EG2100 Power System Analysis

Assignment S2

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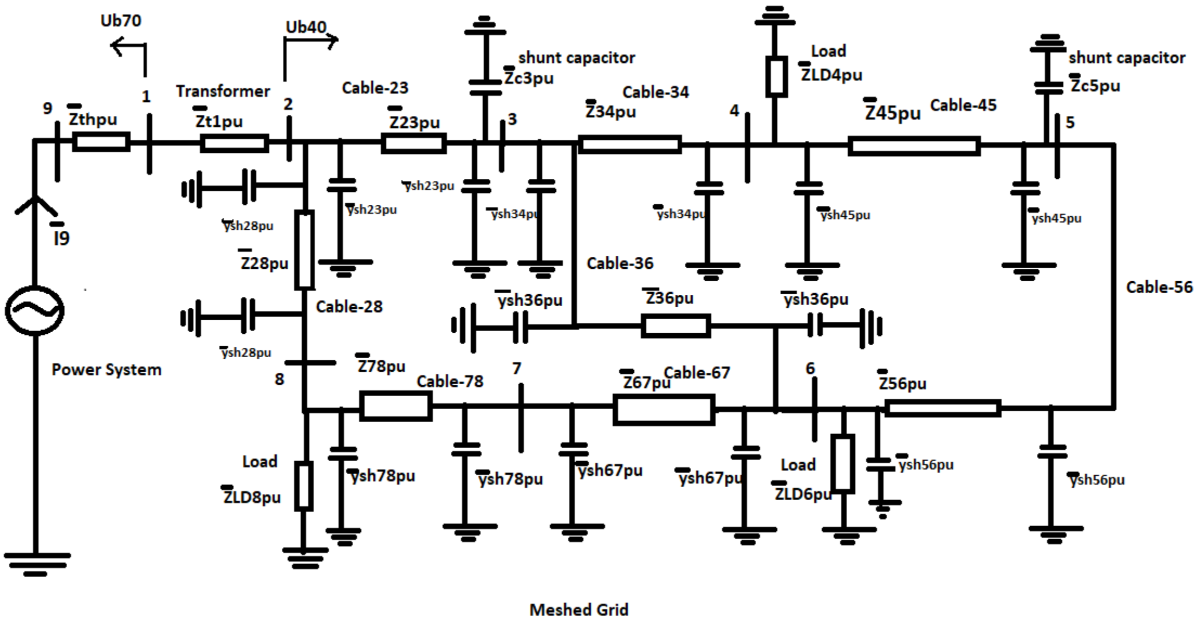
B-number-73

a.) ***Based on the given data, draw the single-line diagram of this meshed system including the Thévenin equivalent of the power system.***



CIRCUIT DIAGRAM-1

Defining the Base values in the system

U_{n1}=70kV, U_{n2}=40kV (Given)

S_{n1}=53.5 MVA (Rating of Transformer-1), Z_{t1}=8%

S_{base}=10 MVA (Given)

U_{base70}=70kV, $I_{base70}=S_{base}/\sqrt{3}*U_{base70}$=0.082(kA), $Z_{base70}=(U_{base70}\hat{}2)/S_{base}$=490(Ω)---(1)

$U_{base40}=(U_{n2}/U_{n1})*U_{base70}$=40kV, $I_{base40}=S_{base}/\sqrt{3}*U_{base40}$=0.144(kA), $Z_{base40}=(U_{base40}\hat{}2)/S_{base}$=160(Ω)---(2)

Thévenin Equivalent of the Power System

$\overline{U}_{th}=U_{n1}$=70kV

$\cos\varphi$=0.15

$\sin\varphi = \sqrt{1-(\cos\varphi)^2}$

$\overline{Z}_{th} = \frac{\overline{U}th(cos\varphi+j\sin\varphi)}{\sqrt{3}*|\overline{Isc}|} = \frac{70(0.15+j0.880)}{25*\sqrt{3}}$

$\overline{Z}_{thpu} = \overline{Z}_{th}/Z_{base70} = 0.0004 + 0.0032j$ ---(3)

<u>Finding Per-unit Impedances</u>

For **Transformer**:

$\overline{Z}_{t1pu} = j*(0.08)*(S_{base}/S_{n1}) = 0.014953j$ --- (4)

For **Cable 23**:

$\overline{Z}_{23pu} = \frac{(0.8+j*0.3)*(15)}{\text{Zbase40}} = 0.075 + 0.028125j$

$\overline{y}_{sh23} = (j*3*10^{-6})*(15)/2\ (S)$

$\overline{y}_{sh23pu} = \overline{y}_{sh23}*Z_{base40} = 0.0036j$ ---(5)

For **Cable 34**:

$\overline{Z}_{34pu} = \frac{(0.8+j*0.3)*(15)}{\text{Zbase40}} = 0.075 + 0.028125j$

$\overline{y}_{sh34} = (j*3*10^{-6})*(15)/2\ (S)$

$\overline{y}_{sh34pu} = \overline{y}_{sh34}*Z_{base40} = 0.0036j$ ---(6)

For **Cable 45**:

$\overline{Z}_{45pu} = \frac{(0.8+j*0.3)*(20)}{\text{Zbase40}} = 0.1 + 0.0375j$

$\overline{y}_{sh45} = (j*3*10^{-6})*(20)/2\ (S)$

$\overline{y}_{sh45pu} = \overline{y}_{sh45}*Z_{base40} = 0.0048j$---(7)

For **Cable 56**:

$\overline{Z}_{56pu} = \frac{(0.8+j*0.3)*(15)}{\text{Zbase40}} = 0.075 + 0.028125j$

$\overline{y}_{sh56} = (j*3*10^{-6})*(15)/2\ (S)$

$\overline{y}_{sh56pu} = \overline{y}_{sh56}*Z_{base40} = 0.0036j$ ---(8)

For **Cable 67**:

