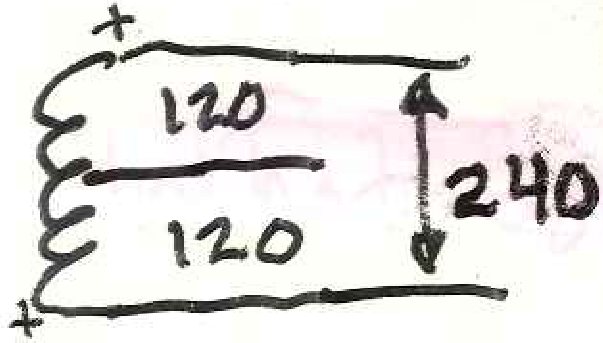
Chapter 11 #1
Transformers

- Special Transformers
- Three Phase
- Open Delta
- Auto Transformers
- Why Auto Transformers

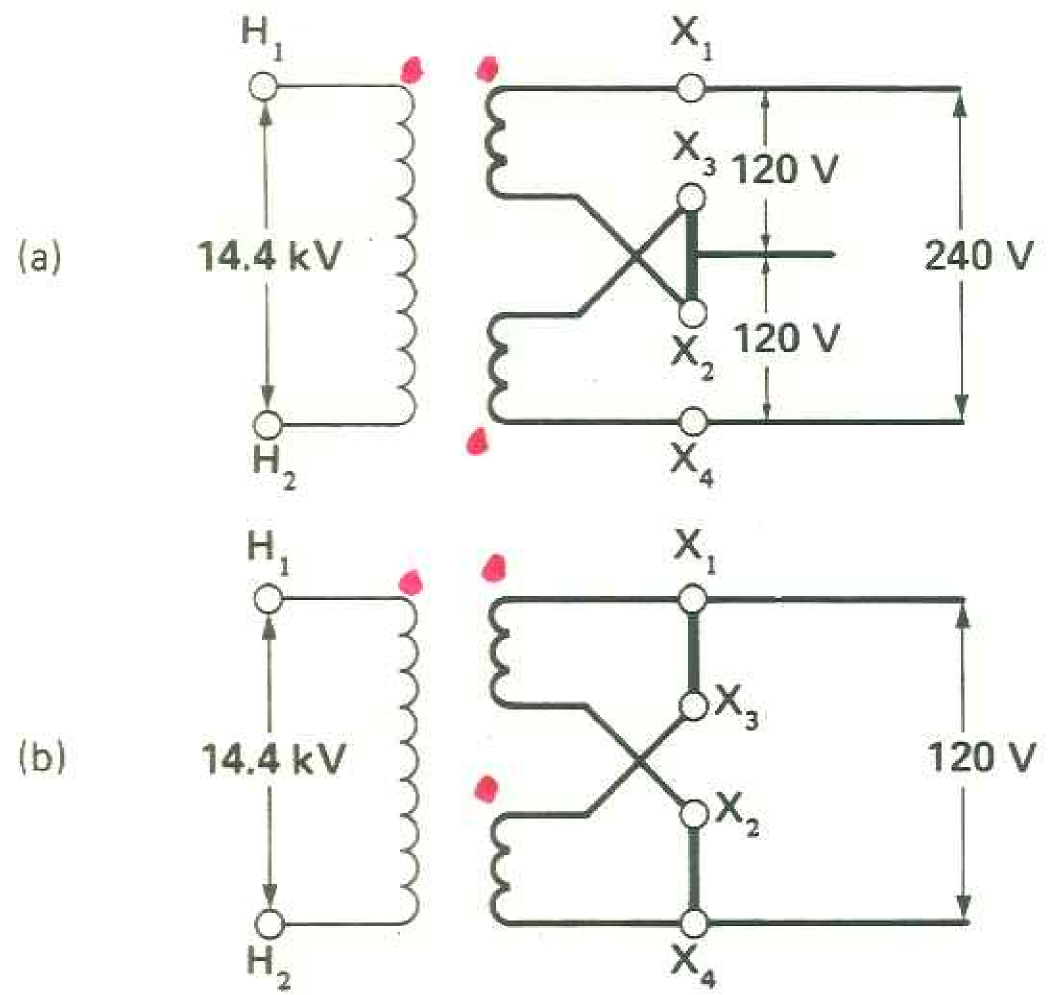
At a location near you!



Careful 3 coils

Figure 11-1 a. Distribution transformer with 120 V/240 V secondary. The central conductor is the neutral. b. Same distribution transformers reconnected to give only 120 V.

Careful of dot location



Why both 120 240?

Why only 120

Wiring on exam?

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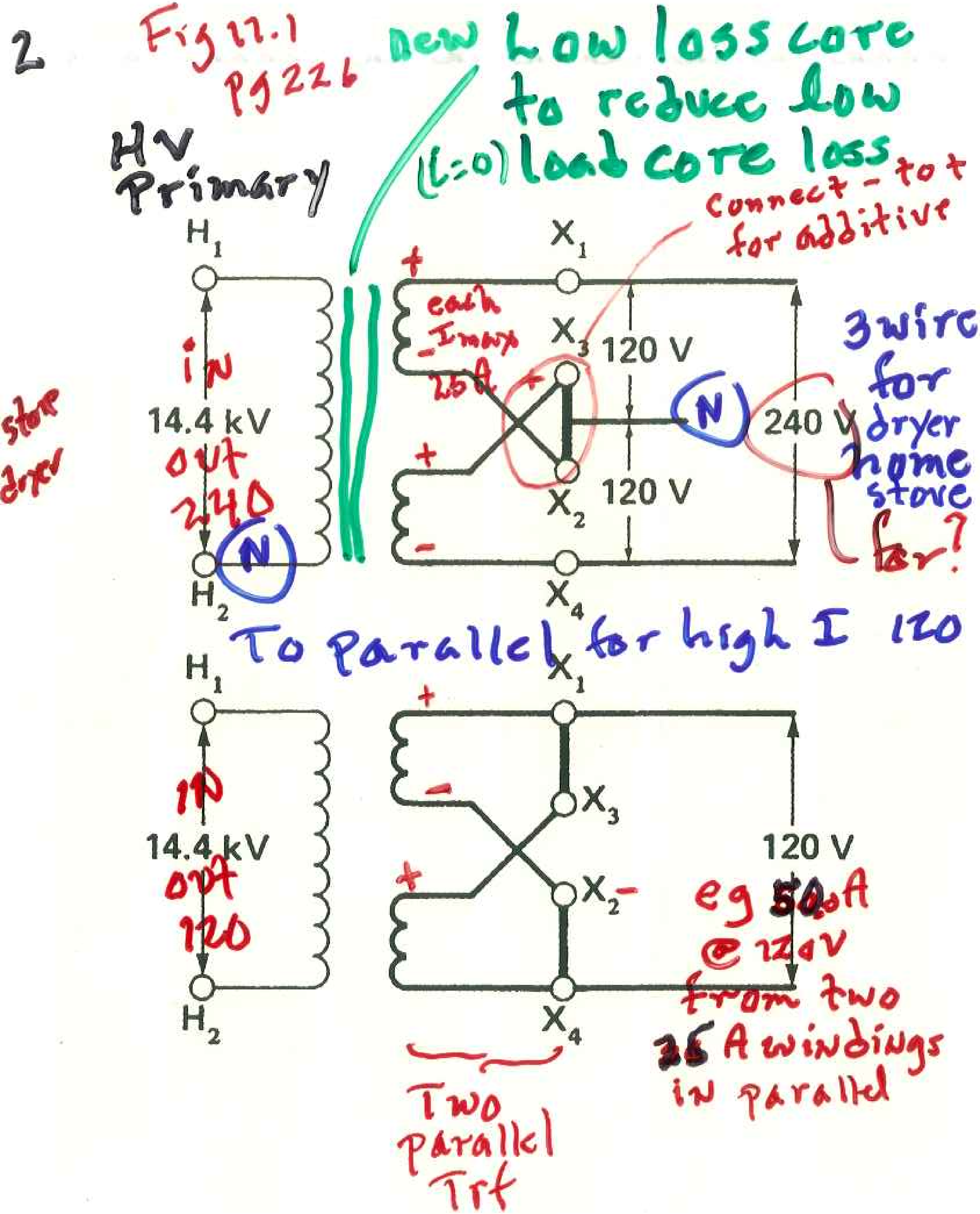
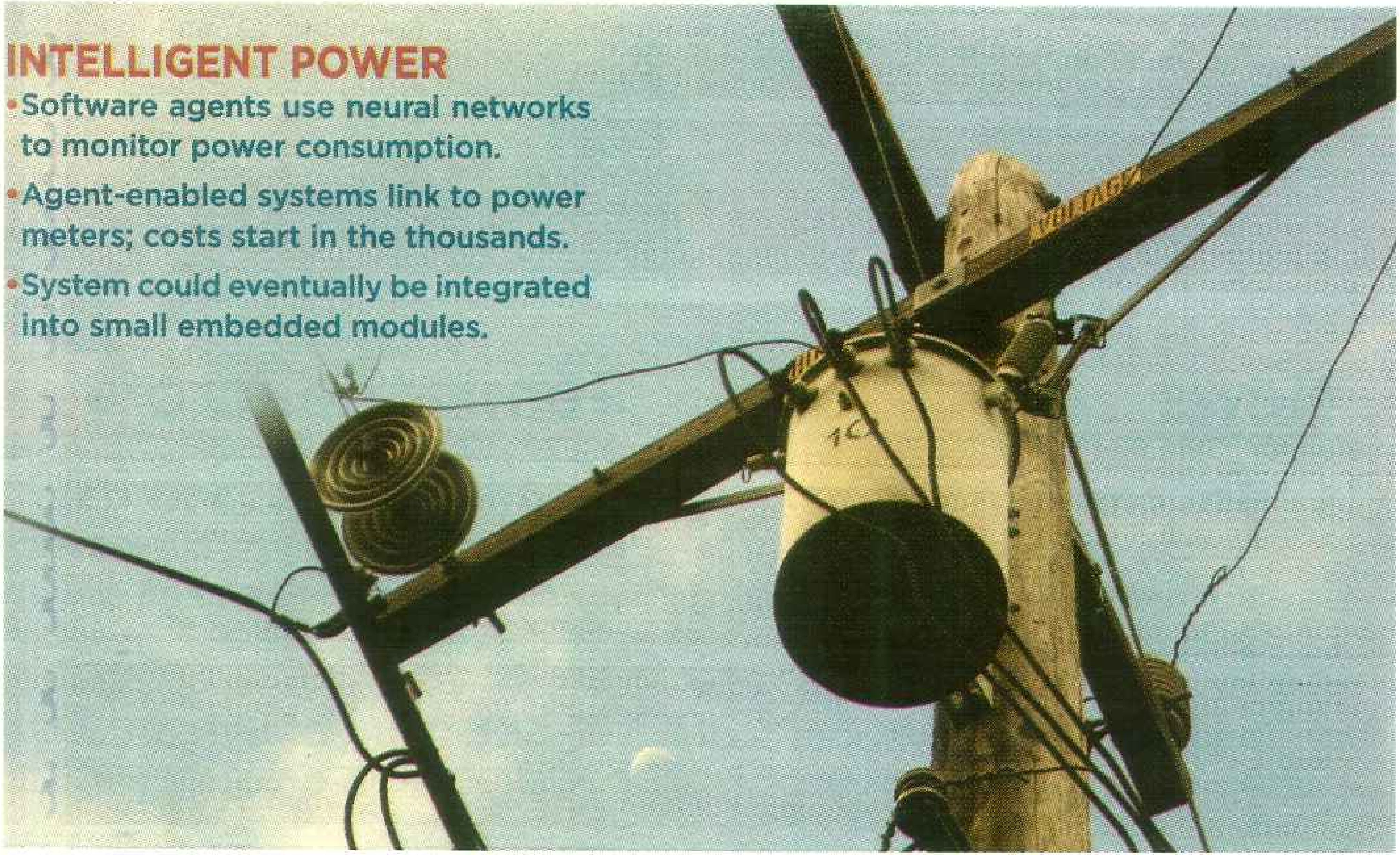


Fig 22.1
Pg 226
new Low loss core to reduce low (I=0) load core loss
HV Primary
H1
H2
X1
X3
X2
X4
14.4 kV
in 14.4 kV out 240
N
each Imax 25A
120 V
120 V
240 V
connect - to + for additive
3 wire for dryer home stove for?
stove dryer
To parallel for high I 120
in 14.4 kV out 120
120 V
eg 50A @ 120V from two 25 A windings in parallel
Two parallel Trf



New grid:
Each house monitored / controlled

Interwinding C could be deadly. How?

Recall VI LT ground?

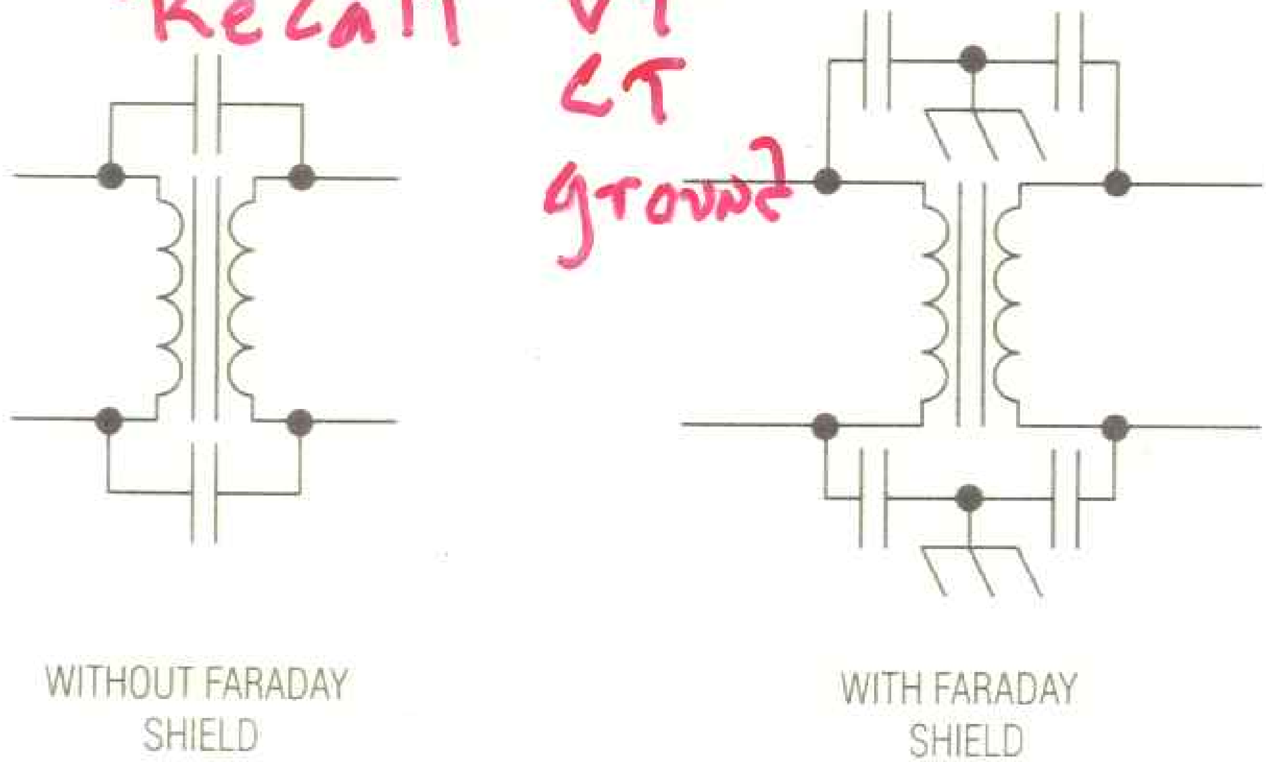


Figure 8. A Faraday shield between primary and secondary blocks common-mode noise that would otherwise pass through the transformer's parasitic interwinding capacitance.

