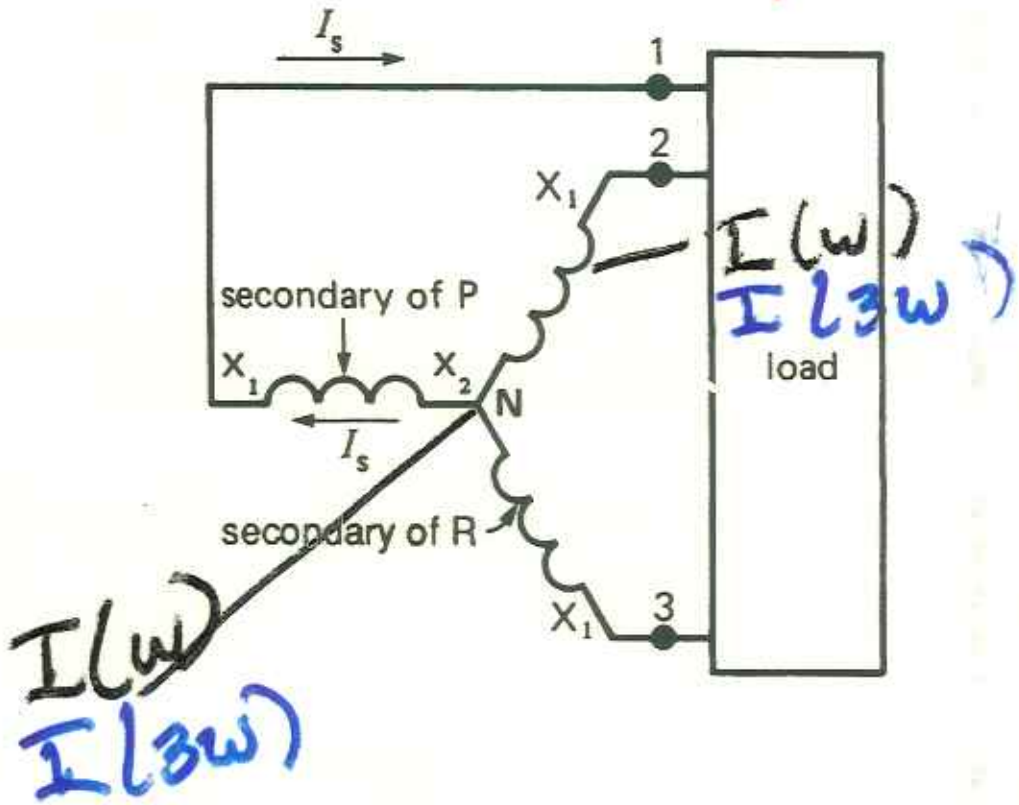
Secondary wired as ?

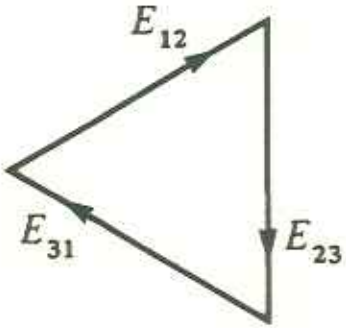
Primary





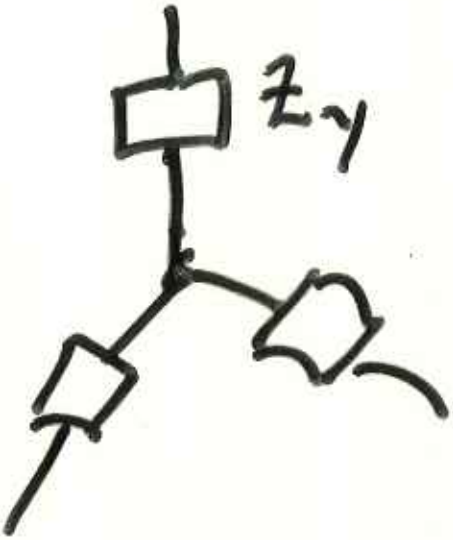
Secondary

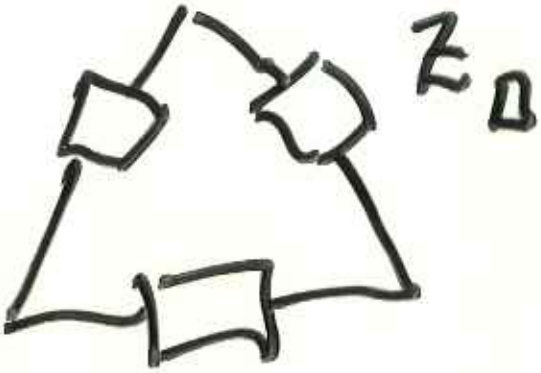




Δ - Y Conversion

$$Z_Y = \frac{Z_\Delta}{3}$$





$$P_{3\phi} = 3P_{1\phi} \qquad Q_{3\phi} = 3Q_{1\phi}$$

$$p(t) = P = \omega T$$

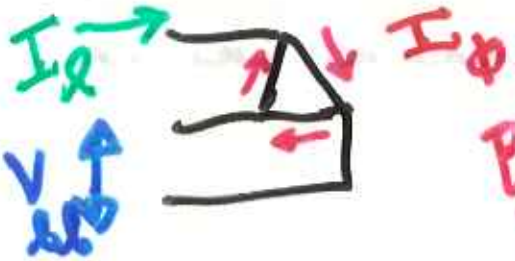
Constant 3 ϕ power

$P \neq f(t)$

Constant Torque

$T \neq f(t)$

Each phase pulsates but not $P_{3\phi}$



phase voltage vs line voltage

$$V_{\ell\ell} = V_\phi \qquad I_\phi = I_\ell$$

$$P_{3\phi} = 3P_{1\phi} = \qquad P_{3\phi} = 3P_{1\phi}$$

$$\Rightarrow I_\phi = \frac{I_\ell}{\sqrt{3}} \qquad \Rightarrow V_\phi = \frac{V_{\ell\ell}}{\sqrt{3}}$$

@ fixed $P_{3\phi}$ Impedance or R per phase

$$R^\phi_\Delta = \frac{V_{\ell\ell}}{\frac{I_\ell}{\sqrt{3}}} \qquad R^\phi_Y = ? = \frac{V_{\ell\ell}/\sqrt{3}}{I_\ell}$$

$$R^\phi_\Delta = \sqrt{3}\,\frac{V_{\ell\ell}}{I_\ell} \qquad R^\phi_Y = \left(\frac{V_{\ell\ell}}{I_\ell}\right)\frac{1}{\sqrt{3}}$$