$\overline{Z}_{67pu} = \frac{(0.8+j*0.3)*(17)}{Zbase40} =$ 0.085 + 0.031875j

$\overline{y}_{sh67}$=(j*3*10^{-6})*(17)/2 (S)

$\overline{y}_{sh67pu}$=$\overline{y}_{sh67}$*Z_{base40}=0.00408j ---(9)

For **Cable 78**:

$\overline{Z}_{78pu} = \frac{(0.8+j*0.3)*(12)}{Zbase40} =$ 0.06 + 0.0225j

$\overline{y}_{sh78}$=(j*3*10^{-6})*(12)/2 (S)

$\overline{y}_{sh78pu}$=$\overline{y}_{sh78}$*Z_{base40}= 0.00288j ---(10)

For **Cable 36**:

$\overline{Z}_{36pu} = \frac{(0.8+j*0.3)*(25)}{Zbase40} =$ 0.125 + 0.046875j

$\overline{y}_{sh36}$=(j*3*10^{-6})*(25)/2 (S)

$\overline{y}_{sh36pu}$=$\overline{y}_{sh36}$*Z_{base40}=0.006j ---(11)

For **Cable 28**:

$\overline{Z}_{28pu} = \frac{(0.8+j*0.3)*(56.5)}{Zbase40} =$ 0.2825 + 0.10594j

$\overline{y}_{sh28}$=(j*3*10^{-6})*(56.5)/2 (S)

$\overline{y}_{sh28pu}$=$\overline{y}_{sh28}$*Z_{base40}=0.01356j ---(11)

For **Load at Node 4**:

$\overline{Z}_{LD4pu}$=$\frac{U4^2}{(SLD^*)}\frac{1}{Zbase40} = \frac{40^2}{\frac{2.073}{0.95}}\frac{1}{160}$ (0.95+j0.31) = 4.3536 + 1.431j ---(12)

For **Load at Node 6**:

$\overline{Z}_{LD6pu}$=$\frac{U6^2}{(SLD^*)}\frac{1}{Zbase40} = \frac{40^2}{\frac{2.573}{0.98}}\frac{1}{160}$ (0.98+j0.19) =3.7326 + 0.75794j ---(13)

For **Load at Node 8**:

$\overline{Z}_{LD6pu}=\frac{U6^2}{(SLD^*)}\frac{1}{Zbase40}=\frac{40^2}{\frac{3.073}{0.95}}\frac{1}{160}$ (0.95+j0.31)= 2.9369 + 0.9653j ---(14)

For **Shunt Capacitor at Node 3:**

$\overline{Z}_{C3pu}=\frac{U3^2}{(-2j)^*}\frac{1}{Zbase40}=\frac{1600}{2j*160}=-5j$ ---(15)

For **Shunt Capacitor at Node 5:**

$\overline{Z}_{C5pu}=\frac{U5^2}{(-2j)^*}\frac{1}{Zbase40}=\frac{1600}{2j*160}=-5j$ ---(16)

$\overline{U}_{9pu}$ = 70/70=$1\angle 0^0$ --- (*)

b.) ***Build the Y-bus matrix of the system and give the numerical values of the elements of the Y-bus matrix in pu.***

$\overline{Y}_{bus}$ is a 9x9 matrix given by; $\overline{Y}_{bus}$ =

[

$[\overline{Y}11 \quad \overline{Y}12 \quad \overline{Y}13 \quad \overline{Y}14 \quad \overline{Y}15 \quad \overline{Y}16 \quad \overline{Y}17 \quad \overline{Y}18 \quad \overline{Y}19]$,

$[\overline{Y}21 \quad \overline{Y}22 \quad \overline{Y}23 \quad \overline{Y}24 \quad \overline{Y}25 \quad \overline{Y}26 \quad \overline{Y}27 \quad \overline{Y}28 \quad \overline{Y}29]$,

$[\overline{Y}31 \quad \overline{Y}32 \quad \overline{Y}33 \quad \overline{Y}34 \quad \overline{Y}35 \quad \overline{Y}36 \quad \overline{Y}37 \quad \overline{Y}38 \quad \overline{Y}39]$,

$[\overline{Y}41 \quad \overline{Y}42 \quad \overline{Y}43 \quad \overline{Y}44 \quad \overline{Y}45 \quad \overline{Y}46 \quad \overline{Y}47 \quad \overline{Y}48 \quad \overline{Y}49]$,

$[\overline{Y}51 \quad \overline{Y}52 \quad \overline{Y}53 \quad \overline{Y}54 \quad \overline{Y}55 \quad \overline{Y}56 \quad \overline{Y}57 \quad \overline{Y}58 \quad \overline{Y}59]$,

$[\overline{Y}61 \quad \overline{Y}62 \quad \overline{Y}63 \quad \overline{Y}64 \quad \overline{Y}65 \quad \overline{Y}66 \quad \overline{Y}67 \quad \overline{Y}68 \quad \overline{Y}69]$,

$[\overline{Y}71 \quad \overline{Y}72 \quad \overline{Y}73 \quad \overline{Y}74 \quad \overline{Y}75 \quad \overline{Y}76 \quad \overline{Y}77 \quad \overline{Y}78 \quad \overline{Y}79]$,

$[\overline{Y}81 \quad \overline{Y}82 \quad \overline{Y}83 \quad \overline{Y}84 \quad \overline{Y}85 \quad \overline{Y}86 \quad \overline{Y}87 \quad \overline{Y}88 \quad \overline{Y}89]$,

$[\overline{Y}91 \quad \overline{Y}92 \quad \overline{Y}93 \quad \overline{Y}94 \quad \overline{Y}95 \quad \overline{Y}96 \quad \overline{Y}97 \quad \overline{Y}98 \quad \overline{Y}99]$

]

$\overline{Y}_{11}=\frac{1}{\overline{Z}thpu}+\frac{1}{\overline{Z}t1pu}$; $\overline{Y}_{12}=-\frac{1}{\overline{Z}t1pu}$; $\overline{Y}_{13}=\overline{Y}_{14}=\overline{Y}_{15}=\overline{Y}_{16}=\overline{Y}_{17}=\overline{Y}_{18}=0$; $\overline{Y}_{19}=-\frac{1}{\overline{Z}thpu}$