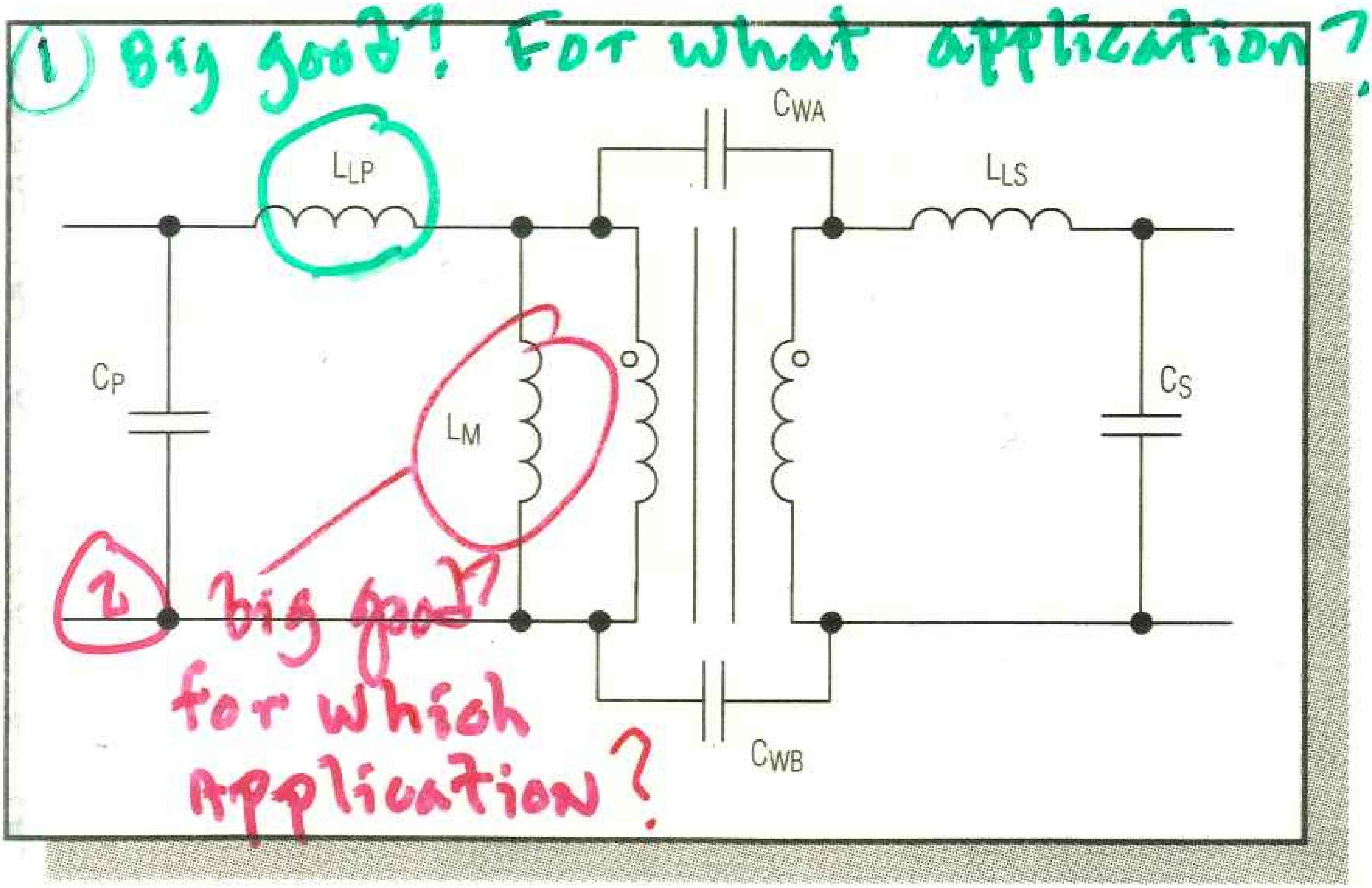


Figure 11. Parasitic elements in the equivalent model for a transformer modify its ideal behavior.

CAN you explain each C and L?

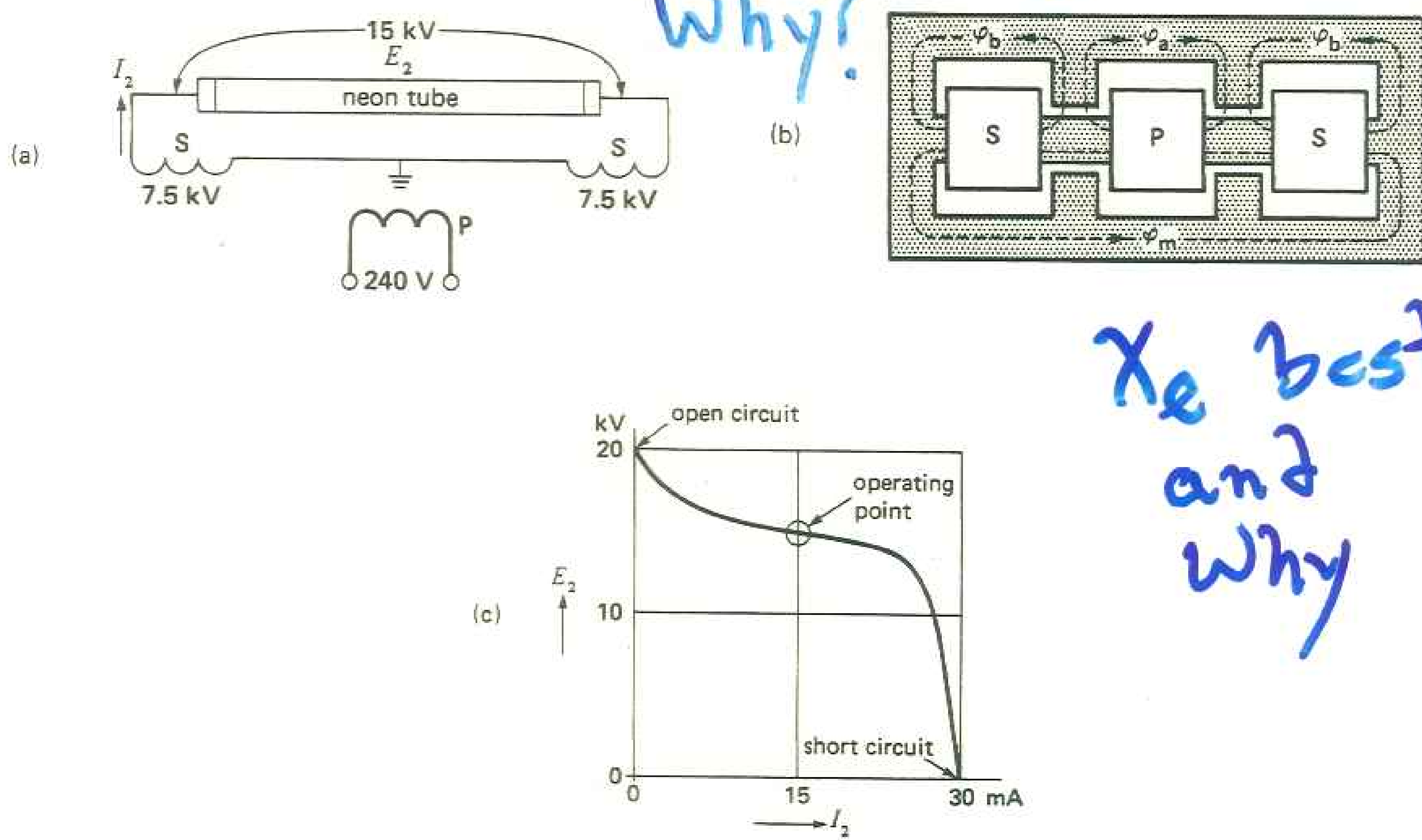
Challange: How to "fix" C_{WA} C_{WB}

Why X_e large can be better

Figure 11-24 a. Schematic diagram of a neon-sign transformer. b. Construction of the transformer. c. Typical E-I characteristic of the transformer.

In gas discharge load

Why?



X_e best if? and Why

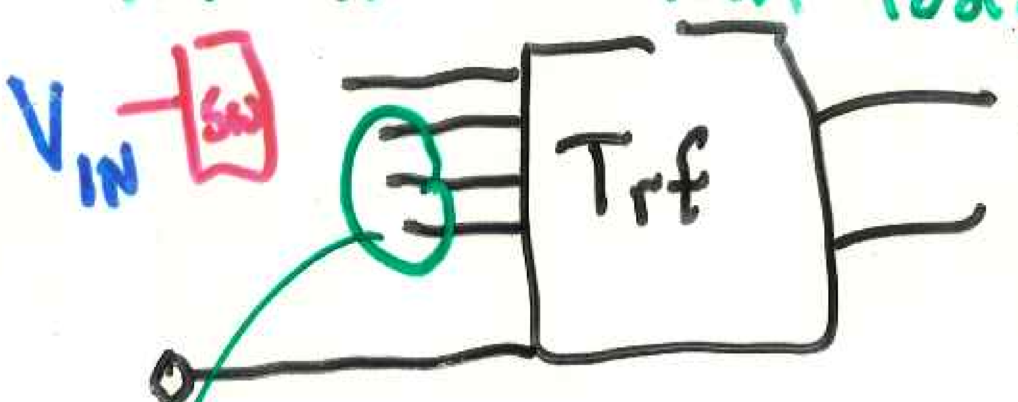
Line variations are normal

Generally AC line varies V_{swell} — V_H

V_{sag} — V_L (known ΔV)