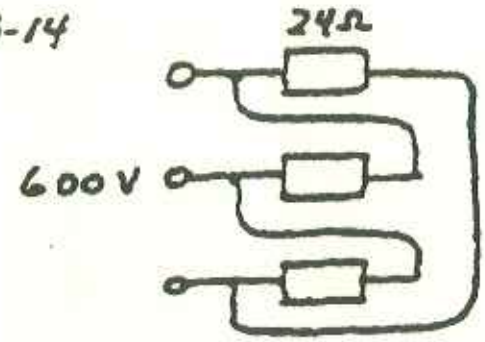
$$\frac{R^\phi_Y}{R^\phi_\Delta} = \frac{1}{3} \qquad R^\phi_\Delta = 3R^\Delta_Y$$

For same power

$24\,\Omega\,(\Delta) = ?\,\Omega\,(Y)$

via memory

8-14



$I_R = 600/24 = 25\,A$

Power dissipated per resistor

$= 600V \times 25\,A = 15\,kW$

If resistors are connected in Y, they must each also dissipate 15 kW. The voltage across each resistor $= 600/\sqrt{3} = 346.4V$.

$\therefore\ 15000 = \dfrac{346.4^2}{R}$ $\qquad \therefore\ R = 8\,\Omega$ (see below)

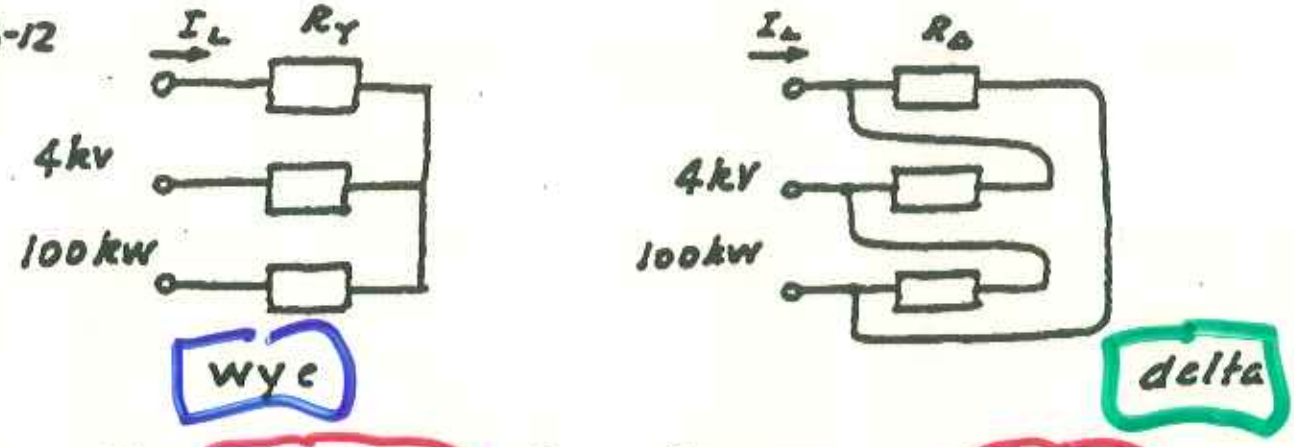
3 resistors of 8Ω each.

Both loads → Desire S = 100 KVA

R_Δ vs R_Y = ?

21

8-12



In both cases $I_L = \dfrac{100\,000}{4000\sqrt{3}} = 14.43\ A$

a. $R_Y = \dfrac{4000}{\sqrt{3} \times 14.43} = 160\ \Omega$

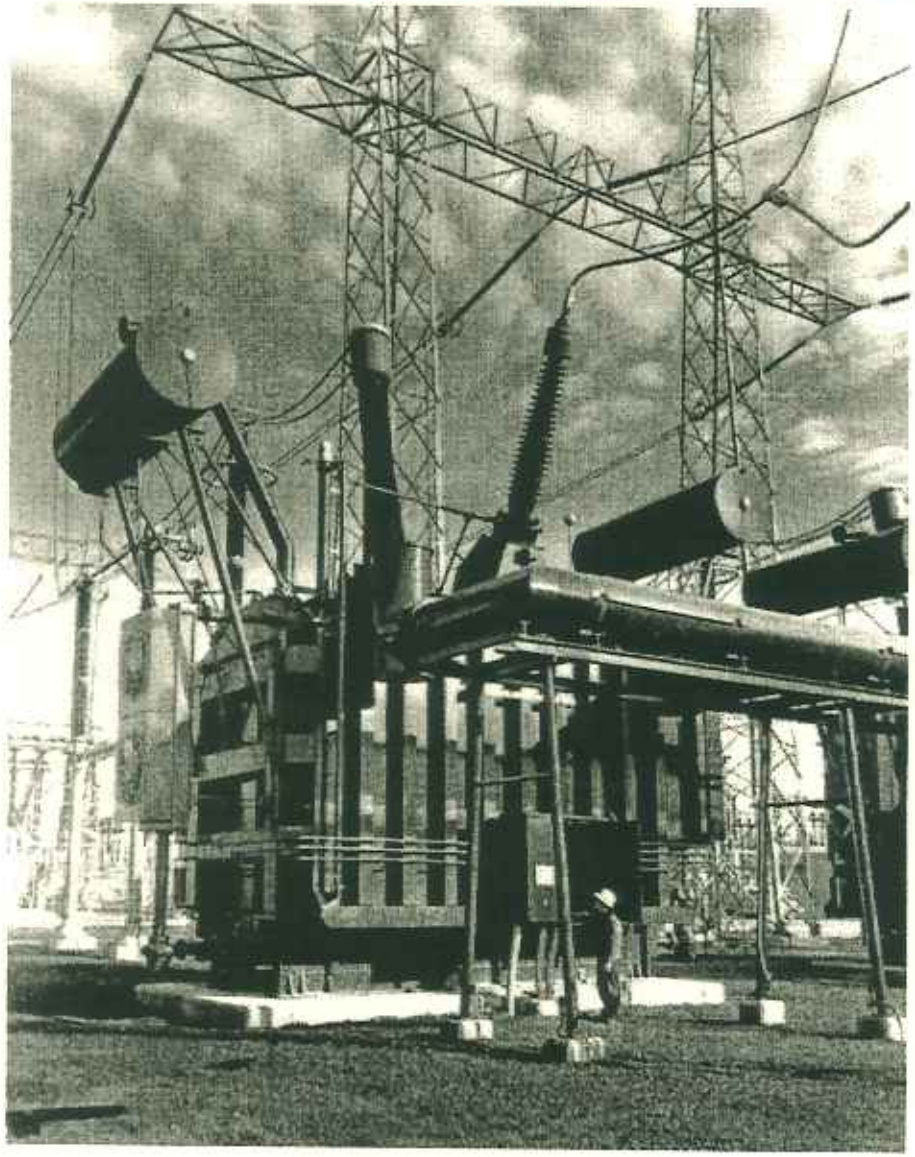
b. $R_\Delta = \dfrac{4000}{(14.43/\sqrt{3})} = 480\ \Omega$

