Text Questions:

3-13: What is a TCUL transformer?
A TCUL is a tap changing under load transformer. It has multiple taps with small percentages of the full-load voltage spacing between them to provide slightly more or less voltage in order to offset the variations in voltages down the line. These can be used to maintain constant voltage while loads and impedances are shifting.

3-19: Why does one hear a hum when standing near a large power transformer?
The hum is created by the magnetomotive force on the core, causing it to expand and contract slightly during magnetization cycles.

Text Problems:

3-2(a,c,d):

a)

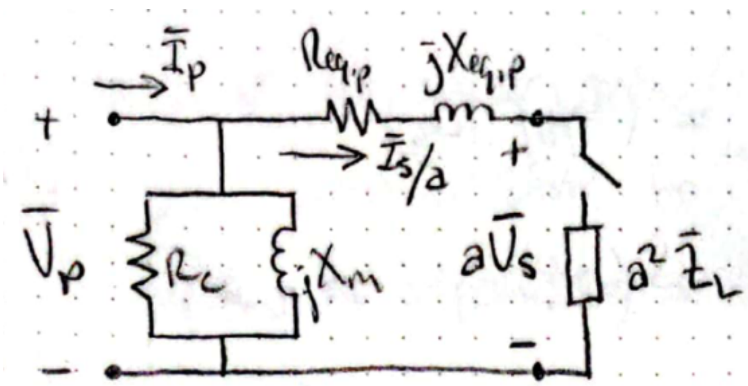

Fig. 1: Equivalent circuit of transformer referred to high-voltage side

Parallel components R_C and X_m are given: $R_C = 250\ k\Omega$, $X_m = 30\ k\Omega$.

$$R_{eq,P} = R_P + a^2 R_S \qquad X_{eq,P} = X_P + a^2 X_S$$

$$a^2 = \left(\frac{V_P}{V_S}\right)^2 = \left(\frac{8000V}{277V}\right)^2 = (28.9)^2$$

Series components are calculated:

$$R_{eq,P} = (32\Omega) + a^2(0.05\Omega) = 73.8\Omega$$

$$X_{eq,P} = (45\Omega) + a^2(0.06\Omega) = 95\Omega$$

c)

Load regulation: $|\tilde{V}_P|_{FL} = \tilde{V}_{drop} + a\tilde{V}_{S,FL}$

$$= \left(\frac{I_S}{a}\right)\left(R_{eq,P} + jX_{eq,P}\right) + a\tilde{V}_{S,FL}$$ where $a|\tilde{V}_S|_{FL} = |\tilde{V}_P|_{NL}$

$$I_S = \frac{S_{rated}{}^{*}}{V_{S,rated}\angle cos^{-1}(PF)} = \frac{20kVA\angle 0°}{277V\angle 37°} = 72.2A\angle -37°$$

$$I_S/a = 2.5A\angle -37°$$

$$|V_P|_{FL} = (2.5A\angle -37°)(73.8 + j95\Omega) + 8000V$$

$$= 8290V\angle 0.54°$$

$$VR_{load} = \frac{|V_P|_{FL} - |V_P|_{NL}}{|V_P|_{NL}} \times 100\% = 3.6\%$$

d)

$$P_{loss} = P_{core} + P_{cu}$$

$$P_{core} = \frac{V_P{}^2}{R_{core}} \qquad P_{cu} = (I_S/a)^2 R_{eq,P}$$

$$= \frac{(8290V)^2}{250k\Omega} \qquad = (2.5A)^2(73.8\Omega)$$

$$= 275W \qquad = 461W$$

$$P_{out} = (20KVA)(0.8) = 16000W$$

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}} \times 100\% = 96\%$$

3-21(b,c):

b)