(sag / swell) occurs over 10 – 60 minutes

How to keep V_{load} fixed with only (transformer, switches) for a critical load



$V_{load} \pm 5\%$ desired

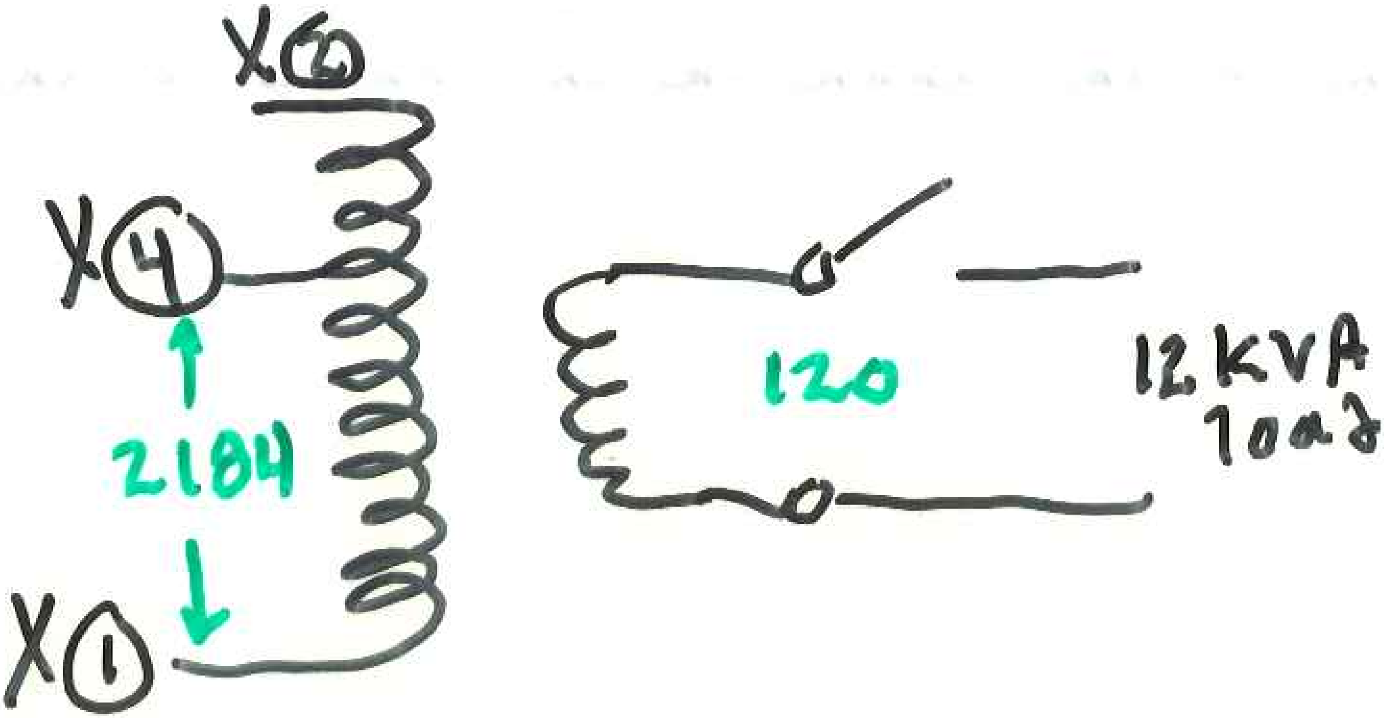
Old SW: e^- mechanical — Δt ms

New SW: IGBT 1kA 12kV — Δt μs

Taps at e.g 95% V_{IN}

⋮

80% V_{IN}



if 2184 rises to 2300

$$V_{out} = \frac{2300}{2184} 120 = 126.4$$

not 120

$V_{12} = ?$ for $2184 = V_{12}$

Prior slide $V_{12} = 2400$

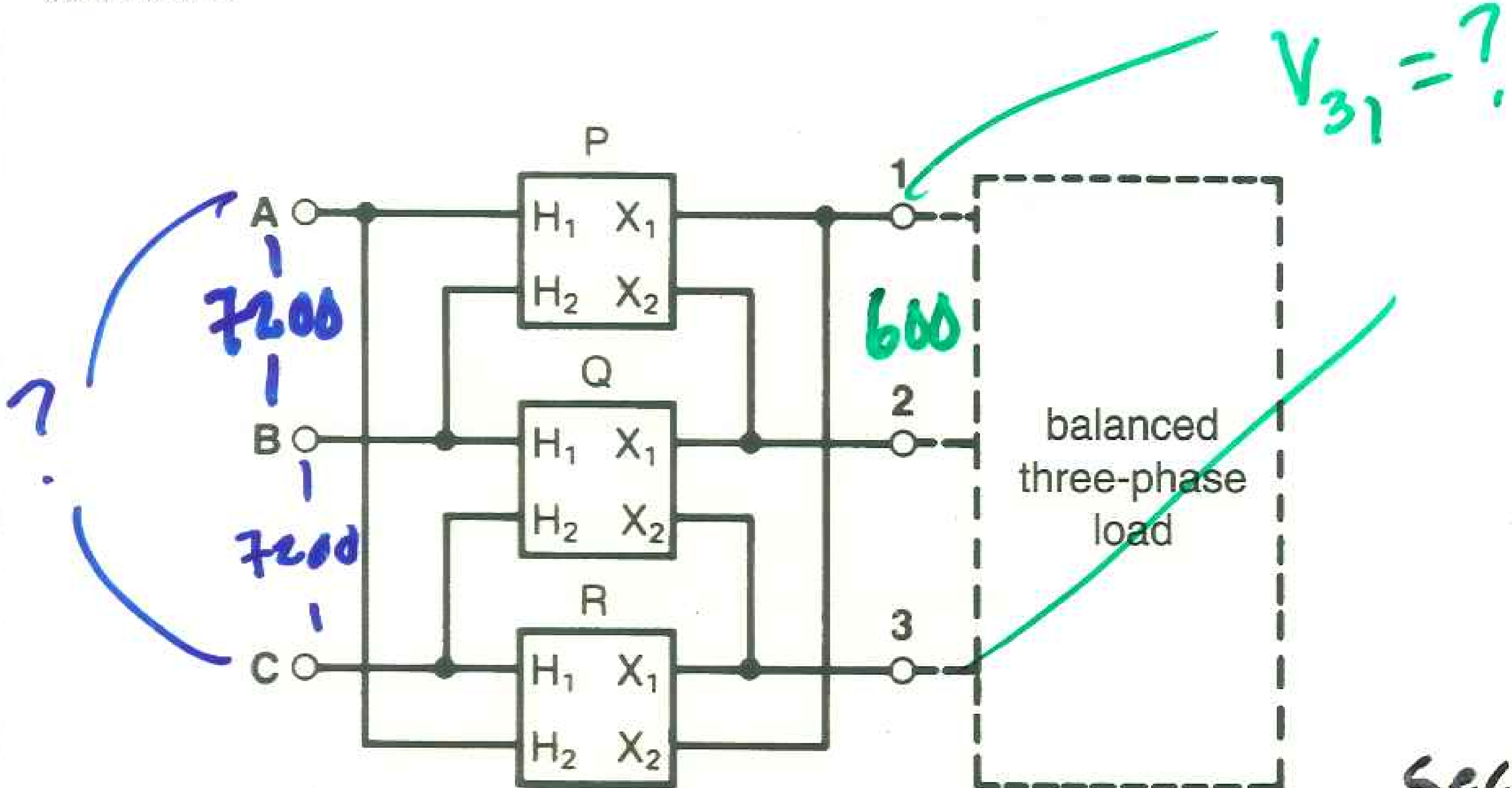
For 12KVA load $V_{14} = 2300$

$$I_{out} = ? = \frac{S}{V} = \frac{12{,}000}{126} = 95\text{ A}$$

$$I_{2300} = ? = \frac{12000}{2300} = 5.2\text{ A}$$

Each Trf. rated at S

Figure 12-1 Delta-delta connection of three single-phase transformers. The incoming lines (source) are A, B, C and the outgoing lines (load) are 1, 2, 3.



Suppose 1 Trf dies – Secondary opens

What can a power engr do?

Vout is 2 Φ only?

Sout is 2 S(trf)

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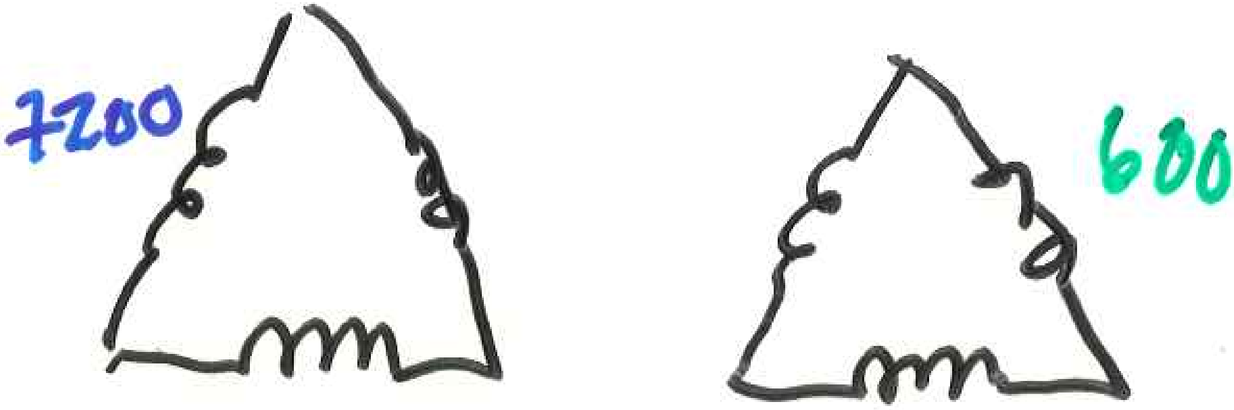


Three 1ϕ transformers: $S^{max} = 150$ KVA

$$I^{max}(\text{600V coil}) = \frac{150\,KVA}{600} = 250\,A$$

$$S^{max}_{3\phi}\left(\begin{matrix}\text{600V}\\ \text{full }\Delta\end{matrix}\right) = 3\,(150) = 450\ KVA$$

$$I_{line}\left(\begin{matrix}\text{600V}\\ \text{delta}\end{matrix}\right) = \frac{450{,}000}{\sqrt{3}\ 600} = \sqrt{3}\ 250$$

Based on 3ϕ relations

What if one 1ϕ trf dies?

Can we rewire two trf?

What do we get? 2ϕ? $2S$?

2 Transformers each rated S

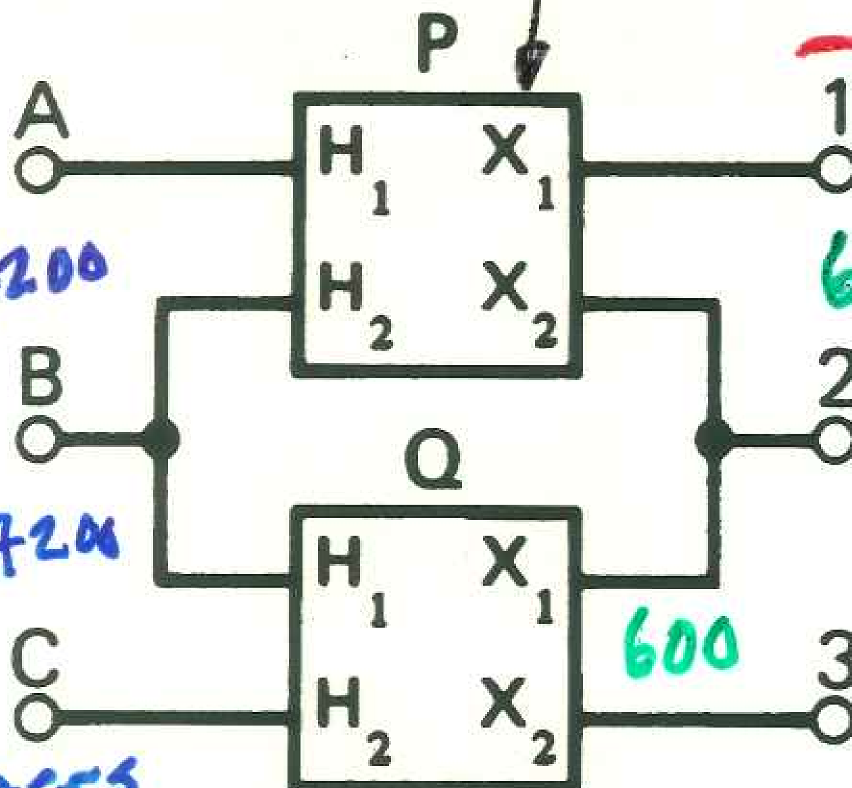
$\Longrightarrow$ Should be able to deliver 2S to load

$$S^{3\phi}_{load} = \sqrt{3}\, \underbrace{I_\ell}_{\text{Not } \sqrt{3} I_\phi \text{ in open } \Delta \text{ but only } I_{max} \text{ (trf rating)}} \underbrace{V_{\ell\ell}}_{\text{normal}}$$

$$I_{max} = \frac{S}{V} = \frac{150\,\text{kVA}}{600} = 250\,\text{A}$$

NO ONLY 260KVA

Open Δ: Each trf 150 KVA Rating



I^{line}_{max} (out)?

① 250 A

② S_{max} (open Δ) ?

③ = 300KVA? guess

Can we do better?

3φ Applied to two wired transformers only

V_{31} = ? Does it exist?

V_{AC} = ?

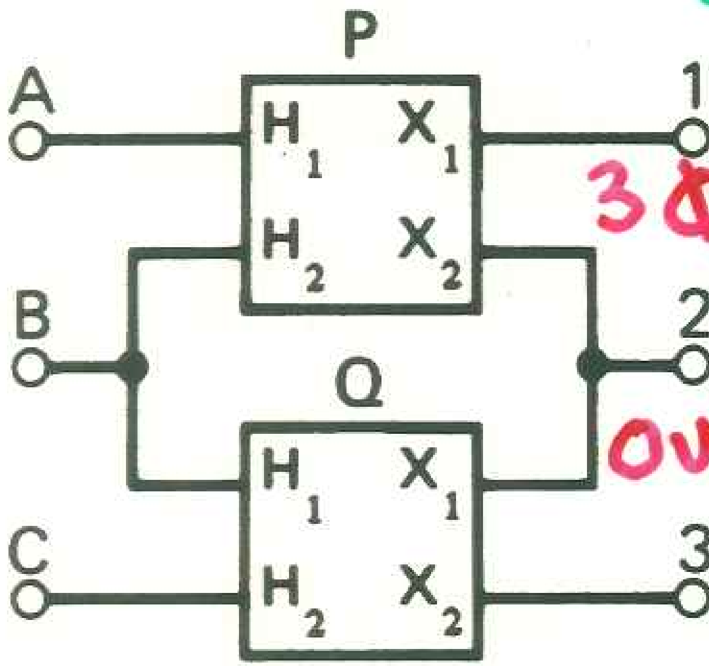
Given Each Trf 150 kV: Two total in Open Δ (Two cases)

Figure 12-8a Open-delta connection.

(1) General

#1 Suprise: E_{out} has all 3 phases! V_{12}, V_{23}, V_{13}!

3Φ in



3Φ out

Can only deliver 86% of 2S w/o overheat! Why

(2) eg V_{IN} (l-l) = 7200 } each trf

V_{out} (l-l) = 600 } 150 MVA

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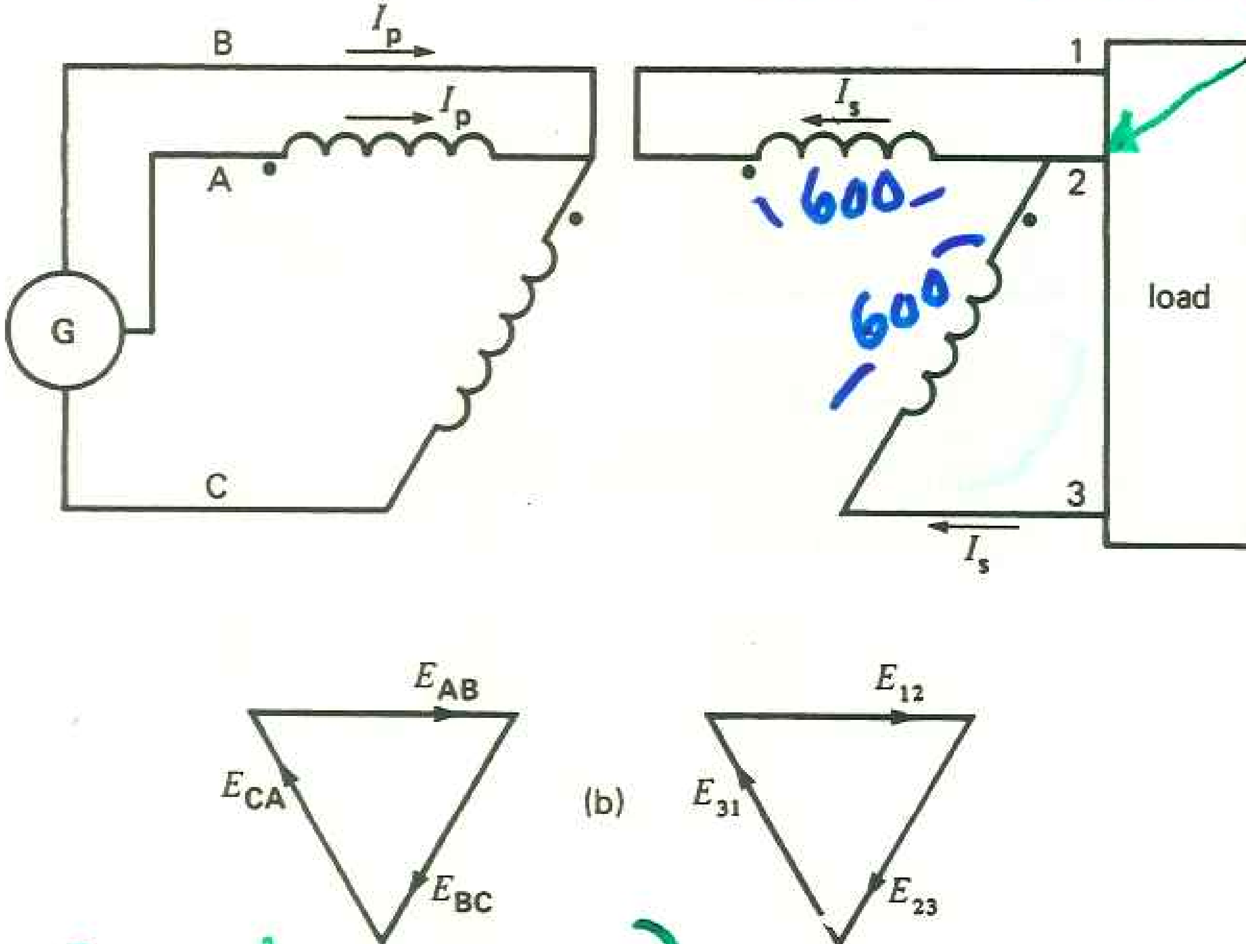
I(load) only? : max each coil → $I(600) = 250\,A$ for all 3 lines of open Δ