$\overline{Y}_{21}=\overline{Y}_{12}$; $\overline{Y}_{22}=\frac{1}{\overline{\overline{Z}}23pu}+\frac{1}{\overline{\overline{Z}}28pu}+\frac{1}{\overline{\overline{Z}}t1pu}+\overline{y}_{sh23pu}+\overline{y}_{sh28pu}$; $\overline{Y}_{23}=-\frac{1}{\overline{\overline{Z}}23pu}$; $\overline{Y}_{24}=\overline{Y}_{25}=\overline{Y}_{26}=\overline{Y}_{27}=0$; $\overline{Y}_{28}=-\frac{1}{\overline{\overline{Z}}28pu}$; $\overline{Y}_{29}=0$

$\overline{Y}_{31}=\overline{Y}_{13}$; $\overline{Y}_{32}=\overline{Y}_{23}$; $\overline{Y}_{33}=\frac{1}{\overline{\overline{Z}}23pu}+\frac{1}{\overline{\overline{Z}}34pu}+\frac{1}{\overline{\overline{Z}}36pu}+\frac{1}{\overline{\overline{Z}}c3pu}+\overline{y}_{sh23pu}+\overline{y}_{sh34pu}+\overline{y}_{sh36pu}$; $\overline{Y}_{34}=-\frac{1}{\overline{\overline{Z}}34pu}$;

$\overline{Y}_{35}=0$; $\overline{Y}_{36}=-\frac{1}{\overline{\overline{Z}}36pu}$; $\overline{Y}_{37}=\overline{Y}_{38}=\overline{Y}_{39}=0$

$\overline{Y}_{41}=\overline{Y}_{14}$; $\overline{Y}_{42}=\overline{Y}_{24}$; $\overline{Y}_{43}=\overline{Y}_{34}$; $\overline{Y}_{44}=\frac{1}{\overline{\overline{Z}}34pu}+\frac{1}{\overline{\overline{Z}}45pu}+\frac{1}{\overline{\overline{Z}}LD4pu}+\overline{y}_{sh34pu}+\overline{y}_{sh45pu}$; $\overline{Y}_{45}=-\frac{1}{\overline{\overline{Z}}45pu}$; $\overline{Y}_{46}=\overline{Y}_{47}=\overline{Y}_{48}=\overline{Y}_{49}=0$

$\overline{Y}_{51}=\overline{Y}_{15}$; $\overline{Y}_{52}=\overline{Y}_{25}$; $\overline{Y}_{53}=\overline{Y}_{35}$; $\overline{Y}_{54}=\overline{Y}_{45}$; $\overline{Y}_{55}=\frac{1}{\overline{\overline{Z}}45pu}+\frac{1}{\overline{\overline{Z}}56pu}+\frac{1}{\overline{\overline{Z}}c5pu}+\overline{y}_{sh45pu}+\overline{y}_{sh56pu}$; $\overline{Y}_{56}=-\frac{1}{\overline{\overline{Z}}56pu}$; $\overline{Y}_{57}=\overline{Y}_{58}=\overline{Y}_{59}=0$

$\overline{Y}_{61}=\overline{Y}_{16}$; $\overline{Y}_{62}=\overline{Y}_{26}$; $\overline{Y}_{63}=\overline{Y}_{36}$; $\overline{Y}_{64}=\overline{Y}_{46}$; $\overline{Y}_{65}=\overline{Y}_{56}$; $\overline{Y}_{66}=\frac{1}{\overline{\overline{Z}}56pu}+\frac{1}{\overline{\overline{Z}}67pu}+\frac{1}{\overline{\overline{Z}}36pu}+\frac{1}{\overline{\overline{Z}}LD6pu}+\overline{y}_{sh56pu}+\overline{y}_{sh67pu}+\overline{y}_{sh36pu}$; $\overline{Y}_{67}=-\frac{1}{\overline{\overline{Z}}67pu}$; $\overline{Y}_{68}=\overline{Y}_{69}=0$

$\overline{Y}_{71}=\overline{Y}_{17}$; $\overline{Y}_{72}=\overline{Y}_{27}$; $\overline{Y}_{73}=\overline{Y}_{37}$; $\overline{Y}_{74}=\overline{Y}_{47}$; $\overline{Y}_{75}=\overline{Y}_{57}$; $\overline{Y}_{76}=\overline{Y}_{67}$; $\overline{Y}_{77}=\frac{1}{\overline{\overline{Z}}78pu}+\frac{1}{\overline{\overline{Z}}67pu}+\overline{y}_{sh78pu}+\overline{y}_{sh67pu}$ $\overline{Y}_{78}=-\frac{1}{\overline{\overline{Z}}78pu}$; $\overline{Y}_{79}=0$

$\overline{Y}_{81}=\overline{Y}_{18}$; $\overline{Y}_{82}=\overline{Y}_{28}$; $\overline{Y}_{83}=\overline{Y}_{38}$; $\overline{Y}_{84}=\overline{Y}_{48}$; $\overline{Y}_{85}=\overline{Y}_{58}$; $\overline{Y}_{86}=\overline{Y}_{68}$; $\overline{Y}_{87}=\overline{Y}_{78}$; $\overline{Y}_{88}=\frac{1}{\overline{\overline{Z}}78pu}+\frac{1}{\overline{\overline{Z}}28pu}+\frac{1}{\overline{\overline{Z}}LD8pu}+\overline{y}_{sh28pu}+\overline{y}_{sh78pu}$; $\overline{Y}_{89}=0$

