EG2100 Power System Analysis

Assignment S1

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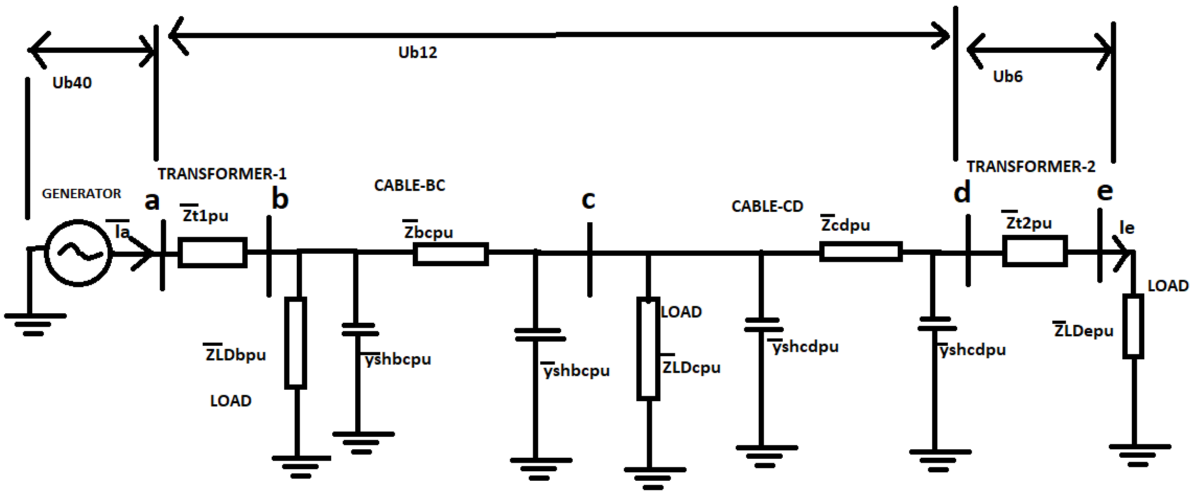
B-number-73

a.) Based on the given data, draw the single-line diagram of the electrical network of the factory.



CIRCUIT DIAGRAM-I

Defining the Base values in the system

U_{n1}=40kV, U_{n2}=12kV, U_{n3}=6kV (Given)

S_{n1}=6MVA (Rating of Transformer-1), Z_{t1}=7%

S_{n2}=5MVA (Rating of Transformer-2), Z_{t2}=8%

S_{base}=10 MVA (Given)

U_{base40}=40kV, $I_{base40}=S_{base}/\sqrt{3}*U_{base40}$=0.144 (kA), $Z_{base40}=(U_{base40}$^2)/S_{base}=160(Ω)---(1)

$U_{base12}=(U_{n2}/U_{n1})*U_{base40}$=12kV, $I_{base12}=S_{base}/\sqrt{3}*U_{base12}$=0.481 (kA), $Z_{base12}=(U_{base12}$^2)/S_{base} =14.4(Ω)---(2)

$U_{base6}=(U_{n3}/U_{n2})*U_{base12}$=6kV, $I_{base6}=S_{base}/\sqrt{3}*U_{base6}$ =0.963(kA), $Z_{base6}=(U_{base6}$^2)/S_{base}=3.6 (Ω)---(3)

Finding Per-unit Impedances

For **Transformer-1**:

$\overline{Z}_{t1pu}=j*(0.07)*(S_{base}/S_{n1})$ = 0.11667j--- (4)

For **Transformer-2**:

$\overline{Z}_{t2pu}$=j*(0.08)*(S_{base}/S_{n2})= 0.16000j --- (5)

For **Cable BC** :

$\overline{Z}_{bcpu} = \frac{(0.16+j*0.08)*(0.273)}{\text{Zbase12}}$ = 0.0030333 + 0.0015167j

$\overline{y}_{shbc}$=(j*3*1E-6)*(0.273)/2(S)

$\overline{y}_{shbcpu}=\overline{y}_{shbc}*Z_{base12}$= 0.0000058968j ---(6)

For **Cable CD** :