$I_\ell \neq \sqrt{3}\,250$



S_{max}(open Δ) $= \sqrt{3}\, V_\ell I_\ell$ (with $V_\ell = 600$, $I_\ell = 250$)

$\approx 260\,kVA$

$$\frac{S_{max}(\text{open } \Delta)}{(2\,S_{trf})_{IN}} = \frac{260}{2(150)} \approx 86\%$$

only 86% of $2\,S_{1\phi}$

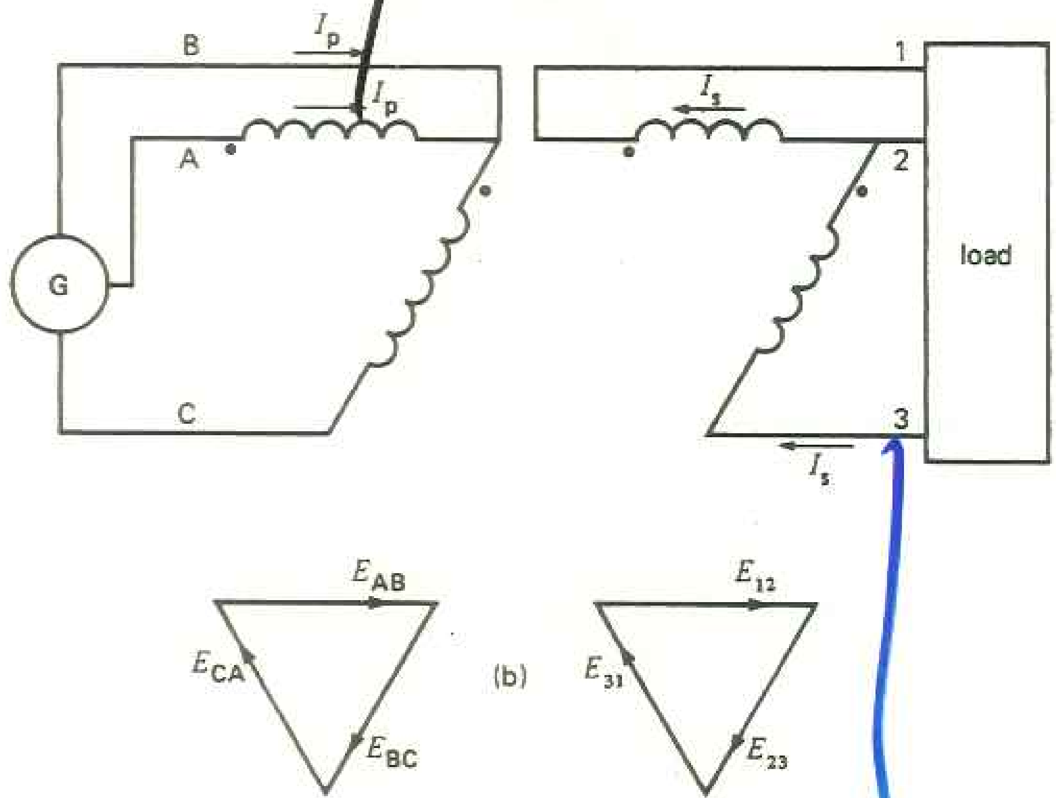
Summary: Open Δ

Two Trf each 150 KVA

Delivers all $V_{3\phi}$ but Open Δ Cannot deliver full $2\,S^{1\phi}_{Trf}$

only 86% of $2\,S^{1\phi}_{trf}$

Figure 12-8b Associated schematic and phasor diagram.



I_ℓ (regular 3 trf Δ) $= \sqrt{3}\, I_\phi$ / I_{line} (open Δ) $= I^{\phi}_{max}$

NO $\sqrt{3}$ possible

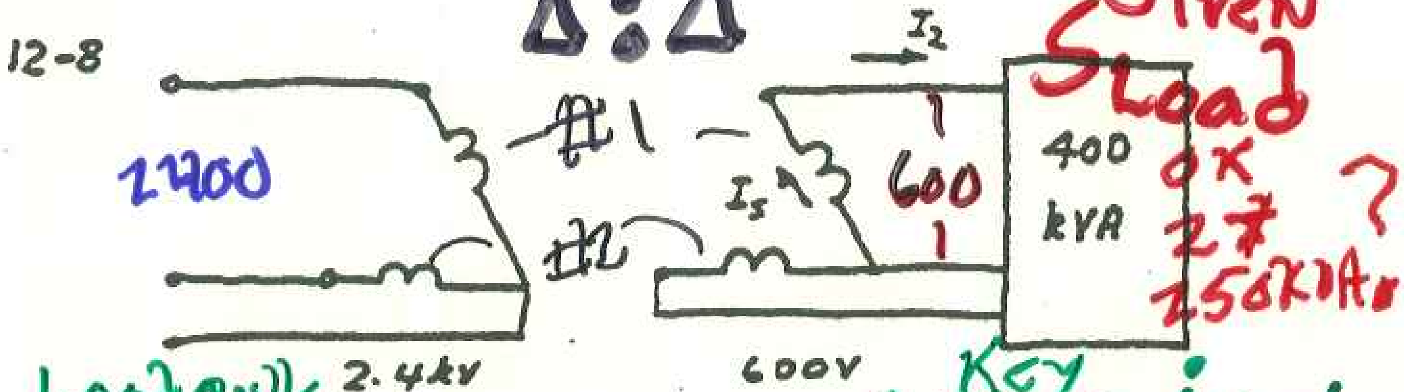
Differ by $\sqrt{3}$

Two Trf S = 250 KVA each trf
2.4 KV/600 4:1

Open Δ $I_{line} = I_{coil}$

Δ : Δ

12-8



Load pulls

$I_\ell = I_2 = 400 \times 10^3 / 600\sqrt{3} = 385A$

Key Open Δ trf $I_\ell = I_\phi$

Nominal value of $I_s = \frac{250\,000}{600} = 417A$

Rated only by single coil

a. The transformers are not overloaded

b. The max load is $417 \times 600 \times \sqrt{3} = 433$ kVA.

in open Δ wiring
Close to overload
For open Δ be careful
CANNOT use $S_L = 500$ kVA

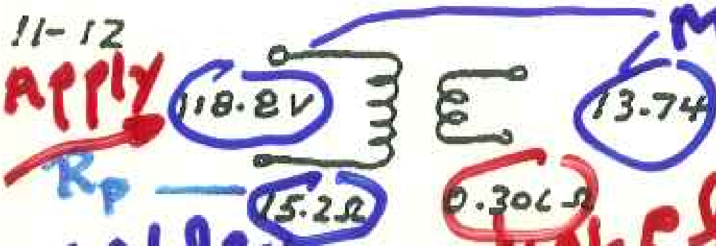
Sum two 250 KVA

Exam!

Nameplate Specs or Trf rating

$S = 50VA$, 120/12.8 } low voltage

11-12



#N $\rho l_p/A_p$ MEASURE

#N_s $\rho l_s/A_s = R_s$ MEASURE

Turns ratio = 118.8/13.74

a = 8.646

b If 120V is applied to primary, the secondary voltage would be 120/8.646 = 13.88V. The 13.88V at no load is higher than the 12.8V shown on

(a) the nameplate. The reason is that when the transformer is "loaded," the internal voltage drop due to the resistence and leakage reactance of the windings, will cause the secondary voltage to fall to about 12.8V at full load. → $I_{max} = S/120$

V drop only when load draws i

120/1 12.8/1

$$\frac{E_1}{N_1} = \frac{E_2}{N_2}$$

$$a = \frac{N_1}{N_2} = \left(\frac{120}{12.8}\right) \approx 9.6$$

Expect 15.2 reflected into secondary is

$$15.2 \frac{1}{a^2} = .203$$

ideal trf Losses are balanced in primary and sec

$$I_p^2 R_p = I_s^2 R_s$$

11-13 In an ideal transformer, the I^2R losses in the primary and secondary should be about the same. Based on the 120 V winding resistance, the calculated resistance of the secondary should be $15.2\,\Omega \times \left(\frac{1}{8.646}\right)^2 = 0.203\,\Omega$. versus The actual measured value is $0.306\,\Omega$. Consequently, we are led to the conclusion that the LV winding is wound on top of the HV winding, because that way the mean length per turn is greater.

Subtle but true

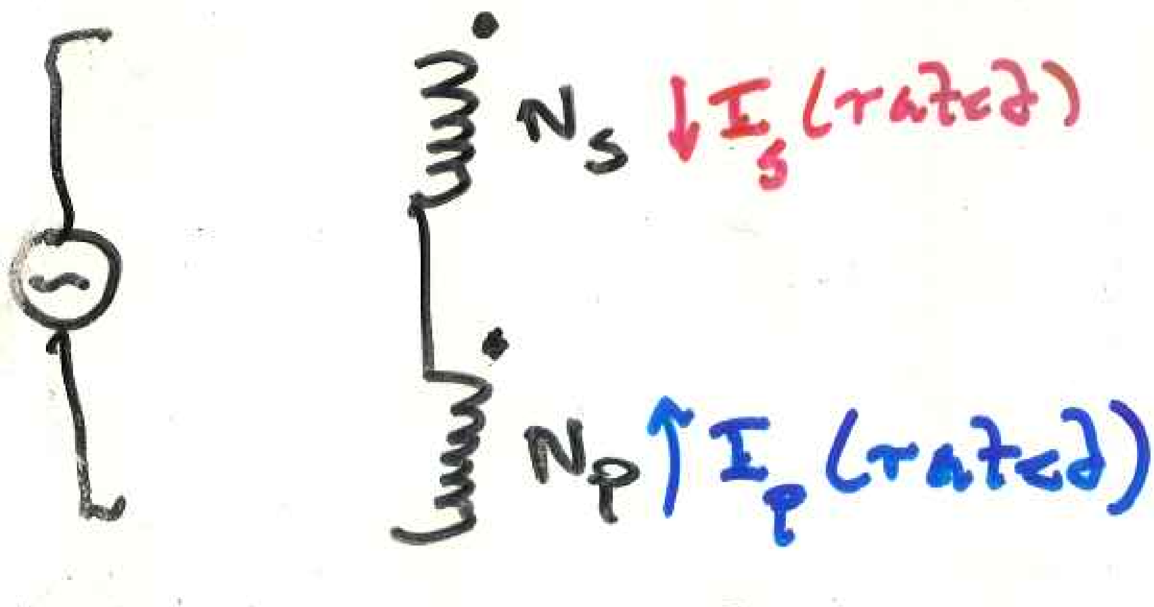
$$R = \frac{\rho\, l}{A}$$ (for 1 turn)

depends what you wind around core or (core plus coil)

Prior

Big S_{load} but limited S_{Trf} Problem (I) use 2 in Parallel. Assumes S_{load} matches S_{source}

(II) Stretch thinking use 1 Trf in a clever way ☺

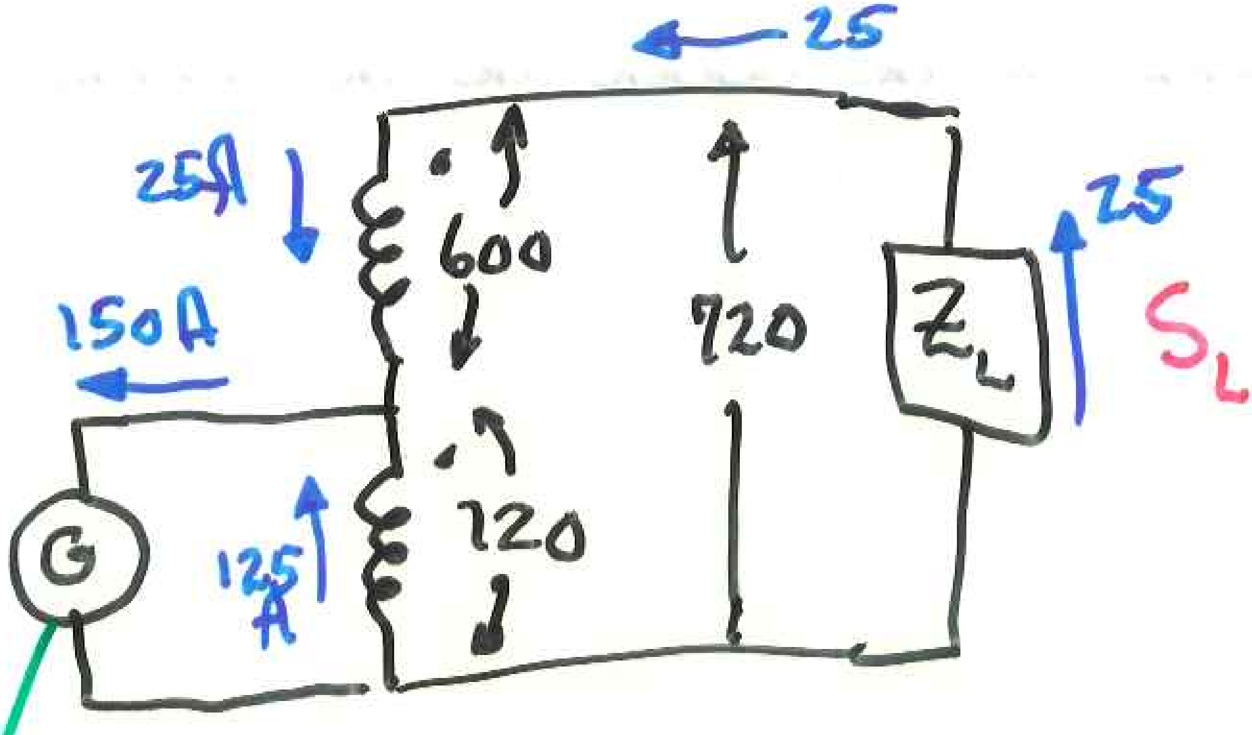


$\Sigma Ni = ?$

$\Rightarrow$

How to wire for maximum S_{load}?

