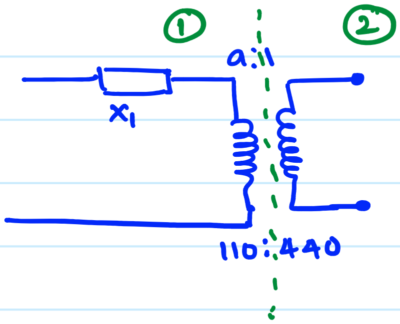
11.2 Per Unit Analysis

Friday, 1 April 2022 3:43 PM

1) transformer 110/440 V, 2.5kVA

$X_1 = j0.06\,\Omega$.



a) Choose $S_B = 2.5\,kVA$

b) Choose voltage bases

$V_{1B} = 110V$ $V_{2B} = 440V$

$$Z_{1B} = \frac{V_{1B}^2}{S_B} = \frac{110^2}{2500} = 4.84\,\Omega$$

$$Z_{2B} = \frac{V_{2B}^2}{S_B} = \frac{440^2}{2500} = 77.44\,\Omega$$

$$X_{1pu} = \frac{X_1}{Z_{1B}} = \frac{j.06}{4.84}$$

$$= j0.01244 \text{ p.u.}$$

Reflect X_1 to the high voltage side.

$$X_1' = \frac{X_1}{a^2} = \frac{j.06}{(1/4)^2} = j0.96\,\Omega$$

$$X'_{1pu} = \frac{X_1'}{Z_{2B}}$$

$$= \frac{j0.96}{77.44}$$

$$\overline{77.44}$$

$$= j\,0.01244\ p.u.$$

Generator

2) $X_{pu} = j\,0.25\ pu.$

Generator rating – 500 MVA, 18 KV, 1 ϕ

<u>Generator rating bases</u>

a) Choose $S_B = 500 \times 10^6$ VA

b) Choose $V_B = 18 \times 10^3$ V

c) $Z_B = \dfrac{V_B^2}{S_B} = \dfrac{18^2 \times 10^6}{500 \times 10^6} = 0.648\,\Omega$

$$X_{pu} = \frac{X_{actual}}{Z_B}$$

$$X_{actual} = X_{pu} \cdot Z_B = 0.648 \times j\,0.25$$

$$X_{actual} = j\,0.162\,\Omega$$

New base values

- $S_B^{new} = 100$ MVA
- $V_B^{new} = 20$ KV

$X_{pu}^{new} = ?$

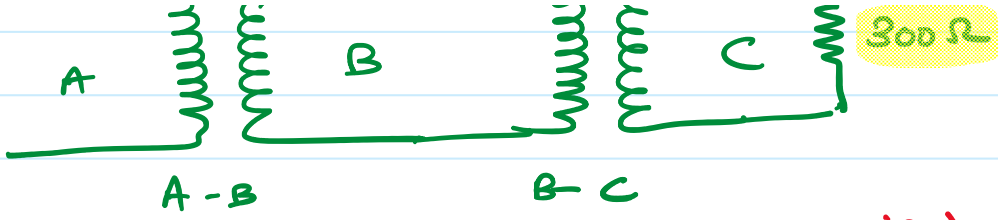
$$Z_B^{new} = \frac{(V_B^{new})^2}{S_B^{new}} = \frac{20^2 \times 10^6}{100 \times 10^6} = 4\,\Omega$$

$$X_{pu}^{new} = \frac{X_{actual}}{Z_B^{new}} = \frac{j\,0.162}{4}$$

$$X_{pu}^{new} = j\,0.0405\ pu$$

3)

3)



A-B → 10000 KVA, (13.8/138) KV, 10% → j0.1 pu

B-C → 10000 KVA, (138/69) KV, 8% → j0.08 pu

Base of circuit B → 10,000 KVA, 138 KV

$S_B = 10000$ KVA

A	B	C
$V_B^A = 138\text{KV} \times \frac{13.8}{138}$	$V_B^B = 138\text{KV}$	$V_B^C = 138\text{KV} \times \frac{69}{138}$
$= 13.8\text{KV}$		$= 69\text{KV}$
$Z_B^A = \frac{13.8^2 \times 10^6}{10 \times 10^6}$	$Z_B^B = \frac{138^2 \times 10^6}{10 \times 10^6}$	$Z_B^C = \frac{69^2 \times 10^6}{10 \times 10^6}$
$= 19.04\,\Omega$	$= 1904\,\Omega$	$= 476.1\,\Omega$

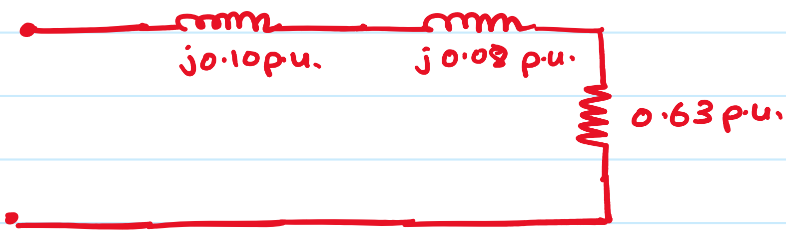
Transformer p.u. values dont change since the manufacturer's base values and our system base values are the same [Both S_B as well as V_B]