$\dfrac{V^2}{R}$

$R_\Delta = 3\,R_Y$ for same power

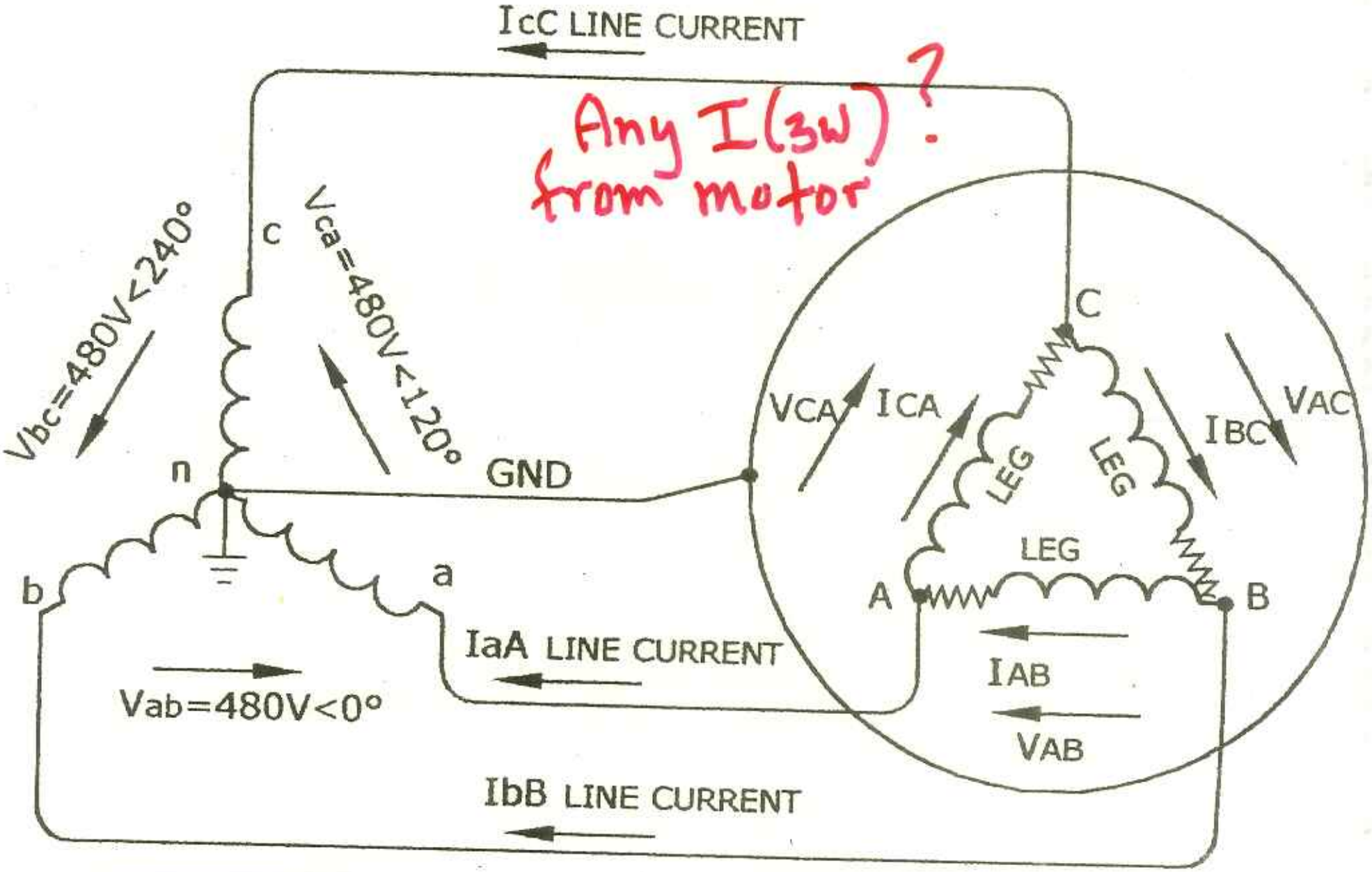
Why?

At a remote substation



Δ or Y
to HV
and
reasons

480Y277V, 3PH,4C, GN TRANSFORMER 480V, 3PH MOTOR



450 kW
575 V_{ll} (3φ) } ⇒ 1300 lb steam/hr

What if V_{ll} ↗ to 612 V?

~~8-33 The quantity of steam is proportional to the thermal power, which in turn varies as the square of the voltage. Thus steam produced = 1300 × $\left(\frac{612}{575}\right)^2$ = 1354 lb/h~~

8-34 (a) $P_{IN}^{e^-}$ = $\frac{40 \times 746}{0.936}$ = 31.88 kW Pmech

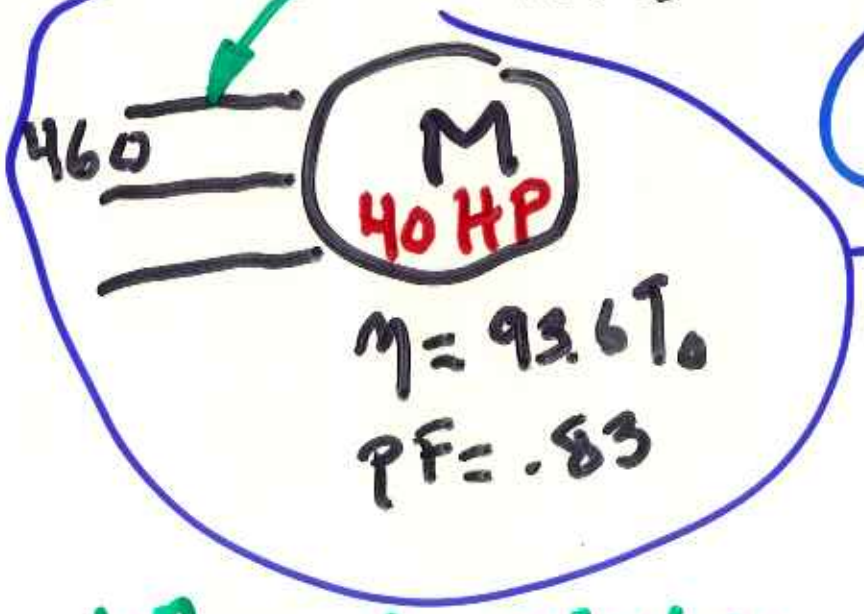
(b) $S_{IN}^{e^-}$ = $\frac{31.88}{0.83}$ = 38.41 kVA

