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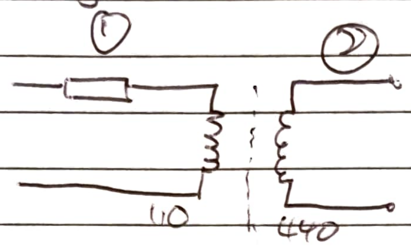
Per Unit Analysis

Date No.

1. transformer 110/440V, 2.5kVA

$X_1 = j0.06\,\Omega$



a. Choose $S_B = 2.5\text{kVA}$

b. Chose voltage bases

$V_{1B} = 110V$

$Z_{1B} = \frac{V_{1B}^2}{S_B}$

$= \frac{110^2}{2500} = 4.84\,\Omega$

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

$V_{2B} = 440V$

$Z_{2B} = \frac{V_{2B}^2}{S_B}$

$= \frac{440^2}{2500}$

$= 77.44\,\Omega$

Reflect x_1 to the high voltage side

$x_1' = \frac{x_1}{a^2} = \frac{j.06}{(1/4)^2} = 0.96\,\Omega$

$x_{1pu}' = \frac{x_1'}{Z_{2B}}$

$= \frac{j0.96}{77.44} = j0.01244 \text{ p.u.}$

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2. Generator

$X_{pu} = j0.25\,pu$ ←

Generator rating – 500 MVA, 18 kV, 1Ø

Generator rating bases

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

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

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

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

$X_{actual} = X_{pu} \cdot Z_B = 0.648 \times j0.25$
$= j0.162\,\Omega$

New base values

– $S_B^{New} = 100\,MVA$

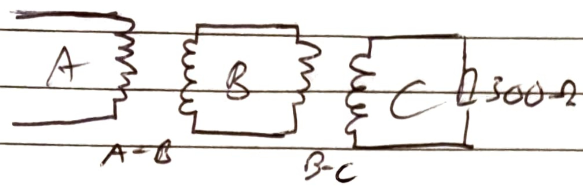
– $V_B^{new} = 20\,kV$

– $X_{pu}^{new} = \dfrac{X_{actual}}{Z_B^{new}} = \dfrac{X_{actual}}{\left[\dfrac{(V_B^{new})^2}{S_B^{new}}\right]}$

$= \dfrac{j0.162}{\left(\dfrac{20 \times 10^6}{100 \times 10^6}\right)}$

$= j0.0405\,pu$

3.



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

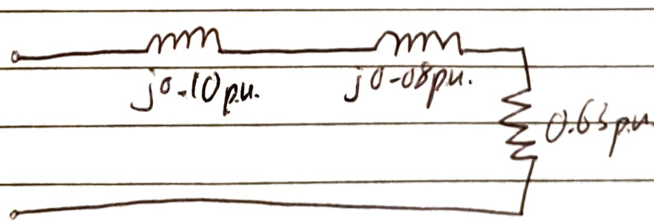
B-C → 10000 KVA, (138/69) KV, 8% → j0.08 pu

Base of circuit B → 10000 KVA, 138 KV

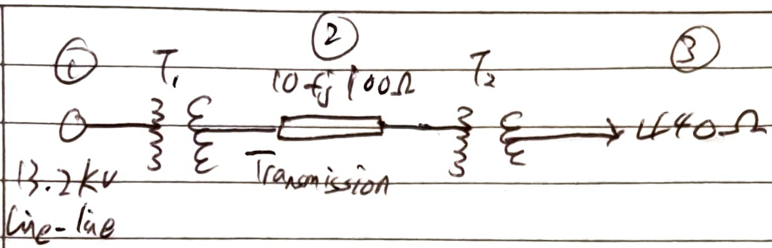
A	B	C
$V_B^A = 138\,kV \times \frac{13.8}{138}$	$V_B^B = 138\,kV$	$V_B^C = 138\,KV \times \frac{69}{138}$
$= 13.8\,KV$		$= 69\,kV$
$Z_B^A = \frac{13.8^2 \times 10^6}{10 \times 10^6}$	$Z_B^B = \frac{138^2 \times 10^6}{10 \times 10^6}$	$Z_B^C = \frac{69^2 \times 10^6}{10 \times 10^6}$
$= 19.04\,\Omega$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

Transformer p.u. values don't change since manufacturer's base values and our system base values are the same [Both S_B as well as V_B]

A	B	C
$Z_L^A = Z_L^B \times \left(\frac{13.8}{138}\right)^2$	$Z_L^B = Z_L^C \times \left(\frac{138}{69}\right)^2$	$Z_L^C = 300\,\Omega$
$= 12\,\Omega$	$= 1200\,\Omega$	
$Z_{L\,pu}^A = \frac{12}{Z_B^A}$	$Z_{L\,pu}^B = \frac{1200}{Z_B^B}$	$Z_{L\,pu}^C = \frac{300}{Z_B^C}$
$= \frac{12}{19.04} = 0.63\,pu$	$= \frac{1200}{1904} = 0.63\,pu$	$= \frac{300}{476.1}$
		$= 0.63\,pu$



4.