$\overline{Y}_{91}=\overline{Y}_{19}$; $\overline{Y}_{92}=\overline{Y}_{29}$; $\overline{Y}_{93}=\overline{Y}_{39}$; $\overline{Y}_{94}=\overline{Y}_{49}$; $\overline{Y}_{95}=\overline{Y}_{59}$; $\overline{Y}_{96}=\overline{Y}_{69}$; $\overline{Y}_{97}=\overline{Y}_{79}$; $\overline{Y}_{98}=\overline{Y}_{89}$; $\overline{Y}_{99}=\frac{1}{\overline{\overline{Z}}thpu}$

c.) ***Find the injected power into the meshed grid from the secondary side of the transformer T1 in MVA, and compare the result with the rating of the transformer.***

$$\overline{Z}_{bus}=\overline{Y}\text{bus}^{-1} \quad --(17)$$

We know that

$[\overline{I}]=[\overline{Y}_{bus}][\overline{U}]$

$[\overline{U}]=[\overline{Z}_{bus}][\overline{I}]$

Where $[\overline{U}]=[\overline{U}_{1pu}, \overline{U}_{2pu}, \overline{U}_{3pu}, \overline{U}_{4pu}, \overline{U}_{5pu}, \overline{U}_{6pu}, \overline{U}_{7pu}, \overline{U}_{8pu}, \overline{U}_{9pu}]^{T}$ here only $\overline{U}_{9pu}$ is known

And $[\overline{I}]=[\cancel{\overline{I}_{1pu}=0, \overline{I}_{2pu}=0, \overline{I}_{3pu}=0,} \overline{I}_{4pu}=0, \overline{I}_{5pu}=0, \overline{I}_{6pu}=0, \overline{I}_{7pu}=0, \overline{I}_{8pu}=0, \overline{I}_{9pu}]$ as current from outside is non zero at Node 9 only.

$\overline{I}_{9pu}=\frac{\overline{U}9\text{pu}}{\overline{Z}\text{bus}(9,9)}$

$\overline{U}_{2pu}= \overline{Z}_{bus}(2,9)* \overline{I}_{9pu}$

Power injected in the mesh grid from secondary side of transformer:

$|\overline{S}_2|=|\ \overline{U}_{2pu}(\overline{I}9\text{pu})^{*}\text{Sbase}\ |$

$$\overline{S}_2=7.4060 - 2.3156i \text{ MVA}$$

$$\boxed{|\ \overline{S}_2| = 7.7596 \text{ MVA} \quad \text{--(18)}}$$

Comparison between equation (18) and rating of the transformer

$$\boxed{\frac{|\overline{S}2|}{Sn1}=\frac{7.7596}{53.5}=\mathbf{0.14504}--(19)}$$

d.) Find the total losses in the mesh grid in MW.

Total Losses in the Mesh grid= $P_{infeed}-\Sigma(P_{consumption\_at\_loads})$

$$\mathbf{P_{infeed}} = \text{Re}\{\overline{S}_2\}=7.4060 \text{ MW}$$

$$P_{cons\_4} = \text{Re}\{\overline{S}_4\}$$

$$\text{Where } \overline{S}_4=\overline{U}_{4pu}(\overline{I}_{LD4pu})^{*}S_{base}$$

$$\overline{U}_{4pu}= \overline{Z}_{bus}(4,9)* \overline{I}_{9pu} \text{ ---(II)}$$

$$\overline{I}_{LD4pu}=\overline{U}_{4pu}/(\overline{Z}_{LD4pu})$$

$$\mathbf{P_{cons\_4}}= 1.8902 \text{ MW}$$

$$P_{cons\_6} = \text{Re}\{\overline{S}_6\}$$

$$\text{Where } \overline{S}_6=\overline{U}_{6pu}(\overline{I}_{LD6pu})^{*}S_{base}$$

$$\overline{U}_{6pu}= \overline{Z}_{bus}(6,9)* \overline{I}_{9pu} \text{ ---(III)}$$

$$\overline{I}_{LD6pu}=\overline{U}_{6pu}/(\overline{Z}_{LD6pu})$$

$$\mathbf{P_{cons\_6}}= 2.2966 \text{ MW}$$

$$P_{cons\_8} = \text{Re}\{\overline{S}_8\}$$

$$\text{Where } \overline{S}_8 = \overline{U}_{8pu}(\overline{I}_{LD8pu})^{*} S_{base}$$

$$\overline{U}_{8pu} = \overline{Z}_{bus}(8,9) * \overline{I}_{9pu} \text{ ---(IV)}$$

$$\overline{I}_{LD8pu} = \overline{U}_{8pu} / (\overline{Z}_{LD8pu})$$

$$\mathbf{P_{cons\_8}} = 2.6828 \text{ MW}$$

$$P_{losses} = (7.4060 - (1.8902 + 2.2966 + 2.6828))$$

$$\mathbf{P_{losses} = 0.53642\ MW}$$

e.) Based on the diagram, as seen from the given bus (indicated in your excel file) find the Thévenin equivalent of the system and give the value of Thévenin voltage and impedance in pu.

The given bus in my system is **Node 7**

Thévenin Voltage at Node 7 will be given by:

$$\overline{U}_{7thpu} = \overline{U}_{7pu} = \overline{Z}_{bus}(7,9) * \overline{I}_{9pu}$$

$$\boldsymbol{\overline{U}_{7thpu} = 0.93874 \underline{/-2.7736^0}} \text{ --(20)}$$

We will have to short circuit the power source at Node 9 to get thévenin impedance.

So, we will get a new admittance matrix of 8x8 size.

$$\overline{Y}_{del} = \overline{Y}_{bus}(1{:}8, 1{:}8)$$

$$\overline{Z}_{del} = \overline{Y}\mathrm{del}^{-1} \text{---(21)}$$

$$\overline{Z}_{7thpu} = \overline{Z}_{del}(7,7)$$

$$\boldsymbol{\overline{Z}_{7thpu} = 0.138203 + 0.064262i}$$

f.) Assumed that a solid three-phase short circuit is applied to the given bus in task e. Find the short circuit current in kA and the three-phase short circuit power in MVA.