Convert $P_{IN} \rightarrow S_{IN}$

(c) I = $\frac{38.41 \times 1000}{460\sqrt{3}}$ = 48.2 A

Choose motor wiring to be either Δ Y

$\sqrt{3}\, I_\ell V_{ll}$



1 — Given

Find
P drawn
S drawn
I_{line} full load

Why Δ wiring best on motor

$\eta = 96\%$

$pF = .9$

Given ①

Find: S, I_ℓ, P, θ

$S = P_e / pF = \sqrt{3}\, V_{\ell\ell} I_\ell$

Δ or Y

8-35 (a) $S = \dfrac{1600 \times 746}{0.96 \times 0.90} = 1381 \text{ kVA}$

$I_L = \dfrac{1381 \times 1000}{2400\sqrt{3}} = 332 \text{ A}$

S ?

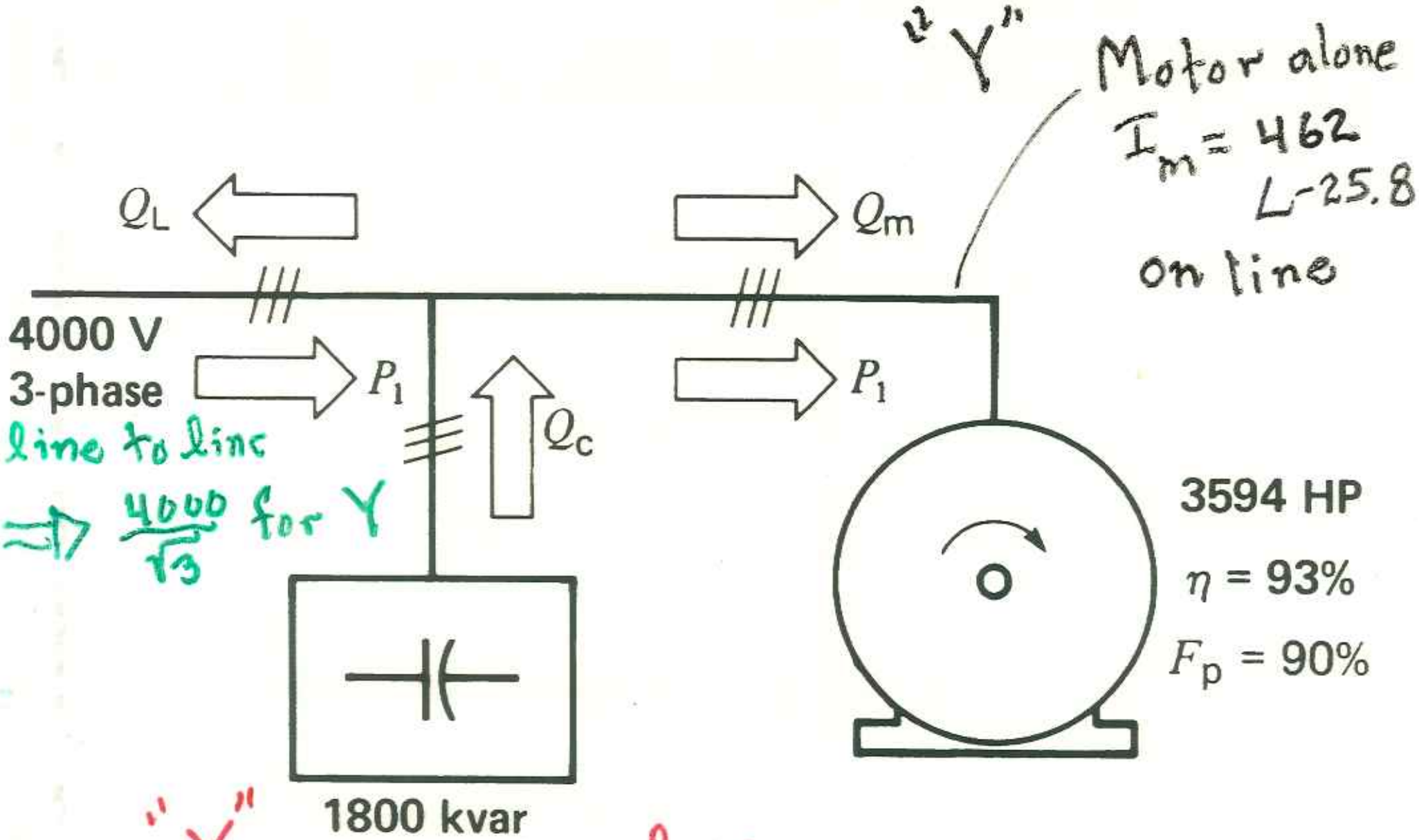
(b) $P = \dfrac{1600 \times 746}{0.96} = 1243 \text{ kW}$