Can get $S(load) > S(trf)$?



$S_G = (120)(150) = 18\,KVA$

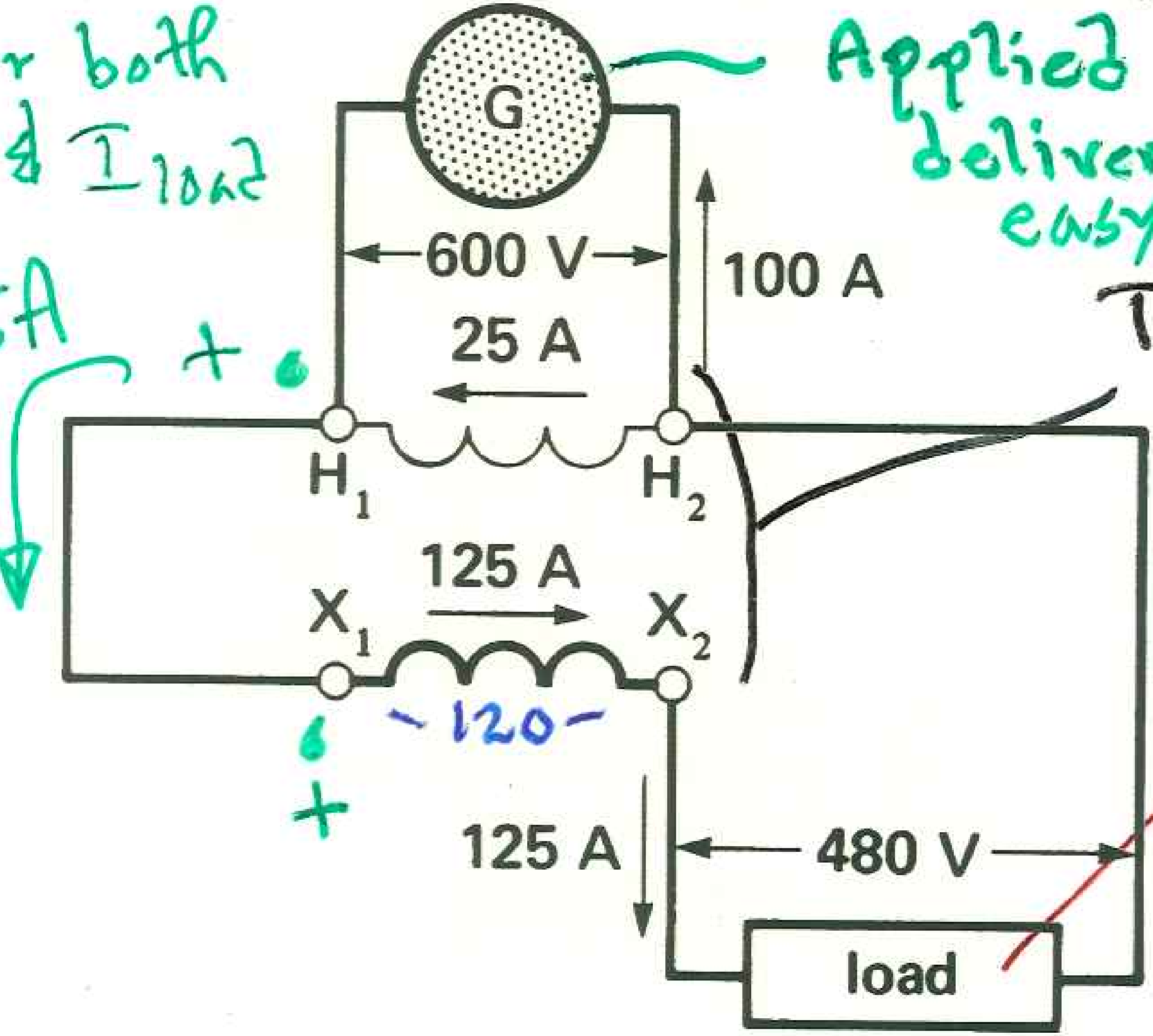
$S_L = (720)(25) = 18\,KVA$

Yet S (transformor) is only 15 KVA

Transformer S = 15 KVA sets I_{max} only

Dots for both V_{load} & I_{load}

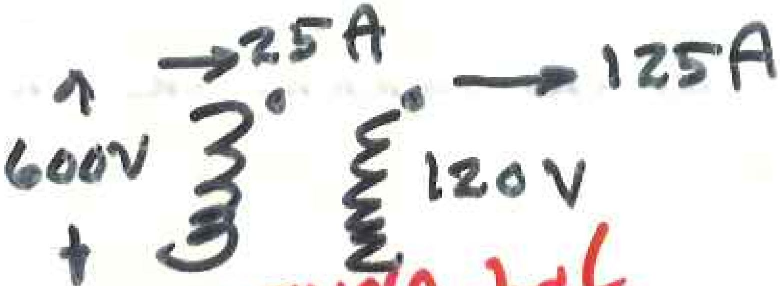
Applied source delivers 60KVA easy eg 100 A



load sinks S = ?
(125) 480
60KVA

S_{trf} vs S_G S_L

15KVA 60KVA



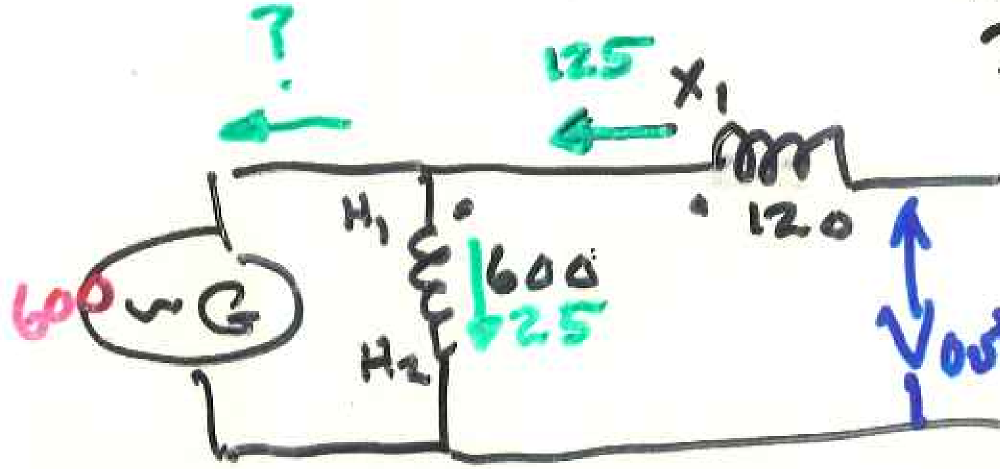
15KVA trf

S_{max} S_{max}

~~P_{IN}~~ = ~~P_{out}~~ = 15KVA

for both coils

Dots on coils for I_{max} directions



load

$P_{out}^{max} = ?$

$I_{out}^{max} = ?$

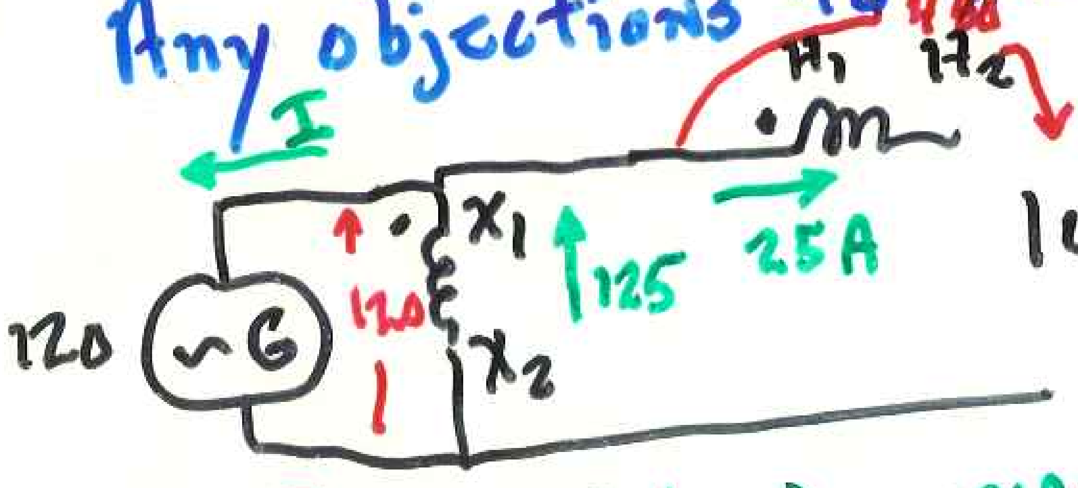
$P_{IN}^{max} = ?$ (100) 600 60KVA

$P_{out}^{max} = ?$

$P_{out}^{max} = (125)(480)$

60KVA

Any objections to the following?