Short Circuit Current in pu; $\overline{I}_{7scpu} = \frac{\overline{U}7\mathrm{thpu}}{\overline{Z}7\mathrm{thpu}}$

$$\overline{I}_{7sc} = \overline{I}_{7scpu} * I_{base40}$$

$$\boldsymbol{\overline{I}_{7sc} = 0.88900 \underline{/-27.711^0}\ \mathrm{kA}}$$

Short circuit power in MVA;

$$\overline{S}_{7sc} = \overline{U}_{7thpu}(\overline{I}_{7sc})^{*} S_{base}$$

$$\mathbf{|\overline{S}_{7sc}| = 57.819\ MVA}$$

g.) Find the injected power into the meshed grid in MVA during the three-phase short circuit at the given bus and compare the result with the rating of the transformer.

We will use the principle of Superposition we know that

$$\overline{U'} = \overline{U}\_del + \overline{U}\text{pre}$$

In my system, the short circuit is applied at Node 7. We need to find the new voltages at every node.

$\overline{U'}_7$ = 0 as this node is short circuited and $\overline{U'}_9 = \overline{U}_{9pu}$ (as it is connected to the voltage source)

$$\textit{Using the equation}:$$

$$\overline{\boldsymbol{U'}}_i = \overline{\boldsymbol{U}}_i - \frac{\overline{\mathbf{Z}}\mathbf{del(i,r)}}{\overline{\mathbf{Z}}\mathbf{del(r,r)}+\overline{\mathbf{Z}}\mathbf{r}} * \overline{\boldsymbol{U}}_r \quad \text{--- (22)}$$

where $\overline{Z}$del is known from equation (21)

in our case $\overline{U}_r$ is $\overline{U}_7$ from equation(20)

$\overline{Z}_r$=0 as impedance of a short circuit is zero.

$$\overline{U'}_1 = \overline{U}_1 - \frac{\overline{Z}\text{del}(1,7)}{\overline{Z}\text{del}(7,7)} * \overline{U}_7$$

$$\overline{U'}_2 = \overline{U}_2 - \frac{\overline{Z}\text{del}(2,7)}{\overline{Z}\text{del}(7,7)} * \overline{U}_7$$

$$\overline{I'}_{9pu} = (\overline{U'}_9 - \overline{U'}_1) / \overline{Z}_{thpu}$$

$$\overline{S'}_2 = \overline{U'}_2 (\overline{I'}_{9pu})^{*}\ Sbase$$

$$\mathbf{|\overline{S'}_2| = 60.381\ MVA}$$

$$\frac{\boldsymbol{|\overline{S}2|}}{\boldsymbol{Sn1}} = \frac{\mathbf{60.381}}{\mathbf{53.5}} = \mathbf{1.1286}$$

h.) Find the total losses in the mesh grid in MW during the three-phase short circuit at the given bus.

Total Losses in the Mesh grid= $P'_{infeed} - \Sigma(P'_{consumption\_at\_loads})$

$$\mathbf{P'_{infeed}} = \mathrm{Re}\{\overline{S'}_2\} = 57.037 \text{ MW}$$

$$P'_{cons\_4} = \mathrm{Re}\{\overline{S'}_4\}$$

Where $\overline{S'}_4 = \overline{U'}_{4pu}(\overline{I'}_{LD4pu})^* S_{base}$

$$\overline{U'}_{4pu} = \overline{U}_{4pu} - \frac{\overline{Z}\mathrm{del}(4,7)}{\overline{Z}\mathrm{del}(7,7)} * \overline{U}_{7pu} \text{ [from equation 22 and equation (II)]}$$

$$\overline{I'}_{LD4pu} = \overline{U'}_{4pu}/(\overline{Z}_{LD4pu})$$

$$\mathbf{P'_{cons\_4}} = 0.6287 \text{ MW}$$

$$P'_{cons\_6} = \mathrm{Re}\{\overline{S'}_6\}$$

Where $\overline{S'}_6 = \overline{U'}_{6pu}(\overline{I'}_{LD6pu})^* S_{base}$

$$\overline{U'}_{6pu} = \overline{U}_{6pu} - \frac{\overline{Z}\mathrm{del}(6,7)}{\overline{Z}\mathrm{del}(7,7)} * \overline{U}_{7pu} \text{ [from equation 22 and equation (III)]}$$

$$\overline{I'}_{LD6pu} = \overline{U'}_{6pu}/(\overline{Z}_{LD6pu})$$

$$\mathbf{P'_{cons\_6}} = 0.27427 \text{ MW}$$

$$P'_{cons\_8} = \mathrm{Re}\{\overline{S'}_8\}$$

Where $\overline{S'}_8 = \overline{U'}_{8pu}(\overline{I'}_{LD8pu})^* S_{base}$

$$\overline{U'}_{8pu} = \overline{U}_{8pu} - \frac{\overline{Z}\mathrm{del}(8,7)}{\overline{Z}\mathrm{del}(7,7)} * \overline{U}_{7pu} \text{ [from equation 22 and equation (III)]}$$

$$\overline{I'}_{LD8pu} = \overline{U'}_{8pu}/(\overline{Z}_{LD8pu})$$

$$\mathbf{P'_{cons\_8}} = 0.082904 \text{ MW}$$

$$P_{losses} = (57.037-(0.6287+0.27427+0.08290))$$

$$\mathbf{P_{losses} = 56.051 \text{ MW}}$$

i.) Let the system in assignment S1 be connected to the given bus in task e, i.e. node **a** in assignment S1 is the given bus in task e. Using the Thévenin equivalent in task e, find the voltage at node **e**, in kV, when the load at this node is reduced to 50%.