P

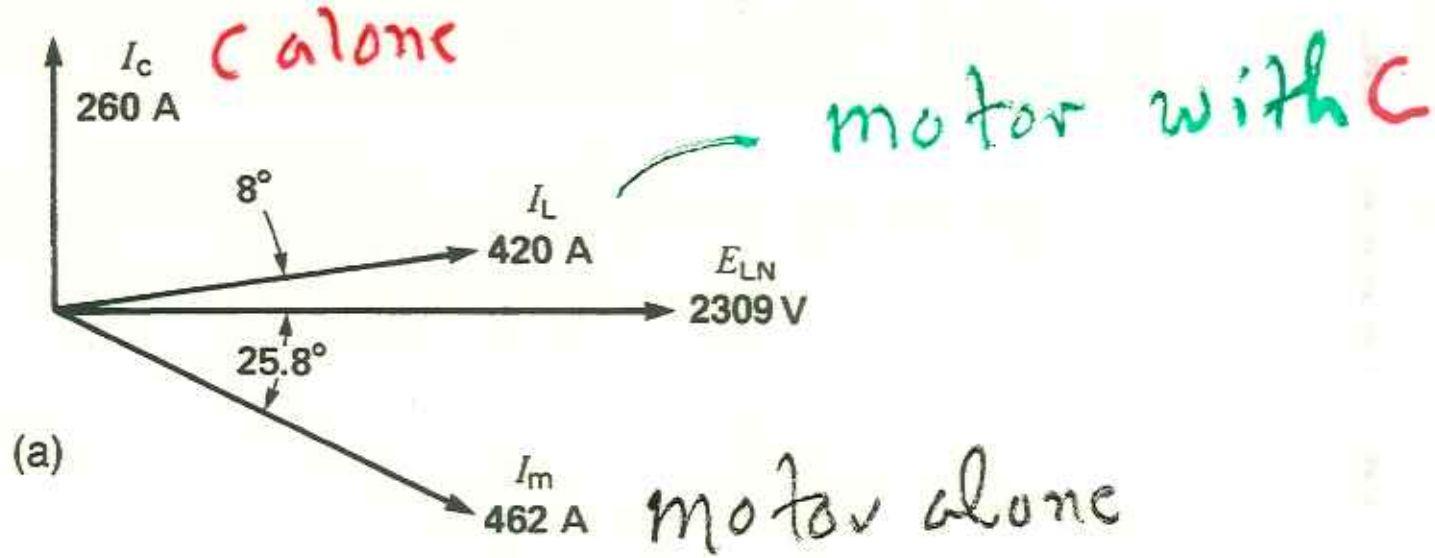
$Q = \sqrt{1381^2 - 1243^2} = 602 \text{ kvar}$

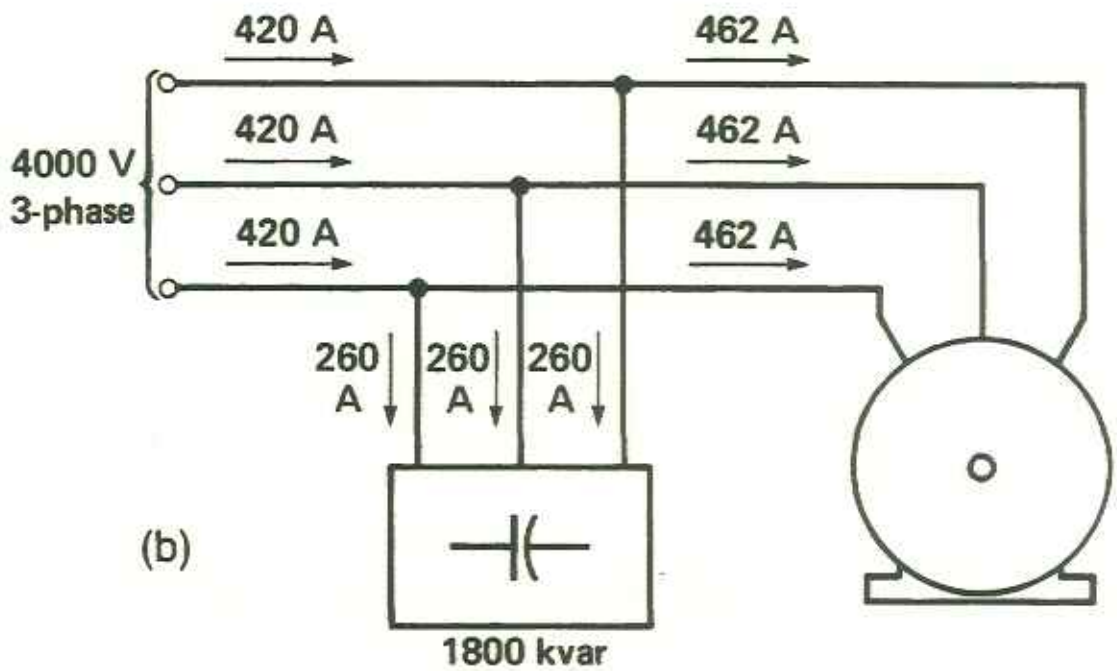
(c) $\theta = \arccos \dfrac{1243}{1381} = 25.8^\circ$

$S \cos\Phi = P$

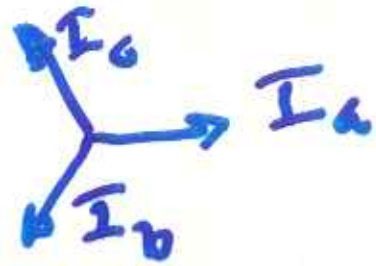


What is I(line) for both in Y

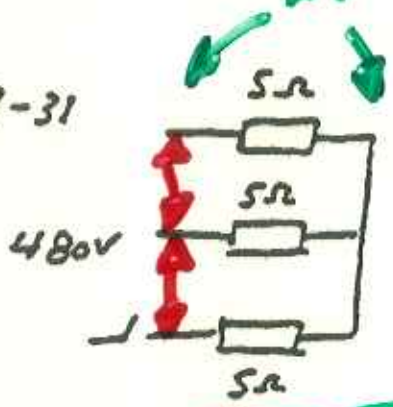

I_c
260 A
C alone
motor with C
8°
I_L
420 A
E_{LN}
2309 V
25.8°
(a)
I_m
462 A
motor alone


420 A
462 A
420 A
462 A
4000 V
3-phase
420 A
462 A
260 A
260 A
260 A
(b)
1800 kvar

277 industrial voltage



B-31



E(line-to-neutral) = $480/\sqrt{3}$ = 277V

$I_A = I_B = I_C =$ 277/5 = 55.4A

If one line is disconnected, the remaining two resistors are in series across the 480V line. The current in each becomes 480V/10Ω = 48 A.