load

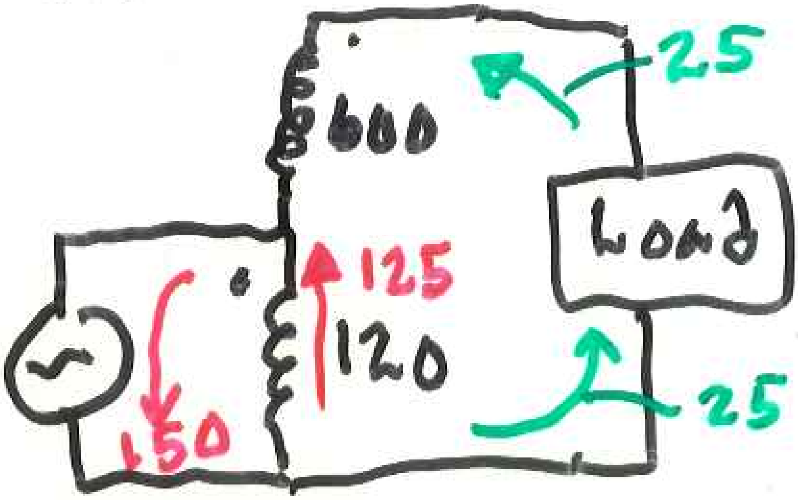
$P_{out} = (25)^*$

480

= 12KVA

$P_{IN} = (100)(120) = 12KA$

Third Case



Dots on coils tell I_{max} directions

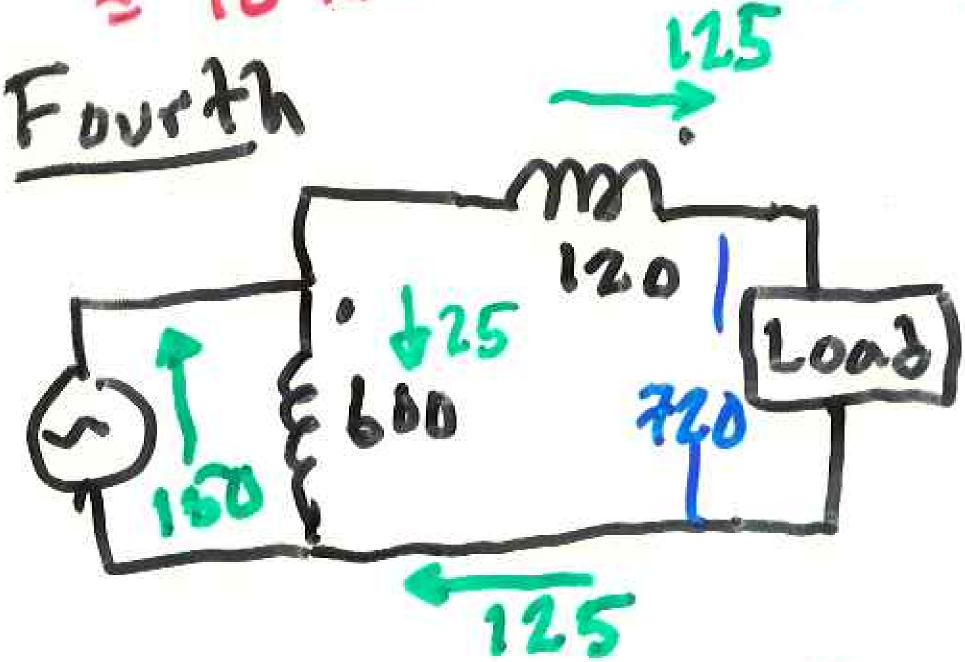
$P_{in} = (150)(120)$

$= 18\ KVA$

$P_{out} = (25)(720)$

$= 18\ KVA$

Fourth



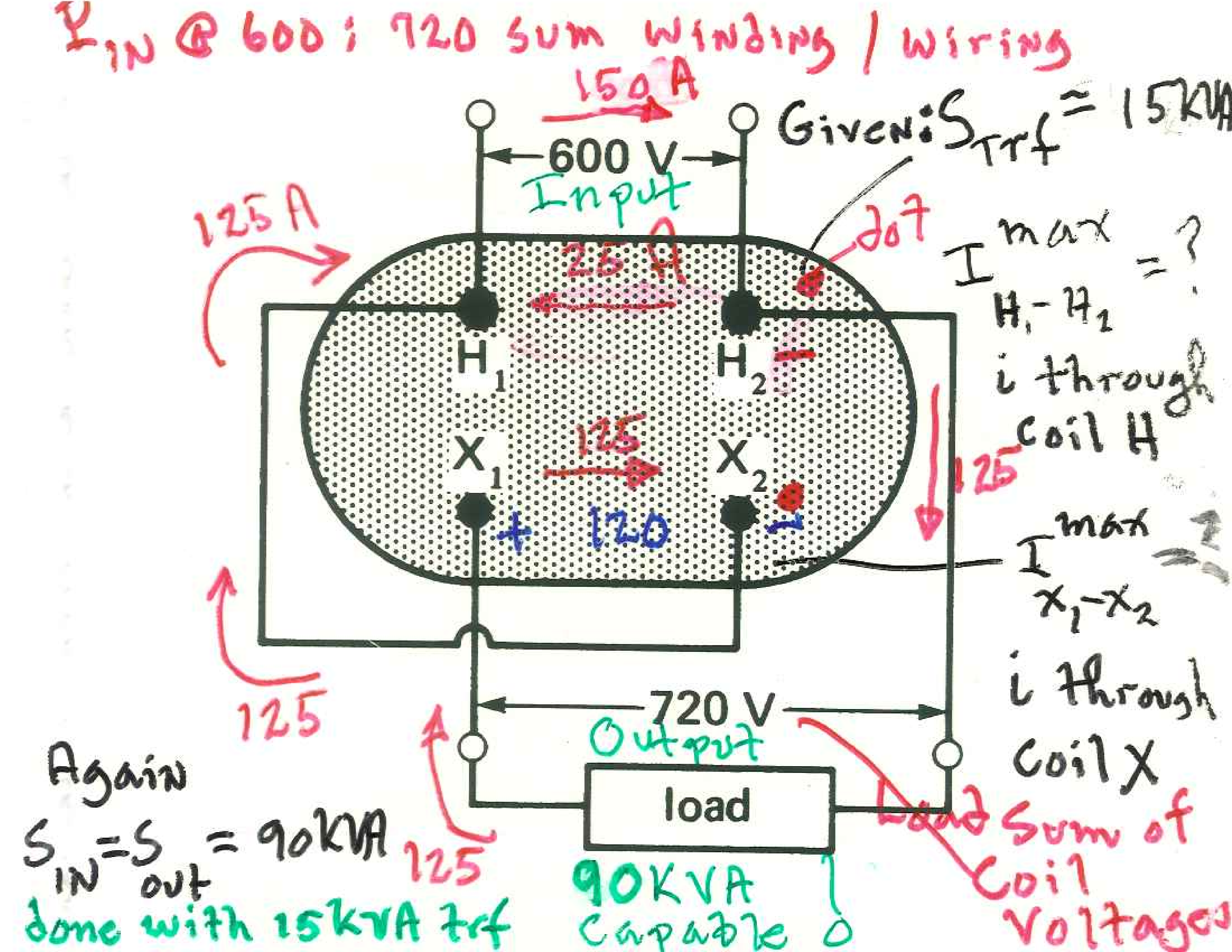
Dots on coil I_{max} directions

$P_{out} = (125)(720)$

$= 90\ KVA$

$P_{in} = 150(600)$

$= 90\ KVA$



I_IN @ 600 : 720 sum winding / wiring
150 A
Given: S_Trf ≃ 15 KVA
600 V
Input
125 A
dot
25 A
I max H1-H2 = ?
i through coil H
H1
H2
X1
X2
125
+
120
-
125
I max X1-X2 = ?
i through coil X
125
720 V
Output
load
Load Sum of Coil Voltages
Again
S_IN = S_out = 90 KVA
done with 15 KVA Trf
125
90 KVA capable

15KVA rated transformer

600V coil ⟹ 25A max

120V coil ⟹ 125A max

New wiring possibilites!

Wire coils so $V_{out} = \underbrace{V_p + V_s}_{720V}$

or $V_{out} = V_p - V_s = 480$

Choose $V_{in} = 600V$

Load across 720V or 480V

$I^{max}_{out} = ?$

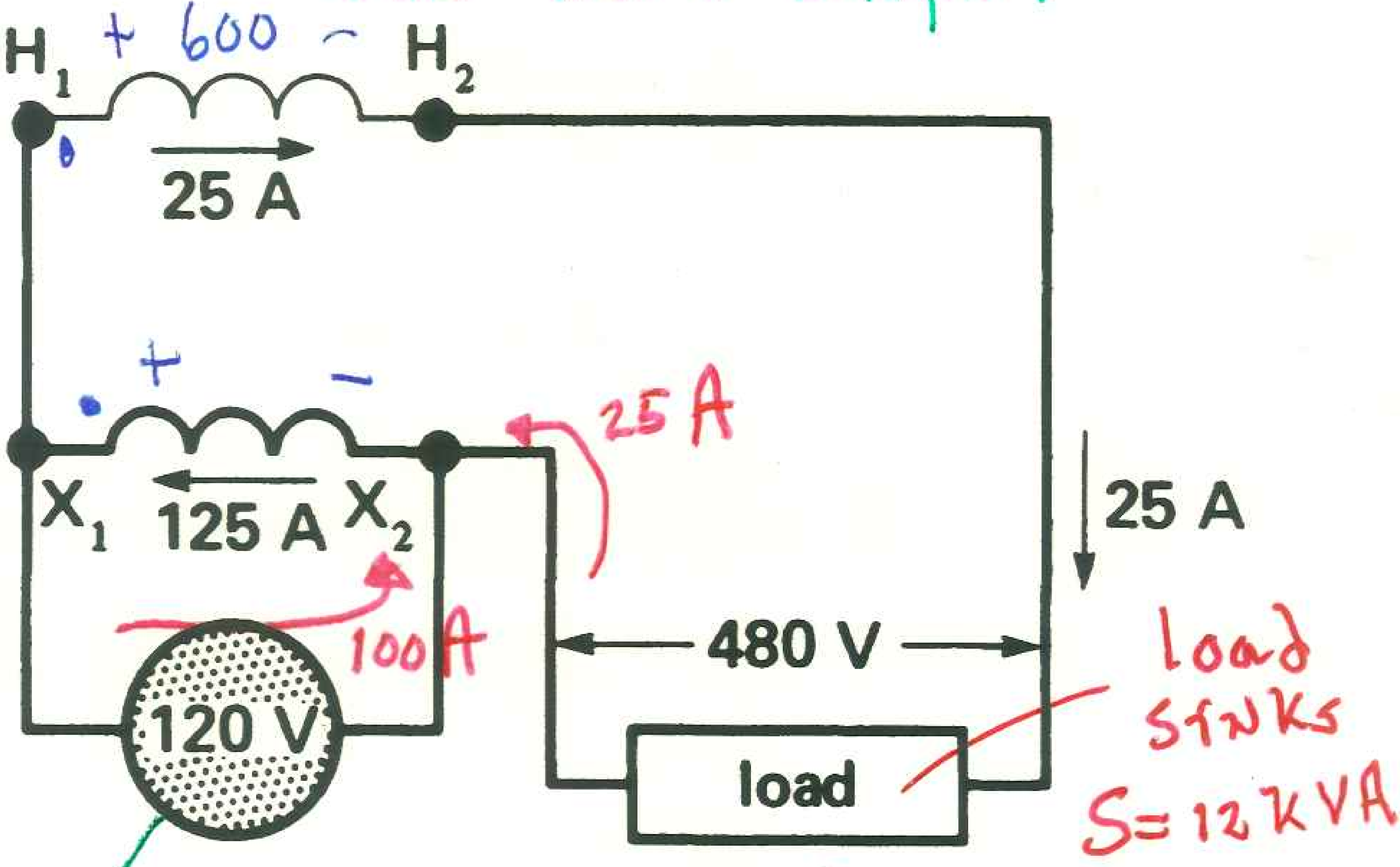
15KVA limit of transformer

Your granpa ma did better!

90KVA! How? Sources are not limited

I_{IN} @ 120: Given winding / wiring 480

Use 120V Input

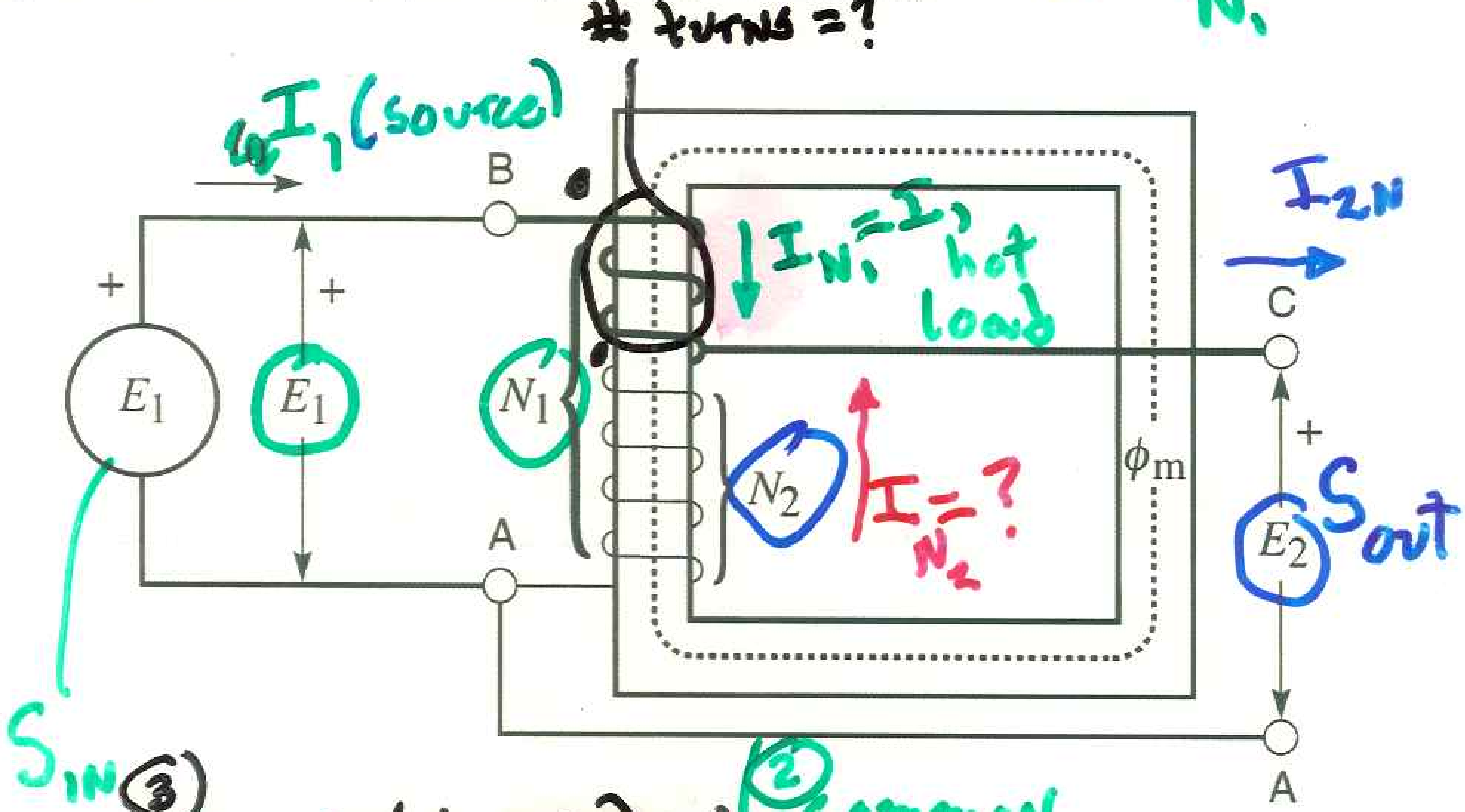


Source provides S = ? I = ? vs S_{trf}

Auto Trf: Intro

① $E_2 = \frac{N_2}{N_1} E_1$

Figure 11-3 Autotransformer having N_1 turns on the primary and N_2 turns on the secondary.



③ I_1 into $(N_1 - N_2)$ coil

I_{N_2} out of N_2 dot

Relation $I(N_1 - N_2) = ?$ $I(N_2) = ?$

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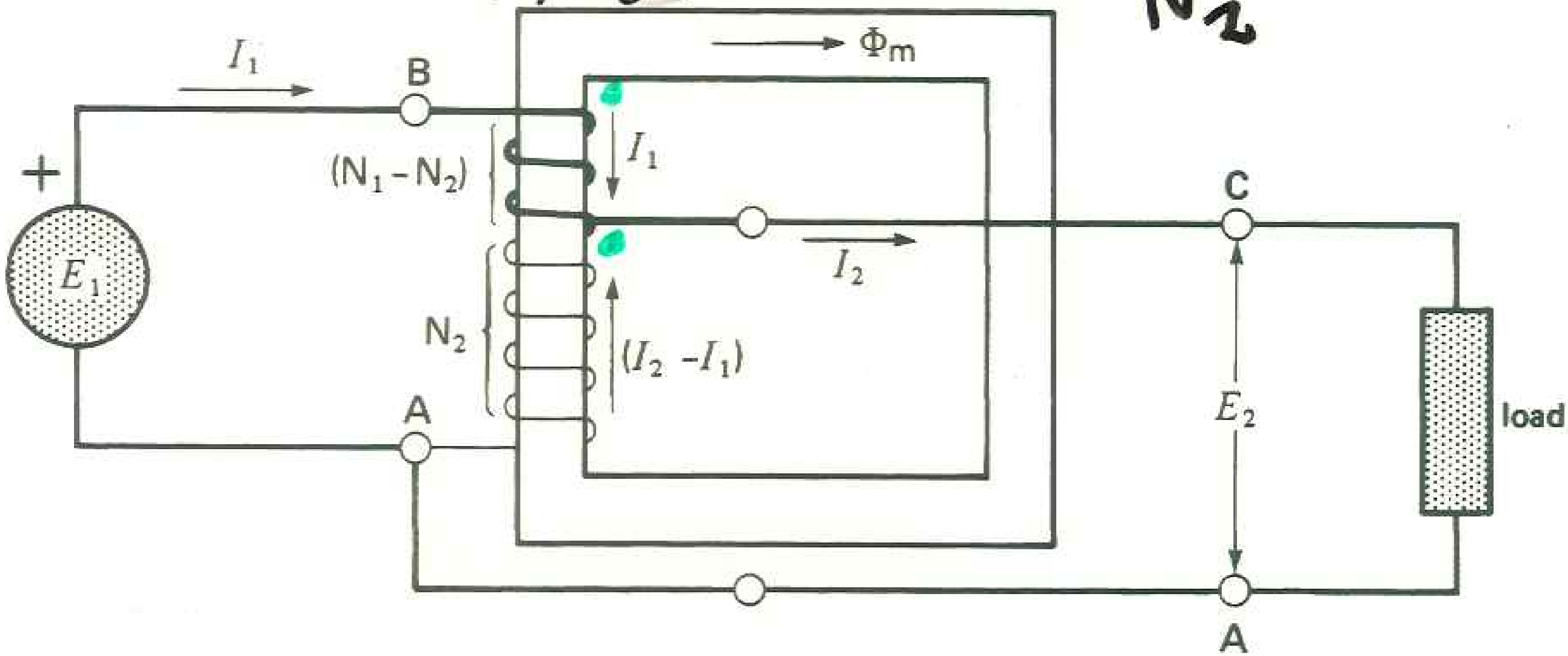
Figure 11-4 Autotransformer under load. The currents flow in opposite directions in the upper and lower windings.