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

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

Base values for transmission section $\rightarrow$ 138kV

$S_B \rightarrow 10MVA$

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

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

$V_{1B} = 138kV \times \dfrac{13.2}{132}$

$= 13.8kV$

$Z_{1B} = \dfrac{13.8^2 \times 10^6}{10\times10^6}$

$= 19.04\Omega$

$V_G = 13.2kV\,(l-l)$

$V_G^{pu} = \dfrac{13.2}{13.8}$

$= 0.956\angle 0°\ pu$

$V_{2B} = 138kV$

$Z_{2B} = \dfrac{138^2 \times 10^6}{10\times10^6}$

$= 1904\Omega$

$Z_L = 10+j100$

$Z_L^{pu} = \dfrac{10+j100}{1904}$

$= 5.25\times10^{-3} + j0.0525\,pu$

$V_{3B} = 138\,kV \times \dfrac{69}{138}$

$= 69kV$

$Z_{3B} = \dfrac{69^2 \times 10^6}{10\times10^6}$

$= 476.1\Omega$

$Z_{Load} = 440\Omega$

$Z_{Load}^{pu} = \dfrac{440}{476.1}$

$= 0.924\,pu$

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

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

$X_{T_1}^{pu} = \dfrac{X_{T_1\,actual}}{Z_{T_1,Base}} \Rightarrow X_{T_1\,actual} = X_{T_1}^{pu} \cdot Z_{T_1\,Base}$

$= j0.1 \times \dfrac{V_{T_1\,Base}^2}{S_B} = j0.1 \times \dfrac{13.2^2 \times 10^6}{5\times10^6}$

$= j3.4848\Omega$

$X_{T_1,new}^{pu} = \dfrac{X_{T_1\,actual}}{Z_{1B}} = \dfrac{j3.4848}{19.04} = j0.183\,p.u.$

Transformer ②

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

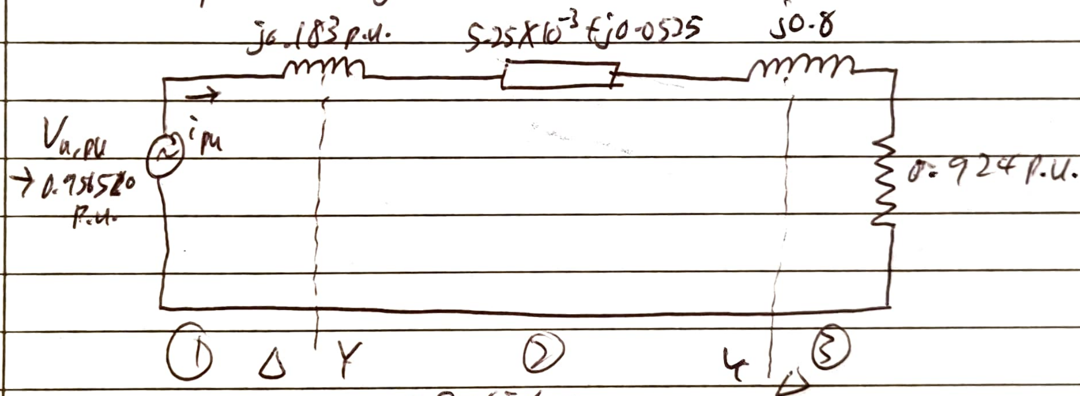
$X_{T_2,old}^{pu} = j0.08\ p.u.$

$$X_{T_2,new}^{pu} = \frac{X_{T_2,actual}}{Z_{B2}} = \frac{X_{T_2,old}^{p.u.} \times Z_{B_1 T_2}}{Z_{B2}}$$

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

$$= j0.08\ p.u.$$

Per unit impedance diagram



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

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

$i_{pu,2} = 0.9747\angle(-18.75 + 30)\ p.u. = 0.9747\angle 11.25^\circ\ p.u.$

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

$S_{Load\,pu} = I_{pu,3} \cdot Z^{*}_{Load,pu}$

$V_{Load\,pu} = I_{pu,3} \cdot Z_{Load}^{pu} = (0.9747\angle -18.75)(0.924)$

$= 0.9006\angle -18.75^\circ\ pu$

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$$P_{Load,actual} = P_{Load\,pu} \times S_B^{3\phi} = 0.8778 \times 10 \times 10^6$$
$$= 8.778\,MW$$

$$S_{source,pu} = V_{a,pu} \cdot I_{pu}^{*} = (0.9565)(0.9747\angle -18.75^\circ)^{*}$$
$$= \underbrace{0.883}_{P_{source,pu}} + j\underbrace{0.299}_{Q_{source,pu}}\ p.u.$$

$$P_{source,actual} = 0.883 \times 10 \times 10^6 = 8.83\,MW$$

$$\eta = \frac{P_{Load}}{P_{source}} = \frac{8.778}{8.83} \times 100\% = 99.4\%$$