When the system in S1 is connected to Node 7 then a new element gets multiplied to the previous total two port of the system in Assignment 1.

$$\text{TP\_tot\_new} = \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} = \begin{bmatrix} 1 & \overline{Z}7thpu \\ 0 & 1 \end{bmatrix} [TP_{tot}]$$

$$\overline{U}_{apu} = \overline{U}_{7thpu}$$

$\overline{\boldsymbol{Z}'}_{\mathbf{LDepu}}\mathbf{=2*}\overline{\boldsymbol{Z}}_{\mathbf{LDepu}}$ [50% load reduction means the rated current through the load is halved which in turn means that the load impedance is doubled].

$$\overline{\boldsymbol{Z}}_{\mathbf{grid}} = \frac{\overline{\boldsymbol{A}\prime} * \overline{\boldsymbol{Z}\prime}\boldsymbol{LDepu} + \overline{\boldsymbol{B}\prime}}{\overline{\boldsymbol{C}\prime} * \overline{\boldsymbol{Z}\prime}\boldsymbol{LDepu} + \overline{\boldsymbol{D}\prime}}$$

$$\overline{I}_{apu} = \overline{U}_{7thpu} / \overline{Z}_{grid}$$

$$\begin{bmatrix} \overline{\boldsymbol{U}}\boldsymbol{epu} \\ \bar{\boldsymbol{I}}\boldsymbol{epu} \end{bmatrix} = [\boldsymbol{TP\_tot\_new}]^{-1} \begin{bmatrix} \overline{\boldsymbol{U}}\boldsymbol{7thpu} \\ \bar{\boldsymbol{I}}\boldsymbol{apu} \end{bmatrix}$$

$$\overline{U}\text{e} = \overline{U}_{epu} * U_{base6}$$

$$\overline{\boldsymbol{U}}_{\mathbf{e}} = \mathbf{5.5828\underline{/-3.1116^{0}}\ kV}$$