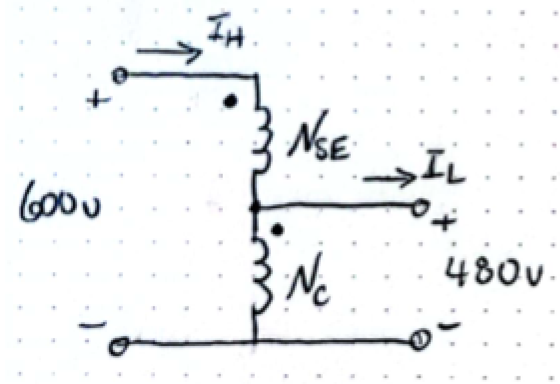

Fig. 2: 600/480-V step down autotransformer

c)

$$V_C/V_{SE} = N_C/N_{SE} = \frac{480V}{(600-480)V} = 4/1$$

$$S_{IO} = S_W\frac{N_{SE}+N_C}{N_{SE}} = (10kVA)\frac{1+4}{1} = 50kVA$$

Problem 1:

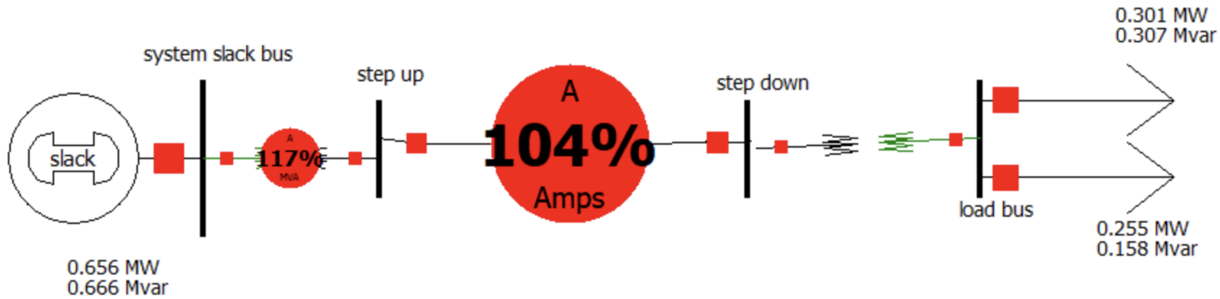

Fig. 3: Single-solution full Newton simulation

$P_G = 656kW$ $\quad\quad\quad$ $P_L = 301kW + 255kW = 556kW$

$\eta = \frac{P_L}{P_G}\% = \frac{556kW}{656kW} \times 100\% = 85\%$

The step-up transformer is at 117% of its rated MVA and the transmission line is at 104% of its rated MVA. These components are not sized properly. The generator is providing slightly more reactive power than real power, which is being stored in the transformer and transmission lines, overloading them.

Problem 2:

75kVA, Single phase 7.20kV-240V distribution transformer

Table 1: Short-circuit and open-circuit test data

$V_{OC} = V_{P,rated} = 7.2kV$	$I_{OC} = 250mA$	$P_{OC} = 1500W$
$V_{SC} = 330V$	$I_{SC} = I_{P,rated} = \frac{75kVA}{7.2kV} = 10.4A$	$P_{SC} = 1600W$

Parallel Components:

$$\bar{Y}_{OC} = Y_{OC}\angle - \Theta_{OC} \qquad Y_{OC} = \frac{I_{OC}}{V_{OC}} = 35\mu S$$

$$\bar{Y}_{OC} = 35\mu S\angle - 34° \qquad \Theta_{OC} = cos^{-1}\left(\frac{P_{OC}}{I_{OC}V_{OC}}\right) = 34°$$

$$= 29 - j20\mu S$$

$$R_{core} = 1/G = 34.5k\Omega \qquad X_m = 1/B = 50k\Omega$$

Series Components:

$$\acute{Z}_{SC} = \acute{Z}_{eq,P} = R_{eq,P} + jX_{eq,P} = Z_{SC}\angle\Theta_{SC}$$

$$Z_{SC} = \frac{V_{SC}}{I_{SC}} = 32\Omega \qquad \Theta_{SC} = cos^{-1}\left(\frac{P_{SC}}{I_{SC}V_{SC}}\right) = 62°$$