(Tricky lose a Φ

unbalanced 3Φ

48

48

equal opposite for pair

upon leg i = 0

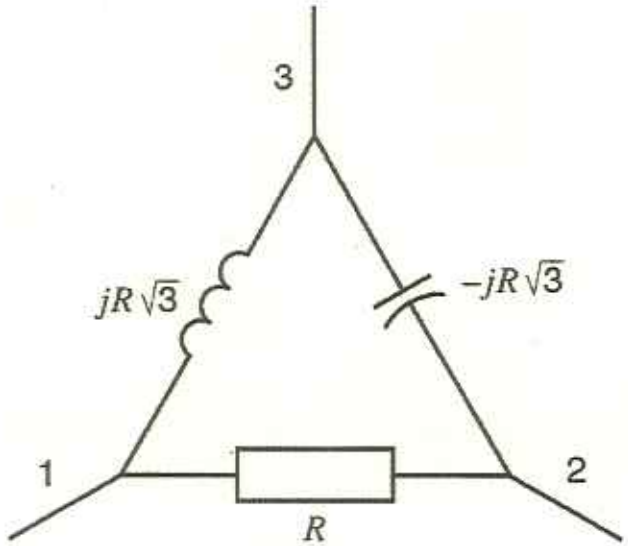
But recall

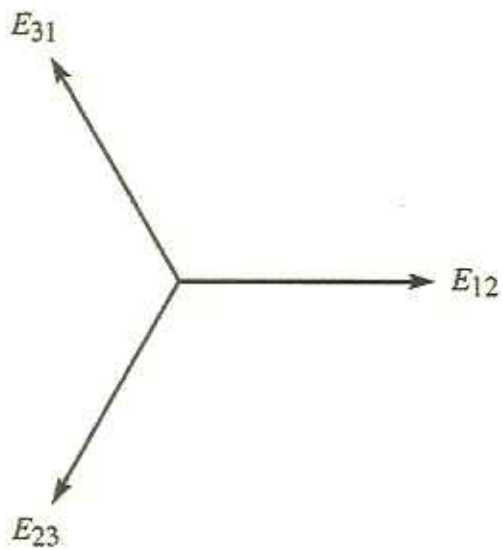
1 R only

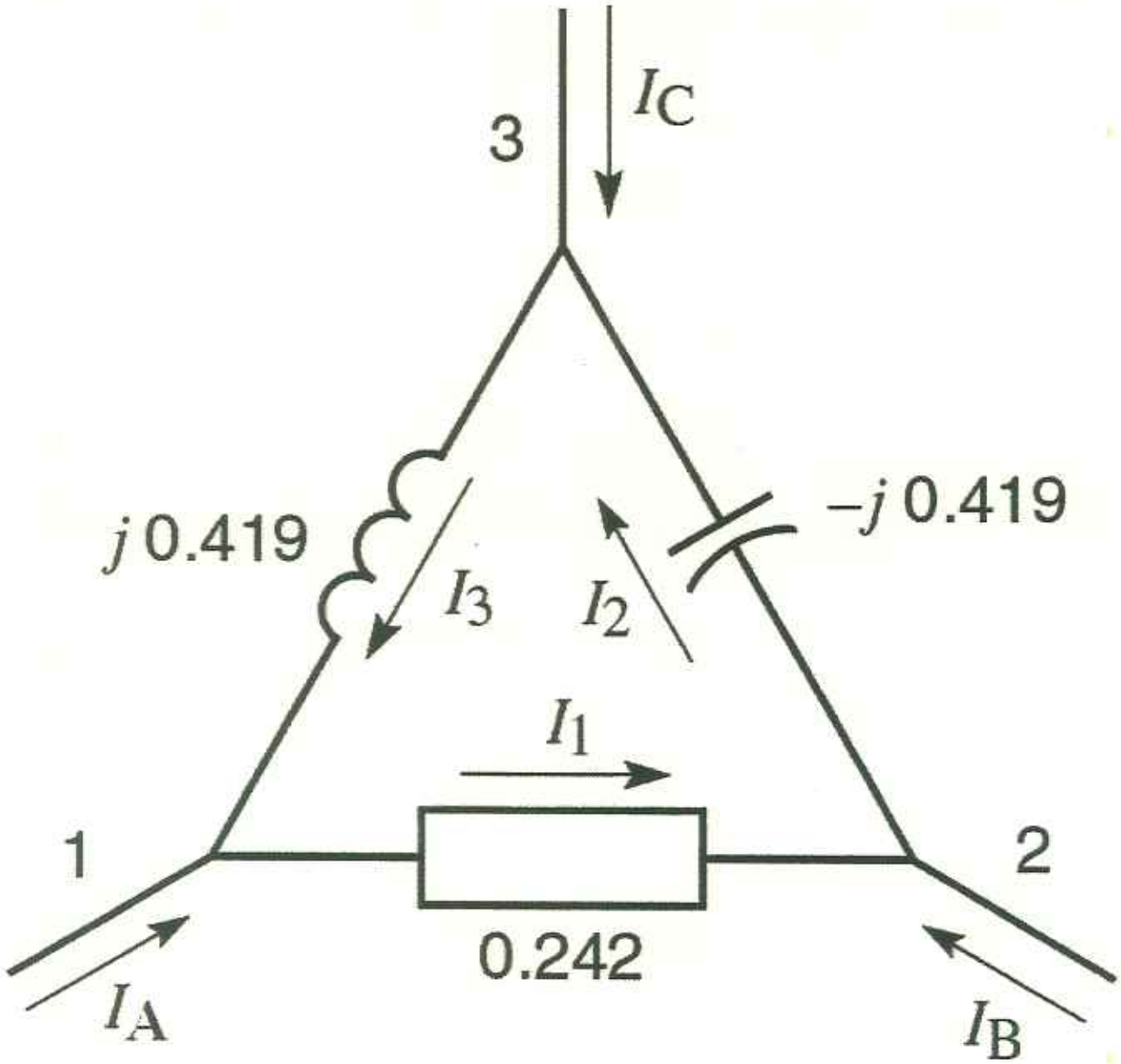
2 R

third line R = ∞

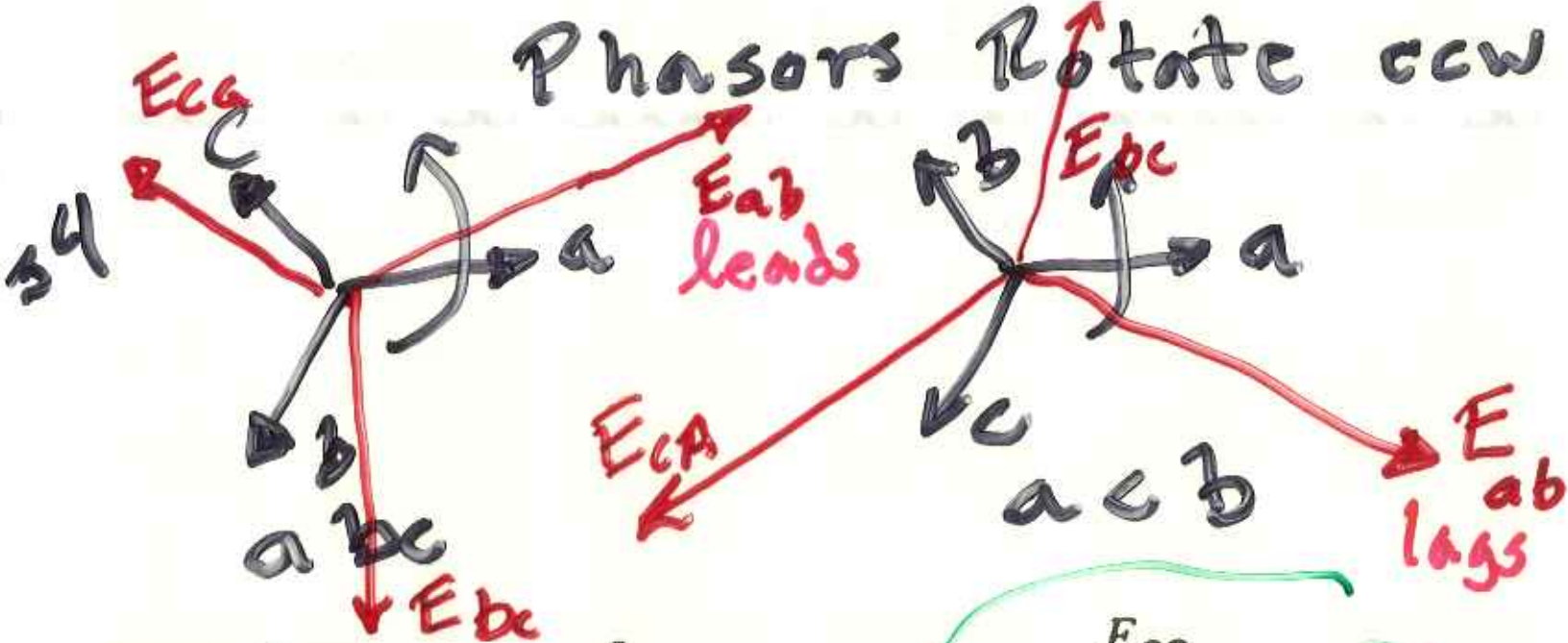
R = 0