MATLAB CODE

[S2]

```
format short g

%defining the conversion of angles

deg=180/pi;

rad=1/deg;


%Base value of Power(MVA)

Sbase=10;


%base voltage(kV)

Ub70=70;

Ub40=40;

%Base current

Ib70=Sbase/(sqrt(3)*Ub70);

Ib40=Sbase/(sqrt(3)*Ub40);

%Base Impedances

Zb70=(Ub70^2)/(Sbase);

Zb40=(Ub40^2)/(Sbase);


Sn1= 53.5; %using the rating of the transformer as it is


%Voltage at Node 9

U9pu=70/70;
```

```
%for power system thevenin

cosphi=0.15;

sinphi=sqrt(1-(cosphi)^2);

Zth=(70/(sqrt(3)*25))*(cosphi+j*sinphi);

Zthpu=Zth/Zb70;


%for transformer-1

Zt1pu=(0.08)*j*(Sbase/Sn1);


%for line-23

Z23pu=((0.8+j*0.3)*(15))/Zb40;

ysh23=(j*3*1E-6)*(15)/2;

ysh23pu=ysh23*Zb40;


%for line-34

Z34pu=((0.8+j*0.3)*(15))/Zb40;

ysh34=(j*3*1E-6)*(15)/2;

ysh34pu=ysh34*Zb40;


%for line-45

Z45pu=((0.8+j*0.3)*(20))/Zb40;

ysh45=(j*3*1E-6)*(20)/2;

ysh45pu=ysh45*Zb40;
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%for line-56

Z56pu=((0.8+j*0.3)*(15))/Zb40;

ysh56=(j*3*1E-6)*(15)/2;

ysh56pu=ysh56*Zb40;


%for line-67

Z67pu=((0.8+j*0.3)*(17))/Zb40;

ysh67=(j*3*1E-6)*(17)/2;

ysh67pu=ysh67*Zb40;


%for line-78

Z78pu=((0.8+j*0.3)*(12))/Zb40;

ysh78=(j*3*1E-6)*(12)/2;

ysh78pu=ysh78*Zb40;


%for line-36

Z36pu=((0.8+j*0.3)*(25))/Zb40;

ysh36=(j*3*1E-6)*(25)/2;

ysh36pu=ysh36*Zb40;


%for line-28

Z28pu=((0.8+j*0.3)*(56.5))/Zb40;

ysh28=(j*3*1E-6)*(56.5)/2;
```

```
ysh28pu=ysh28*Zb40;


%for the load at Node 4

cosphi_4=0.95; sinphi_4=sqrt(1-(cosphi_4^2));

PLD_4=2.073;

magSLD_4=PLD_4/cosphi_4; %magnitude of Complex Power

SLD_4=magSLD_4*(cosphi_4+j*sinphi_4);

U4n=Ub40;

Zld_4=(U4n^2)/conj(SLD_4);

ZLD4pu=Zld_4/Zb40;


%for the load at Node 6

cosphi_6=0.98; sinphi_6=sqrt(1-(cosphi_6^2));

PLD_6=2.573;

magSLD_6=PLD_6/cosphi_6; %magnitude of Complex Power

SLD_6=magSLD_6*(cosphi_6+j*sinphi_6);

U6n=Ub40;

Zld_6=(U6n^2)/conj(SLD_6);

ZLD6pu=Zld_6/Zb40;


%for the load at Node 8

cosphi_8=0.95; sinphi_8=sqrt(1-(cosphi_8^2));

PLD_8=3.073;

magSLD_8=PLD_8/cosphi_8; %magnitude of Complex Power
```

```
SLD_8=magSLD_8*(cosphi_8+j*sinphi_8);

U8n=Ub40;

Zld_8=(U8n^2)/conj(SLD_8);

ZLD8pu=Zld_8/Zb40;


%capacitor at Node 3

Zc3=conj((40^2)/(-2*j));

Zc3pu=Zc3/Zb40;

%capacitor at Node 5

Zc5=conj((40^2)/(-2*j));

Zc5pu=Zc5/Zb40;


%making the Y-Bus Matrix for the system


% Elements of Ybus Matrix

Y11=(1/Zthpu)+(1/Zt1pu);

Y12=-(1/Zt1pu);

Y13=Y14=Y15=Y16=Y17=Y18=0; Y19=-(1/Zthpu);


Y21=Y12;

Y22=(1/Z23pu)+ysh23pu+ysh28pu+(1/Z28pu)+(1/Zt1pu);

Y23=-(1/Z23pu);

Y24=Y25=Y26=Y27=0;

Y28=-(1/Z28pu);Y29=0;
```

```
Y31=Y13;

Y32=Y23;

Y33=(1/Z34pu)+ysh34pu+ysh36pu+(1/Z36pu)+ysh23pu+(1/Z23pu)+(1/Zc3pu);

Y34=-(1/Z34pu);

Y35=0;

Y36=-(1/Z36pu);

Y37=Y38=Y39=0;


Y41=Y14; Y42=Y24; Y43=Y34;

Y44=(1/Z34pu)+ysh34pu+ysh45pu+(1/Z45pu)+(1/ZLD4pu);

Y45=-(1/Z45pu);

Y46=Y47=Y48=Y49=0;


Y51=Y15; Y52=Y25; Y53=Y35; Y54=Y45;

Y55=(1/Z45pu)+ysh45pu+ysh56pu+(1/Z56pu)+(1/Zc5pu);

Y56=-(1/Z56pu);

Y57=Y58=Y59=0;


Y61=Y16; Y62=Y26; Y63=Y36; Y64=Y46; Y65=Y56;

Y66=ysh67pu+(1/Z67pu)+ysh56pu+(1/Z56pu)+ysh36pu+(1/Z36pu)+(1/ZLD6pu);

Y67=-(1/Z67pu);

Y68=Y69=0;
```

```
Y71=Y17; Y72=Y27; Y73=Y37; Y74=Y47; Y75=Y57; Y76=Y67;

Y77=ysh78pu+(1/Z78pu)+ysh67pu+(1/Z67pu);

Y78=-(1/Z78pu);

Y79=0;


Y81=Y18; Y82=Y28; Y83=Y38; Y84=Y48; Y85=Y58; Y86=Y68; Y87=Y78;

Y88=ysh78pu+(1/Z78pu)+ysh28pu+(1/Z28pu)+(1/ZLD8pu);

Y89=0;


Y91=Y19; Y92=Y29; Y93=Y39; Y94=Y49; Y95=Y59;

Y96=Y69; Y97=Y79; Y98=Y89;

Y99=(1/Zthpu);


%Ybus matrix


Ybus=[Y11 Y12 Y13 Y14 Y15 Y16 Y17 Y18 Y19;

    Y21 Y22 Y23 Y24 Y25 Y26 Y27 Y28 Y29;

    Y31 Y32 Y33 Y34 Y35 Y36 Y37 Y38 Y39;

    Y41 Y42 Y43 Y44 Y45 Y46 Y47 Y48 Y49;

    Y51 Y52 Y53 Y54 Y55 Y56 Y57 Y58 Y59;

    Y61 Y62 Y63 Y64 Y65 Y66 Y67 Y68 Y69;

    Y71 Y72 Y73 Y74 Y75 Y76 Y77 Y78 Y79;

    Y81 Y82 Y83 Y84 Y85 Y86 Y87 Y88 Y89;

    Y91 Y92 Y93 Y94 Y95 Y96 Y97 Y98 Y99];
```

```
disp(Ybus);     %PART B


%Injected power at the secondary end of the transformer


Zbus=inv(Ybus); %impedance matrix for the given system


I9pu=1/Zbus(9,9);

U2pu=Zbus(2,9)*I9pu;  %u2


S2=U2pu*conj(I9pu)*Sbase;

disp(222);

disp(abs(S2));

disp(abs(S2)/abs(Sn1));   %PART C


%Total Power given to the system

P_tot=real(S2);


%power consumption at Node 4

U4pu=Zbus(4,9)*I9pu;    %u4

ILD4pu=U4pu/ZLD4pu;

SLD4=U4pu*conj(ILD4pu)*Sbase;

P_cons_4=real(SLD4);
```

```
%power consumption at Node 6
U6pu=Zbus(6,9)*I9pu; %u6
ILD6pu=U6pu/ZLD6pu;
SLD6=U6pu*conj(ILD6pu)*Sbase;
P_cons_6=real(SLD6);

%power consumption at Node 8
U8pu=Zbus(8,9)*I9pu;  %u8
ILD8pu=U8pu/ZLD8pu;
SLD8=U8pu*conj(ILD8pu)*Sbase;
P_cons_8=real(SLD8);

P_losses=(P_tot-(P_cons_4+P_cons_6+P_cons_8));

disp(P_losses);   %PART D

%Thevenin equivalent from Node 7
U7pu=Zbus(7,9)*I9pu; %u7

U7Th=U7pu; %thevenin voltage in pu %PART E

absU7Th=abs(U7Th)
angleU7th=angle(U7Th)*deg
```

```
%for thevenin impedance..remove the last row and column of the Ybus

Y_del=Ybus(1:8,1:8);

Z_del=inv(Y_del);


Z7Th=Z_del(7,7)%thevenin impedance in pu  %PART E


%Short Circuit Current and Three Phase Short circuit power

I7scpu=(U7Th/Z7Th);

I7sc=I7scpu*Ib40;

disp(abs(I7sc)); %PART F

disp(angle(I7sc)*deg);  %PART F


S7scpu=U7Th*conj(I7scpu);

S7sc=S7scpu*Sbase;

disp(abs(S7sc)); %PART F


U1pu=Zbus(1,9)*I9pu;

U3pu=Zbus(3,9)*I9pu;

U5pu=Zbus(5,9)*I9pu;


%the voltage at Node 9 won't change so we shouldn't think about it


%Using superposition theorem...U'=Upre+del(U)

%del_I will be zero except del_I7
```

```
U1pu_new=U1pu-((Z_del(1,7)*U7pu)/Z_del(7,7));
U2pu_new=U2pu-((Z_del(2,7)*U7pu)/Z_del(7,7));
I9pu_new=(U9pu-U1pu_new)/Zthpu;

S2_new=U2pu_new*conj(I9pu_new)*Sbase;
abs(S2_new)
disp(abs(S2_new)/abs(Sn1));  %PART G
P_tot_new=real(S2_new);

U4pu_new=U4pu-((Z_del(4,7)*U7pu)/Z_del(7,7));
ILD4pu_new=U4pu_new/ZLD4pu;
SLD4_new=U4pu_new*conj(ILD4pu_new)*Sbase;
P_cons_4_new=real(SLD4_new);

U6pu_new=U6pu-((Z_del(6,7)*U7pu)/Z_del(7,7));
ILD6pu_new=U6pu_new/ZLD6pu;
SLD6_new=U6pu_new*conj(ILD6pu_new)*Sbase;
P_cons_6_new=real(SLD6_new);

U8pu_new=U8pu-((Z_del(8,7)*U7pu)/Z_del(7,7));
ILD8pu_new=U8pu_new/ZLD8pu;
SLD8_new=U8pu_new*conj(ILD8pu_new)*Sbase;
P_cons_8_new=real(SLD8_new);
```

```
P_losses_new=P_tot_new-(P_cons_4_new+P_cons_6_new+P_cons_8_new);

disp(P_losses_new);   %PART H


S1_B73(U7Th,Z7Th); %PART I
```