$\overline{Z}_{cdpu} = \frac{(0.16+j*0.08)*(0.273)}{\text{Zbase12}}$ = 0.0030333 + 0.0015167j

$\overline{y}_{shcd}$=(j*3*1E-6)*(0.273)/2(S)

$\overline{y}_{shcdpu}=\overline{y}_{shcd}*Z_{base12}$ = 0.0000058968j---(7)

For **Load at Node B**:

$\overline{Z}_{LDbpu}=\frac{Ub\hat{}2}{(conj(SLD))}\frac{1}{Zbase12} = \frac{12\hat{}2}{\frac{0.173}{0.9}}\frac{1}{14.4}$ (0.9+j0.43)= 46.821 + 22.676j---(8)

For **Load at Node C**:

$\overline{Z}_{LDcpu}=\frac{Uc\hat{}2}{(conj(SLD))}\frac{1}{Zbase12} = \frac{12\hat{}2}{\frac{0.103}{0.95}}\frac{1}{14.4}$ (0.95+j0.312)= 87.621 + 28.800j---(9)

For **Load at Node E**:

$\overline{Z}_{LDepu}=\frac{Ue\hat{}2}{(conj(SLD))}\frac{1}{Zbase6} = \frac{6\hat{}2}{\frac{0.187}{0.9}}\frac{1}{3.6}$ (0.9+j0.43)= 43.316 + 20.979j---(10)

$\overline{U}_{apu}=1.0\lfloor 0°$ ---(11)

b.) As seen from node **a**, make the two-port model and give the values of the elements of the two-port matrix in pu.

$A_{bc}=1+\overline{y}_{shbcpu}*\overline{Z}_{bcpu}$
$B_{bc}=\overline{Z}_{bcpu}$
$C_{bc}=\overline{y}_{shbcpu}*(2+\overline{y}_{shbcpu}*\overline{Z}_{bcpu})$
$D_{bc}=1+\overline{y}_{shbcpu}*\overline{Z}_{bcpu}$

$A_{cd}=1+\overline{y}_{shcdpu}*\overline{Z}_{cdpu}$
$B_{cd}=\overline{Z}_{cdpu}$
$C_{cd}=\overline{y}_{shcdpu}*(2+\overline{y}_{shcdpu}*\overline{Z}_{cdpu})$

$D_{cd}=1+\overline{y}_{shcdpu}*\overline{Z}_{cdpu}$

Let TP_tot be defined as two port model for the entire system.

$$\text{TP\_tot}=\begin{bmatrix}1 & \overline{Z}t1pu\\0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\\frac{1}{\overline{Z}LDbpu} & 1\end{bmatrix}\begin{bmatrix}Abc & Bbc\\Cbc & Dbc\end{bmatrix}\begin{bmatrix}1 & 0\\\frac{1}{\overline{Z}LDcpu} & 1\end{bmatrix}\begin{bmatrix}Acd & Bcd\\Ccd & Dcd\end{bmatrix}\begin{bmatrix}1 & \overline{Z}t2pu\\0 & 1\end{bmatrix}$$

TP_tot = TP_1 * TP_2 * TP_3 * TP_4 * TP_5 * TP_6-----(#)

$$\textbf{TP\_tot}=\begin{bmatrix}\mathbf{1.0014061 + 0.0032255i} & \mathbf{0.0055499 + 0.2799445i}\\\mathbf{0.0276007 - 0.0117408i} & \mathbf{1.0020452 + 0.0044232i}\end{bmatrix}\textbf{---(12)}$$

c.) Give the value of the impedance of the entire system in pu.

$\overline{U}_{apu}=A\overline{U}_{epu}+B\overline{I}_{epu}$

$\overline{I}_{apu}=C\overline{U}_{epu}+D\overline{I}_{epu}$

$\overline{U}_{epu}=\overline{I}_{epu}\overline{Z}_{ldepu}$

Using the formula

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

Where A, B, C, D are elements of Matrix in Equation-(12)

$$\overline{Z}_{\mathbf{grid}}\mathbf{=17.9753 + 8.2171i\ ---(13)}$$

d.) Assume that the transformer "TI1" is fed with nominal voltage. Find the voltage at node **e** in kV.