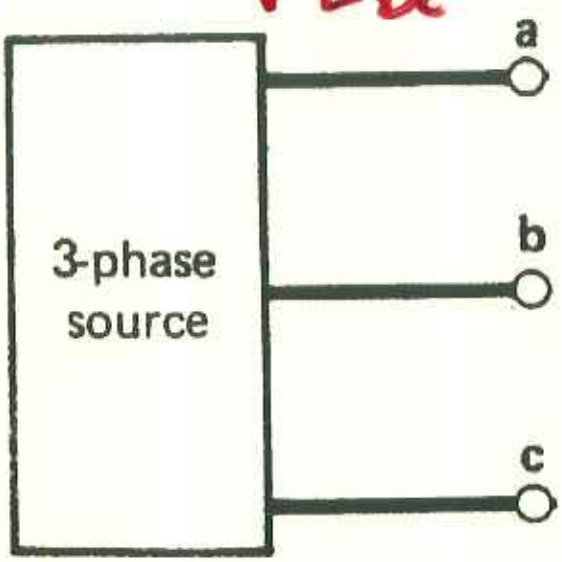

3
$jR\sqrt{3}$
$-jR\sqrt{3}$
1
2
R

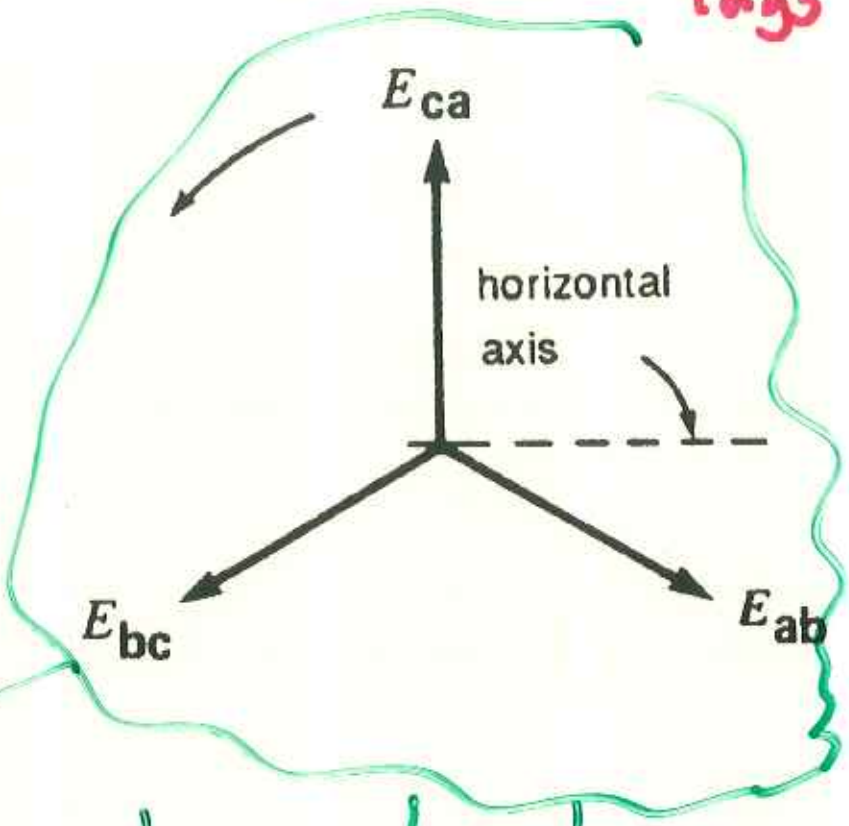

E_{31}
E_{12}
E_{23}


3
I_C
$j\,0.419$
$-j\,0.419$
I_3
I_2
I_1
1
2
0.242
I_A
I_B

Phasors Rotate ccw







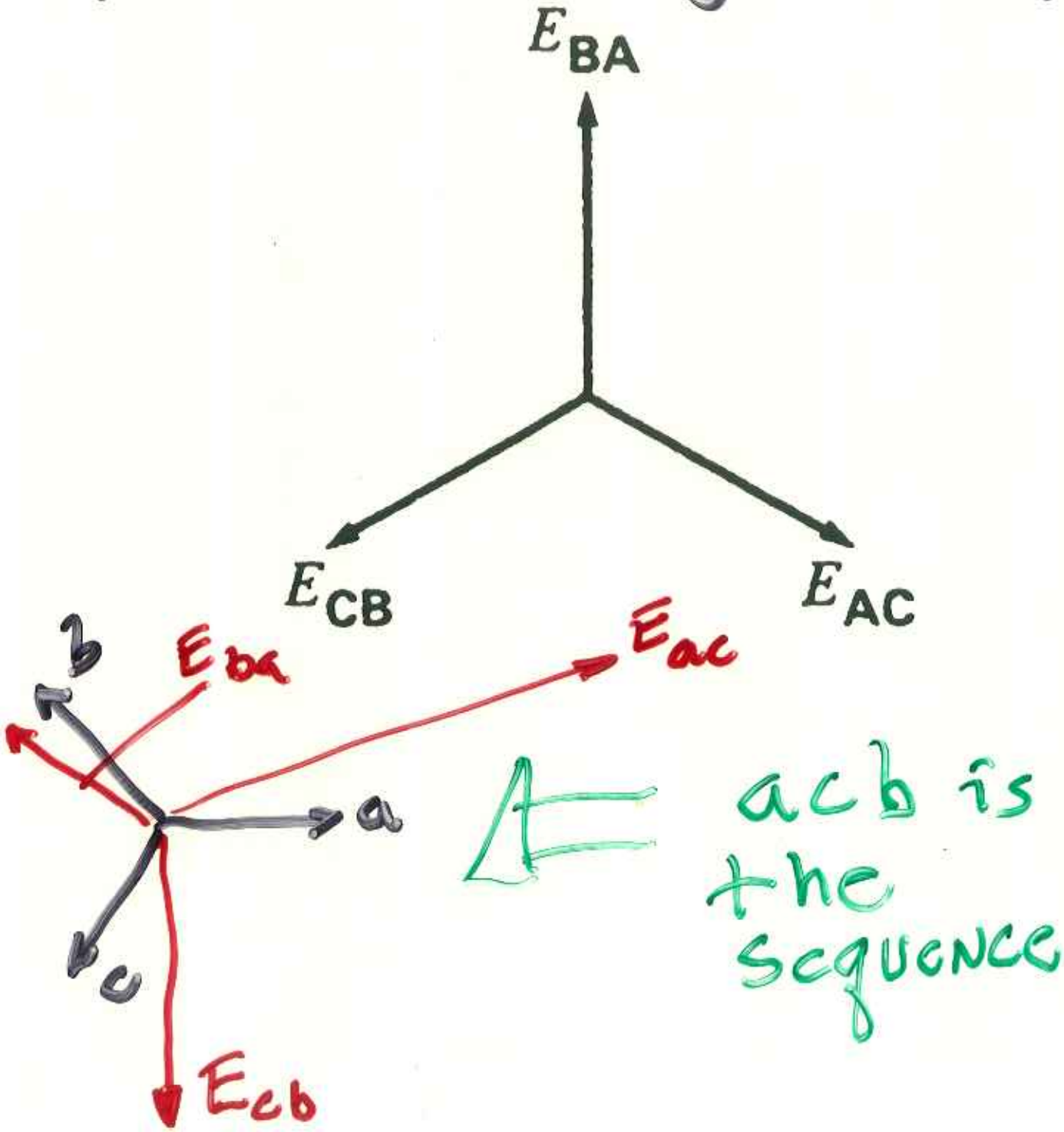
① CCW
Corresponds to what