[S1]

```
function retval=S1_B73(Uapu,Z_th)

format short g

%defining the conversion of angles

deg=180/pi;

rad=1/deg;




%Defining the base power(Sbase) in MVA

Sbase=10;


%Defining Base voltages in kV

Ub40=40; Ub12=12; Ub6=6;

%Defining Base Currents in kA and Impedances

Ib40=Sbase/(sqrt(3)*Ub40); Zb40=(Ub40^2)/(Sbase);

Ib12=Sbase/(sqrt(3)*Ub12); Zb12=(Ub12^2)/(Sbase);

Ib6=Sbase/(sqrt(3)*Ub6); Zb6=(Ub6^2)/(Sbase);
```

```
%for the transformers

Sn1=6;

Sn2=5;


%per-unit voltage of the generator at node a

%Uapu=1.0; %Ua=Ua40=40kV

%per-unit impedance of Transformer-1

Zt1pu=j*(0.07)*(Sbase/Sn1);

Zt1pu=Zt1pu




%per-unit impedance of Cable-bc

Zbc=(0.16+j*0.08)*(0.273) ;%length of the cable is 0.273km

Zbcpu=Zbc/Zb12;

yshbc=(j*3*1E-6)*(0.273)/2;

yshbcpu=yshbc*Zb12;


%per-unit impedance for LD_b

cosphi_b=0.9; sinphi_b=sqrt(1-(cosphi_b^2));

PLD_b=0.173;

magSLD_b=PLD_b/cosphi_b; %magnitude of Complex Power

SLD_b=magSLD_b*(cosphi_b+j*sinphi_b);

Ubn=Ub12;

Zld_b=(Ubn^2)/conj(SLD_b);
```

```
ZLDbpu=Zld_b/Zb12;


%per-unit impedance of Cable-cd

Zcd=(0.16+j*0.08)*(0.273) ;%length of the cable is 0.385km

Zcdpu=Zcd/Zb12;

yshcd=(j*3*1E-6)*(0.273)/2;

yshcdpu=yshcd*Zb12;


%per-unit impedance of LD_c

cosphi_c=0.95; sinphi_c=sqrt(1-(cosphi_c^2));

PLD_c=0.103;

magSLD_c=PLD_c/cosphi_c; %magnitude of Complex Power

SLD_c=magSLD_c*(cosphi_c+j*sinphi_c);

Ucn=Ub12;

Zld_c=(Ucn^2)/conj(SLD_c);

ZLDcpu=Zld_c/Zb12;


%per-unit impedance of Transformer-2

Zt2pu=j*(0.08)*(Sbase/Sn2);
```

```
%per-unit impedance of LD_e

cosphi_e=0.9; sinphi_e=sqrt(1-(cosphi_e^2));

PLD_e=0.187;

magSLD_e=PLD_e/cosphi_e; %magnitude of Complex Power

SLD_e=magSLD_e*(cosphi_e+j*sinphi_e);

Uen=Ub6;

Zld_e=(Uen^2)/conj(SLD_e);

ZLDepu=Zld_e/Zb6;

ZLDepu=ZLDepu*2;  %-----------------------------------------------Assignment S2 requirement 50%load

disp(ZLDepu);

%two-port of the given system

TP_0=[1 Z_th;0 1];

TP_1=[1 Zt1pu;0 1];


TP_2=[1 0;(1/ZLDbpu) 1];


A_bc=1+yshbcpu*Zbcpu;

B_bc=Zbcpu;

C_bc=yshbcpu*(2+yshbcpu*Zbcpu);

D_bc=1+yshbcpu*Zbcpu;

TP_3=[A_bc B_bc;C_bc D_bc];


TP_4=[1 0;(1/ZLDcpu) 1];
```

```
A_cd=1+yshcdpu*Zcdpu;

B_cd=Zcdpu;

C_cd=yshcdpu*(2+yshcdpu*Zcdpu);

D_cd=1+yshcdpu*Zcdpu;

TP_5=[A_cd B_cd;C_cd D_cd];


TP_6=[1 Zt2pu;0 1];




TP_tot_E=((((((TP_0*TP_1)*TP_2)*TP_3)*TP_4)*TP_5)*TP_6);   %PART B

disp(TP_tot_E);


%impedance of the entire system in per unit

Z_totpu=((TP_tot_E(1,1)*ZLDepu)+(TP_tot_E(1,2)))/((TP_tot_E(2,1)*ZLDepu)+(TP_tot_E(2,2)));
%PART C

disp(Z_totpu);


%Assuming that the system is fed with nominal voltage at node a

Iapu=Uapu/Z_totpu;


Uepu_Iepu=inv(TP_tot_E)*[Uapu;Iapu];

%nominal voltage at node e in kV

Ue=abs(Uepu_Iepu(1,1))*Ub6;    %PART D

disp(Ue);
```

```
disp(angle(Uepu_Iepu(1,1))*deg);

endfunction
```