$$\frac{V_{N_1-N_2} = E_1}{N_1 - ?} = \frac{V_{N_2} = E_2}{N_2}$$



$$I_1(N_1 - N_2) - (I_2 - I_1)N_2 = 0$$

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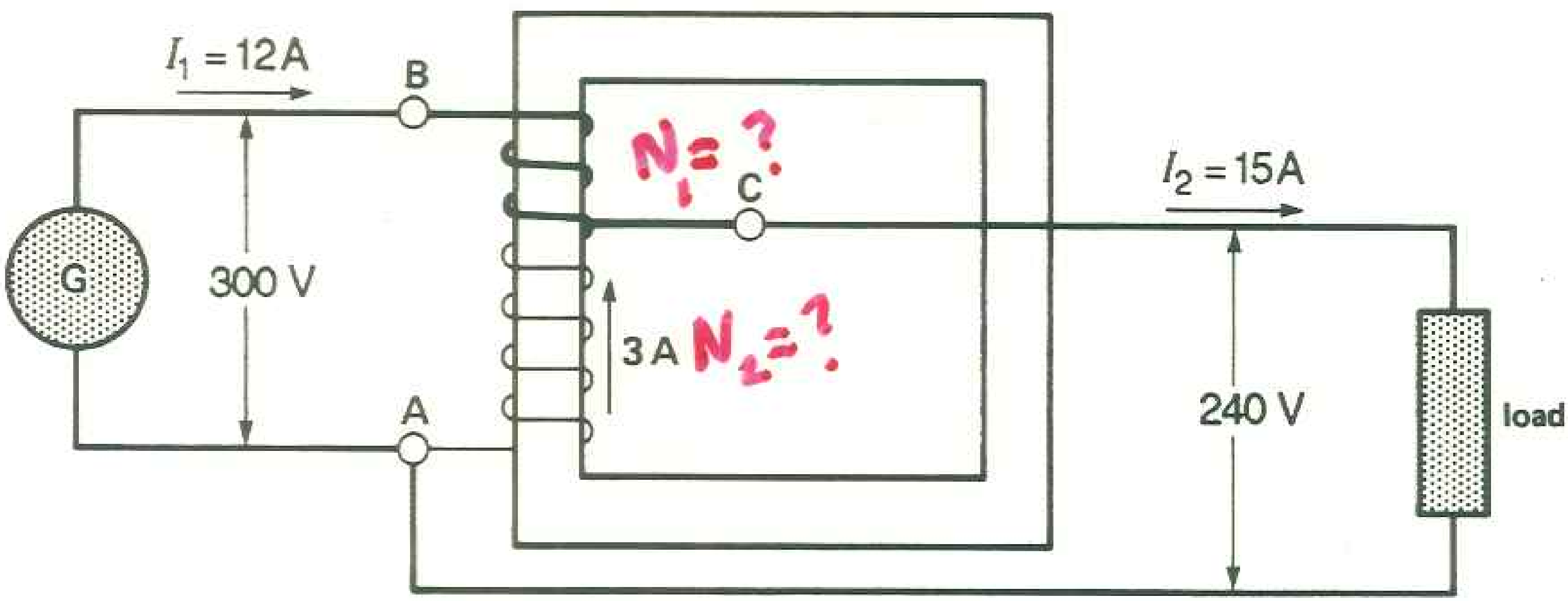
E_1/N_1

Another Equation

$$S_{IN} = S_{out}$$

$$(12)(300) \approx (15)240$$

Figure 11-5 Autotransformer of Example 11-1.



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$I_{max} = \frac{15,000}{600} = 25\text{ A}$

$I_{max} = \frac{15000}{120} = 125\text{ A}$

Wire additive or subtractive

$V_{out} = V_H \pm V_L$

720 Add V
or
480 Sub V

Two V_o and two V_{IN}

For $V_{out} = 480$

V_{IN} @ 600 coil
120 coil

@ 600 V input
I = ?

I_{out} and S_{out} two cases

I_{out} @ 480 could be either:

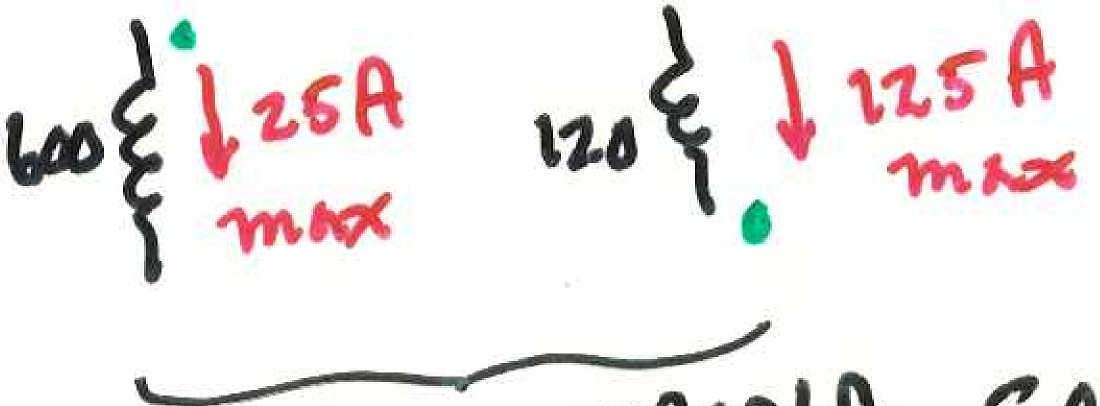
I(480) = 25 A to load

S = 1.8 KVA

I(480) = full 125 A to load

S = 60 KVA

Consider



$S = 15\,KVA$ coils

We will show that:

(1) We can arrange "dots" on coils and wire for

$V_{out} = $ 720, 480   OK?   600, 120

(2) We can wire load for

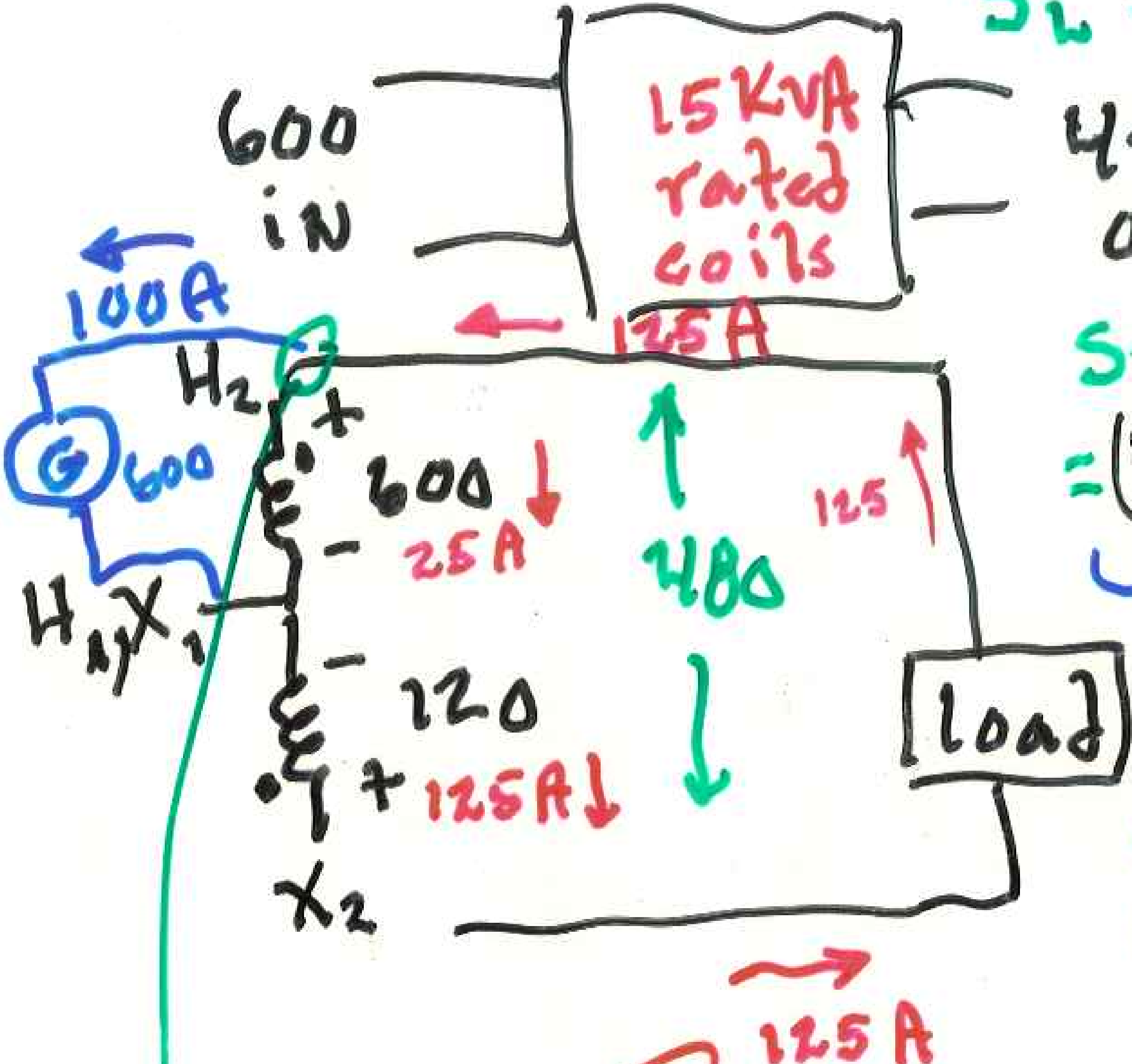
$I_{out} = $ 125A, 100A   OK?   150A?

$S_{out} = $ 90 KVA, 60 KVA, 18 KVA } S_{in} must match

? Use 15 KVA trf/coils for all?

Windings for $I_{load} = 125\,A$

$S_L = 60\,KVA$



$S = 60\,KVA$
$= (480)(125)$

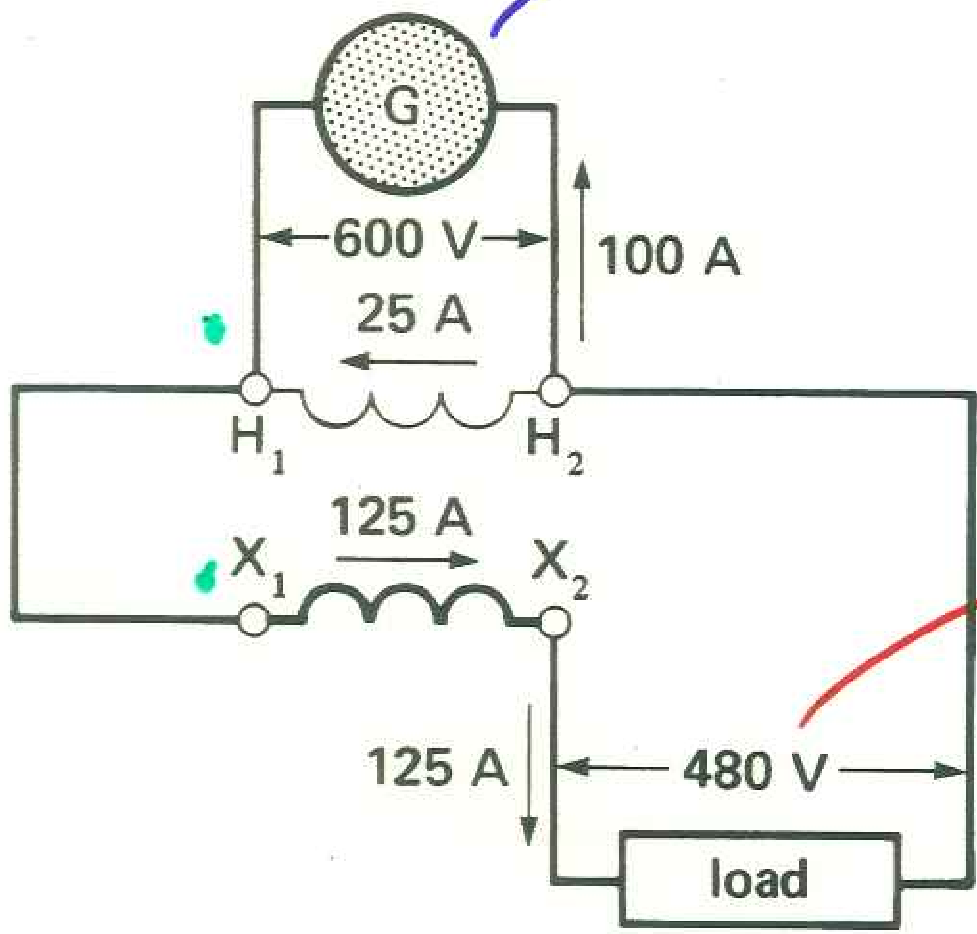
How avoid energy conservation?

120V coil feeds load

Σ currents balances

G provides $S_{IN} = 60\,KVA = S_{out}$
through a 15 KVA trf

Figure 11-8 Schematic diagram of Fig. 11.7 showing voltages and current flows.