sequence ?

CW ?
rotation } challange!

ac abc

35

Below corresponds to what ϕ sequence?

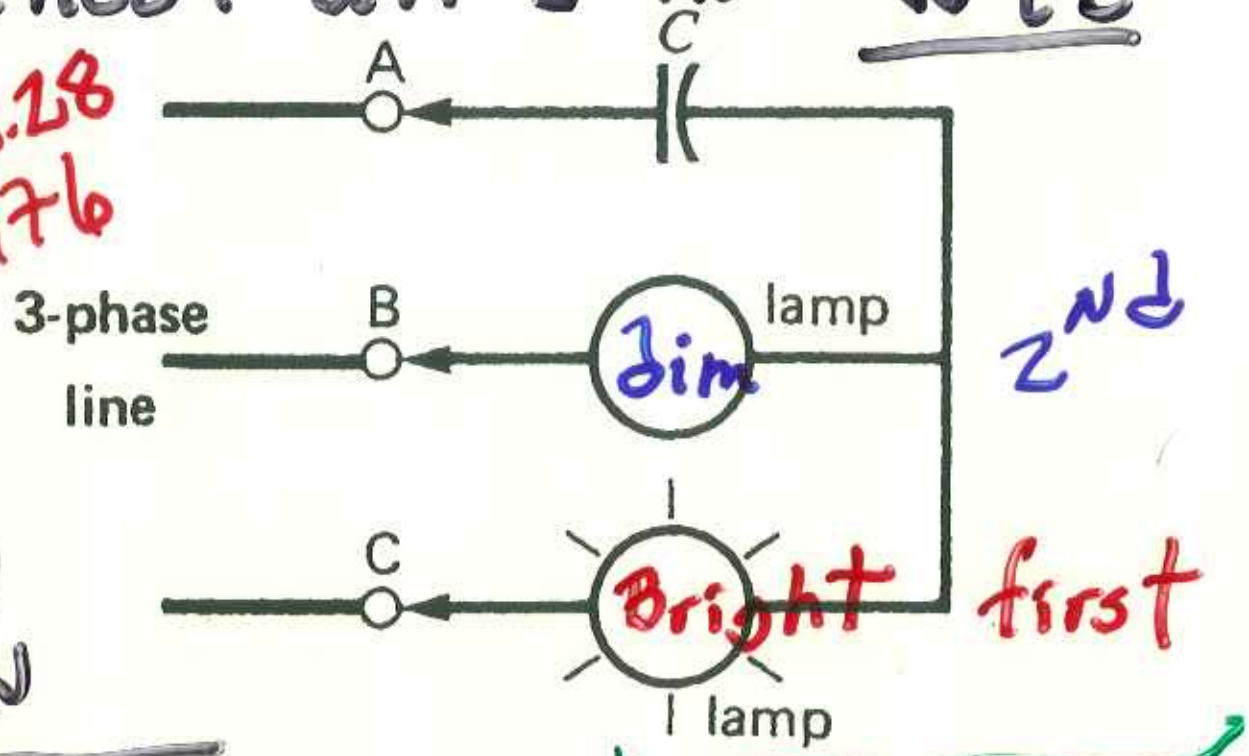


acb is the sequence

2 Hot filament bulbs } easy to find
1 Capacitor

Connect all 3 in "WYE"

Fig 8.28
Pg 176



Key

leave neutral unconnected

Yield
c b a