From Equation (12) and Equation(13), we know that
$\overline{I}_{apu}=\overline{U}_{apu}/\overline{Z}_{grid}$---(14)
$\overline{I}_{apu}=1.0\lfloor 0°/17.9753 + 8.2171i$
$\overline{I}_{apu}=0.05\lfloor -24.57°$ (kA)

$$\begin{bmatrix}\overline{\boldsymbol{U}}\boldsymbol{epu}\\\overline{\boldsymbol{I}}\boldsymbol{epu}\end{bmatrix}=[\boldsymbol{TP\_tot}]^{-1}\begin{bmatrix}\overline{\boldsymbol{U}}\boldsymbol{apu}\\\overline{\boldsymbol{I}}\boldsymbol{apu}\end{bmatrix}\textbf{---(14)}$$

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

$$\overline{\boldsymbol{U}}_{\mathbf{e}}\mathbf{=5.9756}\lfloor -\mathbf{0.47992°kV}$$

e.) Find the consumed active power of the load at node **e** in MW, and also its power factor.

$$P_{cons\_e}=\mathrm{Real}(\overline{S}_e)$$
Where $\overline{S}_e = \overline{U}_{epu}\overline{I}_{LDepu}{}^{*}S_{base}$
$$\overline{I}_{ldepu}=\overline{U}_{epu}/(\overline{Z}_{LDepu})$$
$$S_e=0.20609\lfloor 25.842°$$
Active Power=P_{cons_e}=0.185483MW---(15)

Power Factor=0.90000

f.) Find the total losses in the factory in kW.

Total Losses in factory= P_{tot} - (P_{cons_b}+ P_{cons_c}+ P_{cons_e})

$$P_{tot}=Real(\overline{U}_{apu}\,\overline{I}_{apu}{}^{*})*S_{base}$$
$$P_{tot}= 0.46016\ MW\text{---}(16)$$

$$P_{cons\_b}=\mathrm{Real}(\overline{S}_b)$$
Where $\overline{S}_b = \overline{U}_{bpu}\overline{I}_{LDbpu}{}^{*}S_{base}$

To find the value of U_{bpu} :

$$\begin{bmatrix} \overline{\boldsymbol{U}}\boldsymbol{bpu} \\ \overline{\boldsymbol{I}}\boldsymbol{bpu} \end{bmatrix} = [\boldsymbol{TP\_1}]^{-1} \begin{bmatrix} \overline{\boldsymbol{U}}\boldsymbol{apu} \\ \overline{\boldsymbol{I}}\boldsymbol{apu} \end{bmatrix}$$

$$\overline{I}_{ldbpu}=\overline{U}_{bpu}/(\overline{Z}_{LDbpu})$$
P_{cons_b}= 0.17216 MW ---(17)

$$P_{cons\_c}=\mathrm{Real}(\overline{S}c)$$
Where $\overline{S}_c = \overline{U}_{cpu}\overline{I}_{LDcpu}{}^{*}S_{base}$

To find the value of U_{cpu} :

$$\begin{bmatrix} \overline{\boldsymbol{U}}\boldsymbol{cpu} \\ \overline{\boldsymbol{I}}\boldsymbol{cpu} \end{bmatrix} = [\boldsymbol{TP\_1} * \boldsymbol{TP\_2} * \boldsymbol{TP\_3}]^{-1} \begin{bmatrix} \overline{\boldsymbol{U}}\boldsymbol{apu} \\ \overline{\boldsymbol{I}}\boldsymbol{apu} \end{bmatrix}$$
$$\overline{I}_{ldcpu}=\overline{U}_{cpu}/(\overline{Z}_{LDcpu})$$
P_{cons_c}= 0.10248 MW---(18)

From Equation (15), (16),(17), (18):