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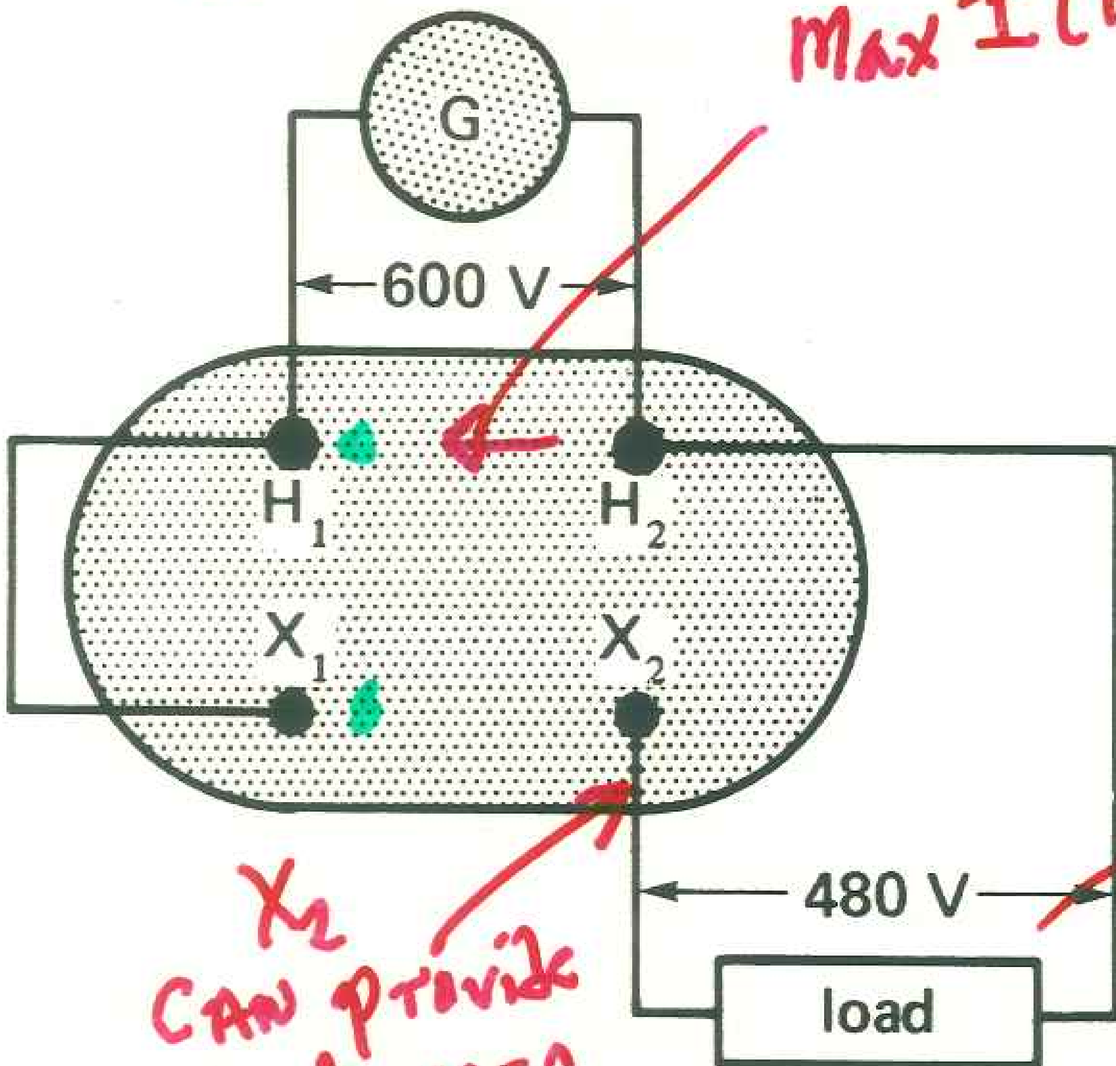
Summary Insights

480 V out

Figure 11-7 Transformer reconnected as an autotransformer to give a ratio of 600 V/480 V.

Max I (H1 - H2) = 25 A



S = ?

X2 can provide up to 125 A

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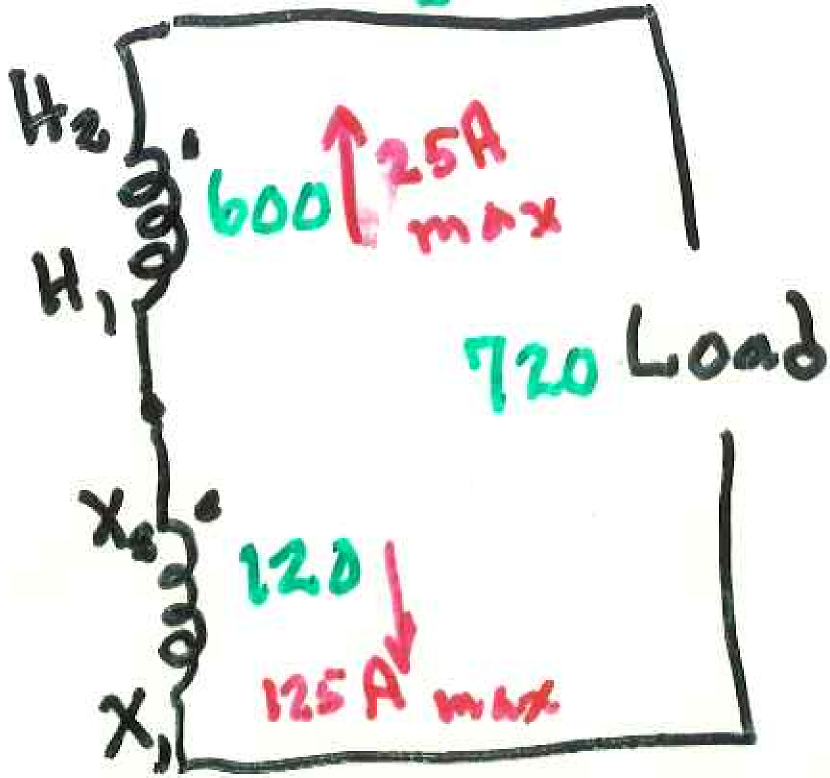
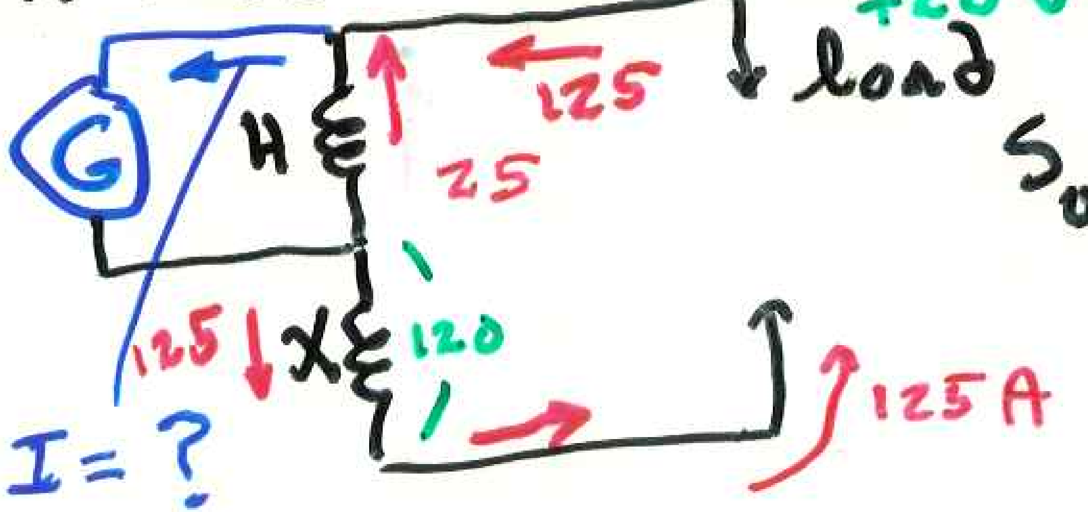
$S_L = 90\,KVA$

Phasing on I's



Place G on either H or X

H case



$S_{out} = (720)\,125 = 90\,kVA$

Must be 150A from G

$S_{in} = (600)\,150 = 90\,kVA$

Figure 11-9 Transformer reconnected to give a ratio of 600 V/720 V.

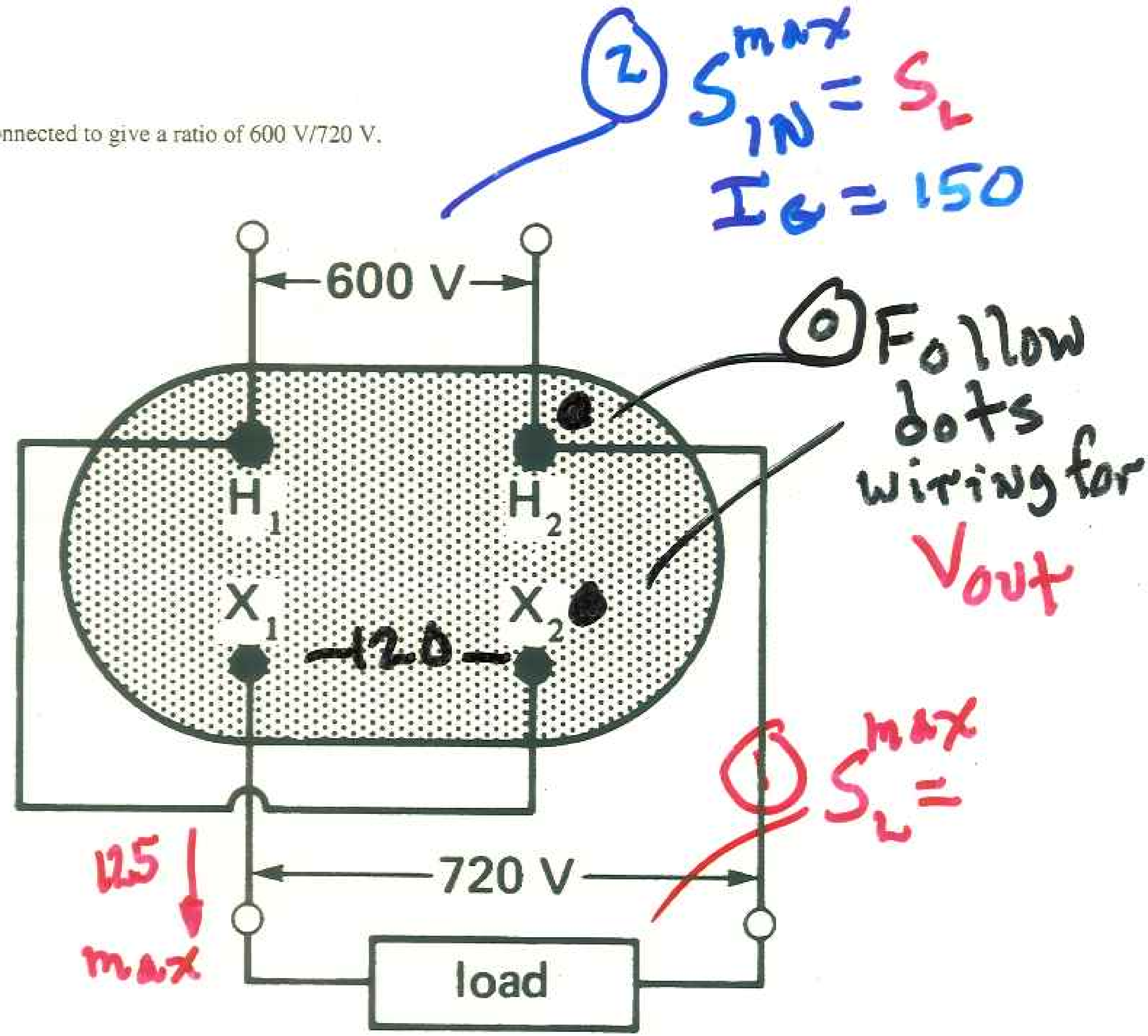


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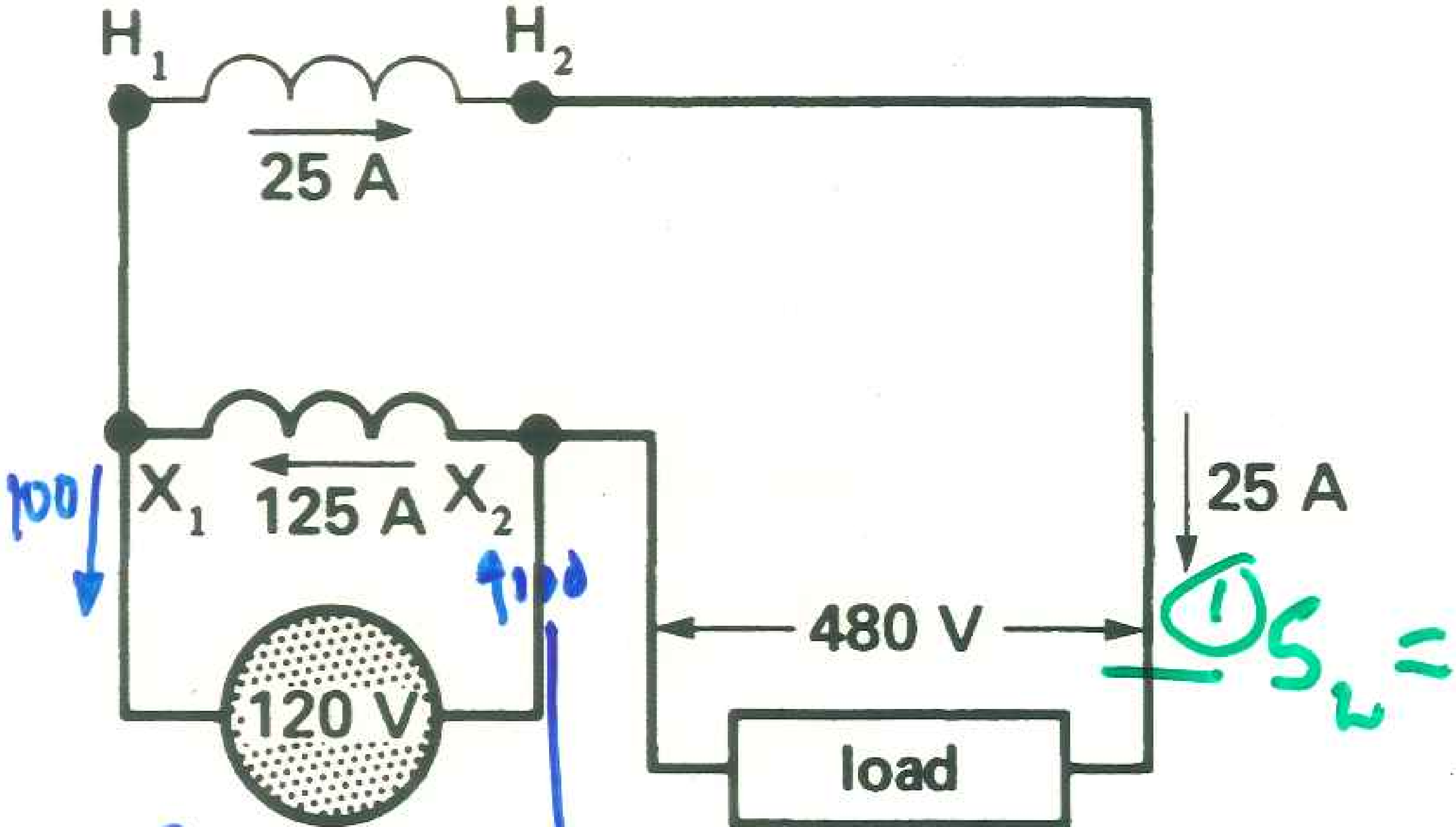
Figure 11-10 Transformer reconnected to give a ratio of 120 V/480 V.



② $S_{120} = ?$, $I_{120} = ?$

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$S_{120} = 12KVA$ $I = 100$ $S_2 = 12\ KVA\ @\ 480$