$$Z_{SC}\angle\Theta_{SC} = 32\Omega\angle 62° = 15 + j28\Omega$$

$$R_{eq,P} = 15\Omega \qquad X_{eq,P} = 28\Omega$$

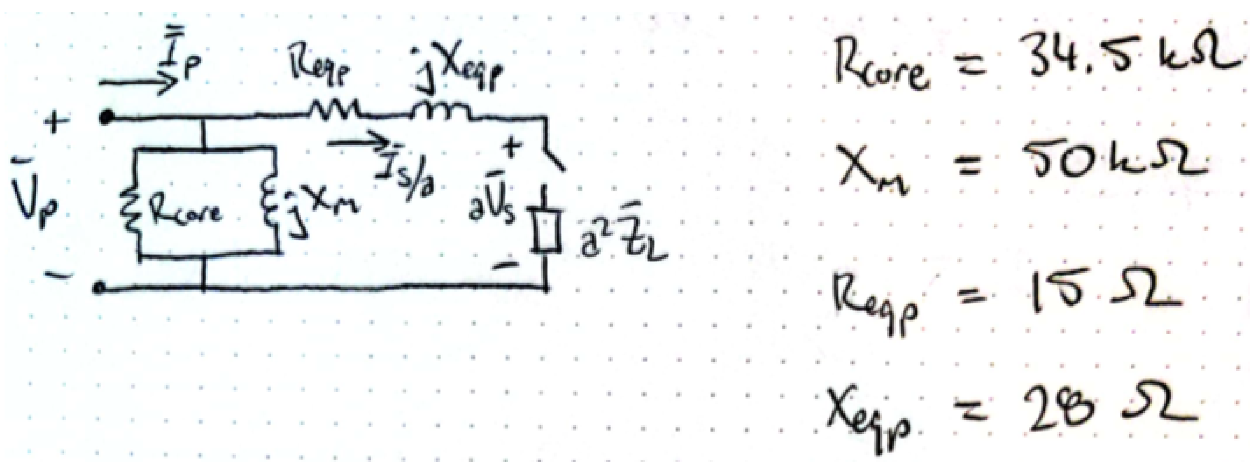

Fig. 4: Primary-side cantilever equivalent circuit

PF=0.85 lagging with rated load of 75kVA

Load regulation: $|\tilde{V}_P|_{FL} = \tilde{V}_{drop} + a\tilde{V}_{S,FL}$

$$= \left(\frac{I_S}{a}\right)\left(R_{eq,P} + jX_{eq,P}\right) + a\tilde{V}_{S,FL} \qquad \text{where } a|\tilde{V}_S|_{FL} = V_{OC}$$

$$I_S = \frac{S_{rated}{}^{*}}{V_{S,rated}\angle cos^{-1}(PF)} = \frac{75kVA\angle 0°}{240V\angle 32°} = 312A\angle - 32°$$

$$a = V_P/V_S = 30$$

$$I_S/a = 10A\angle - 37°$$

$$|V_P|_{FL} = (10A\angle - 32°)(15 + j28\Omega) + 7200V$$

$$= 7530V$$

$$VR_{load} = \frac{|V_P|_{FL} - |V_P|_{NL}}{|V_P|_{NL}} \times 100\% = 4.6\%$$

Efficiency:

$$P_{loss} = P_{core} + P_{cu}$$

$$P_{core} = \frac{V_P{}^2}{R_{core}} \qquad P_{cu} = (I_S/a)^2 R_{eq,P}$$

$$= \frac{(7530V)^2}{34.5k\Omega} \qquad = (10A)^2(15\Omega)$$

$$= 1644W \qquad = 1500W$$

$$P_{out} = (75KVA)(0.85) = 64kW$$

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}} \times 100\% = 95\%$$

FE Problem 1:

$S = \frac{P}{PF} = \frac{50kW}{0.77} = 65kVA$

$Q = Ptan(cos^{-1}(0.77)) = 41kVAr$

$Q' = Ptan(cos^{-1}(0.95)) = 16kVAr$

$Q_c = Q' - Q = -25kVAr$

Power factor correction capacitors are placed in parallel.

(D)