		$Z_L^C = 300\,\Omega.$
$Z_L^A = Z_L^B \times \left(\frac{13.8}{138}\right)^2$	$Z_L^B = Z_L^C \times \left(\frac{138}{69}\right)^2$	
$= 12\,\Omega$	$= 1200\,\Omega$	$Z_{Lpu}^C = \frac{300}{Z_B^C}$
$Z_{L\,pu}^A = 12$	$Z_{L\,pu}^B = 1200$	$= 300 = 0.63$ pu

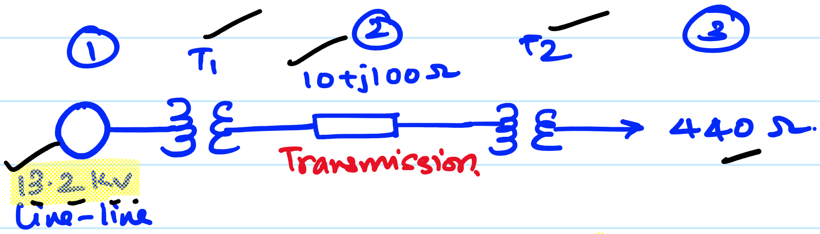
$$Z^A_{L\,pu} = \frac{12}{Z^A_B} = \frac{12}{19.04} = 0.63\,pu$$

$$Z^B_{L\,pu} = \frac{1200}{Z^B_B} = \frac{1200}{1904} = 0.63\,pu$$

$$Z_B^{C} = \frac{300}{476.1} = 0.63\,pu$$



4)



$T_1 \rightarrow$ 5MVA, 13.2 Δ - 132 Y kV, $X_{T_1} = 10\%$

$T_2 \rightarrow$ 10MVA, 138 Y - 69 Δ kV, $X_{T_2} = 8\%$

Base values for transmission section → 138kV

$S_B \rightarrow$ 10MVA.

$S_B^{3\phi} = 10$ MVA.

$$Z_B = \frac{(V_B^{LL})^2}{S_B^{3\phi}}$$

①	②	③
$V_{1B} = 138kV \times \frac{13.2}{132}$	$V_{2B} = 138kV$	$V_{3B} = 138kV \times \frac{69}{138}$
$= 13.8 kV$		$= 69 kV$
$Z_{1B} = \frac{13.8^2 \times 10^6}{10 \times 10^6}$	$Z_{2B} = \frac{138^2 \times 10^6}{10 \times 10^6}$	$Z_{3B} = \frac{69^2 \times 10^6}{10 \times 10^6}$
$= 19.04\,\Omega$	$= 1904\,\Omega$	$= 476.1\,\Omega$

$= 19.04\,\Omega$ | $= 1904\,\Omega$ | $= 476.1\,\Omega$

$V_G = 13.2\,kV\,[\ell-\ell]$ | $Z_L = 10 + j100$ | $Z_{load} = 440\,\Omega$

$V_u^{pu} = \dfrac{13.2}{13.8}$ | $Z_L^{pu} = \dfrac{10+j100}{1904}$ | $Z_{load}^{pu} = \dfrac{440}{476.1}$

$= 0.956\angle 0^\circ\,pu$ | $= 5.25\times10^{-3} + j0.0525$ p.u. | $= 0.924$ p.u.

Transformer $T_1 \rightarrow$ 5MVA, 13.2 | 132 kV

$X_{T_1} = 10\,\% \Rightarrow X_{T_1}^{pu} = j0.1$ p.u.

$$X_{T_1}^{pu} = \frac{X_{T_1 actual}}{Z_{T_1, Base}}$$

$$X_{T_1 actual} = X_{T_1}^{pu} \cdot Z_{T_1 Base}.$$

$$= j0.1 \times \frac{V_{T_1 BASE}^2}{S_B} = j0.1 \times \frac{13.2^2 \times 10^6}{5\times10^6}$$

$$= j\,3.4848\,\Omega$$

$$X_{T_1, new}^{pu} = \frac{X_{T_1, actual}}{Z_{1B}} = \frac{j3.4848}{19.04}$$

$$X_{T_1, new}^{pu} = j0.183 \text{ p.u.}$$

Transformer ②

$T_2 \rightarrow$ 10MVA, 138 /69 kV $X_{T_2} = 8\%$

$X_{T_2 old}^{pu} = j0.08$ p.u.

$$X_{T_2, new}^{pu} = \frac{X_{T_2, actual}}{Z_{B2}}$$

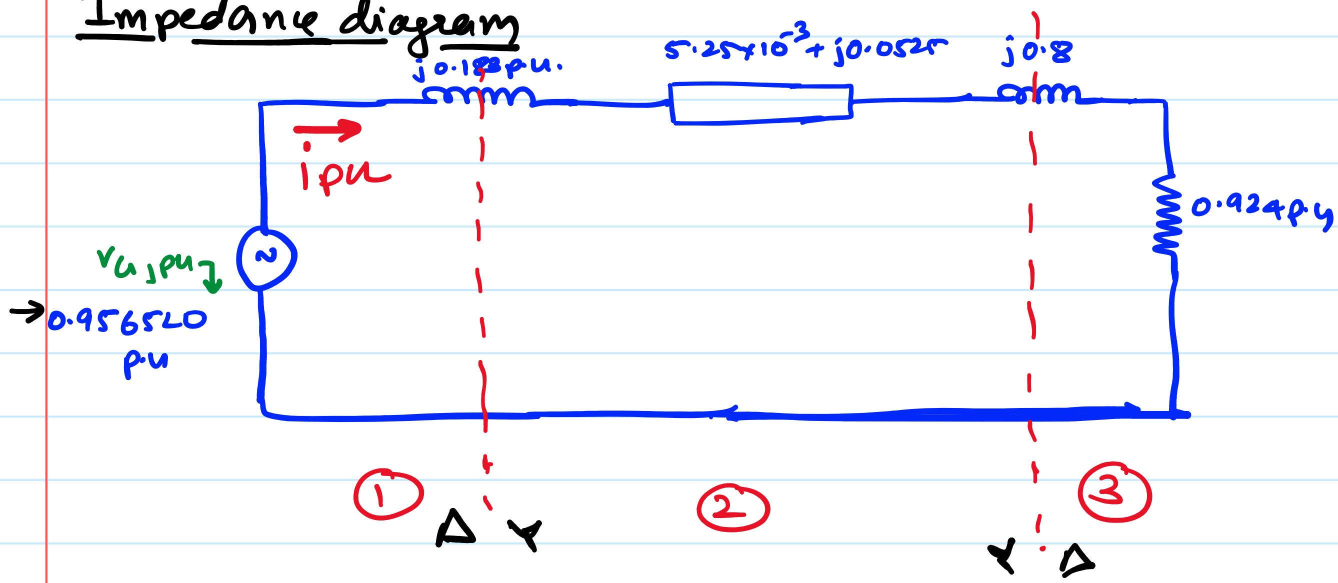
$$X_{T_2,new} = \frac{\ldots}{Z_{B2}}$$

$$= \frac{X^{p.u.}_{T2old} \times Z_{B,T_2}}{Z_{B2}}$$

$$= \frac{j0.08 \times \dfrac{138^2 \times 10^6}{10 \times 10^6}}{1904}$$

$$= j0.08 \text{ p.u.}$$

per unit Impedance diagram



$$i_{pu} = \frac{0.9565\angle 0}{j0.183 + j0.08 + 0.924 + 5.25\times10^{-3} + j0.0525}$$

$$= 0.9747\angle -18.75^\circ \text{ p.u.}$$

$$i_{pu,2} = 0.9747\angle(-18.75+30) \text{ p.u.}$$

$$= 0.9747\angle 11.25^\circ \text{ p.u.} \leftarrow$$

$$i_{pu,3} = 0.9747\angle -18.75^\circ \text{ p.u.}$$

$$S_{Load,pu} = V_{LOAD\,pu} \cdot I^*_{Load,pu}.$$

$V_{Load\,pu} = I_{pu,3} \cdot Z_{LOAD}^{pu}$

$= (0.9747\angle -18.75)(0.924)$

$= 0.9006\angle -18.75^\circ$ p.u.

$S_{LOAD\,pu} = (0.9006\angle -18.75)(0.9747\angle -18.75)^*$

$= 0.8778\angle 0^\circ$ p.u.

$= P_{Load,pu}$ [Since load is resistive]

$P_{Load,actual} = P_{Load\,pu} \times S_B^{3\phi}$

$= 0.8778 \times 10 \times 10^6$

$= 8.778$ MW

$S_{source,pu} = V_{g,pu} \cdot I_{pu}^*$

$= (0.9565)(0.9747\angle -18.75^\circ)^*$

$= \underbrace{0.883}_{P_{source,pu}} + j\underbrace{0.299}_{Q_{source,pu}}$ p.u.

$P_{source,actual} = 0.883 \times 10 \times 10^6$

$= 8.83$ MW

$\eta = \dfrac{P_{Load}}{P_{Source}} = \dfrac{8.778}{8.83} \times 100\%$

$= 99.4\%$

$\eta = \dfrac{P_{Load,pu}}{P_{Source,pu}}$

EE 3505C, EE 3506C

$$c = 2 + 4j$$

$$= 4.47 \angle 63.43^\circ$$

$$= 4.47\, e^{j63.43^\circ}$$

$$\sqrt{c} = \sqrt{4.47}\ \left(e^{j63.43}\right)^{1/2}$$

$$= 2.11\ e^{j31.715}$$