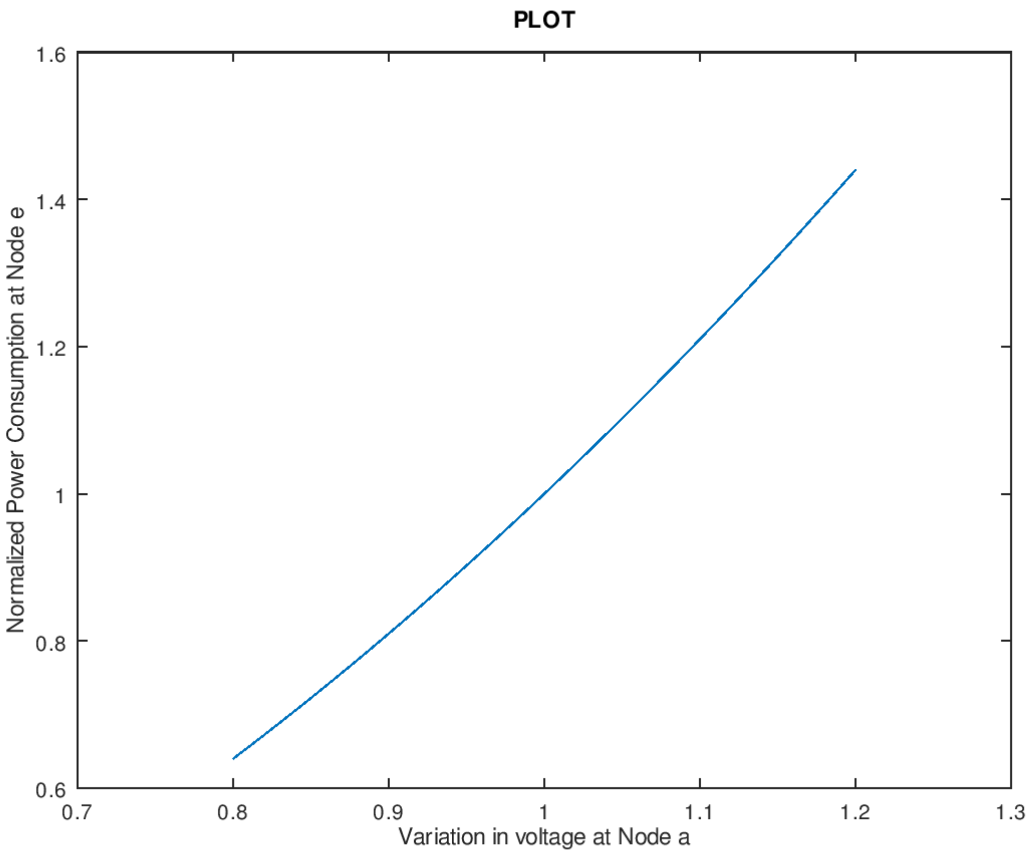
P_{losses}= (0.46016-(0.185483+ 0.17216+0.10248))*10^3 (kW)

P_{losses}=0.042960kW ---(19)

g.) Plot the normalized active power consumption at node **e** (based on the obtained active power in task e) when the voltage at node **a** varies from 0.8 to 1.2 pu.

The graph obtained when U_{apu} is varied from 0.8 to 1.2pu is shown below.

Note : For Normalization use P_{cons_e} from Equation (15)



GRAPH

MATLAB CODE

For Part A-F

```
%Assignment S1
function retval=S1_B73(Uapu)   %Give Uapu=1.0 for Part a-f

%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);

%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;
disp(ZLDbpu);
disp(ZLDepu);

%two-port of the given system

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_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(angle(Uepu_Iepu(1,1)));
disp(Ue);

%Consumed active power at Node e
ILDepu=Uepu_Iepu(1,1)/ZLDepu;
S_cons_e=Uepu_Iepu(1,1)*conj(ILDepu)*Sbase;  %power consumption at Load E
P_cons_e=real(S_cons_e);  %PART E
```

```
disp(P_cons_e);
disp(S_cons_e);
disp(abs(S_cons_e));
disp(angle(S_cons_e)*deg);
pf_e=P_cons_e/abs(S_cons_e);  %PART E
disp(pf_e);

%Consumed active power at Node b
TP_tot_B=TP_1;
Ubpu_Ibpu=inv(TP_tot_B)*[Uapu;Iapu];
disp(Ubpu_Ibpu);

ILDbpu=Ubpu_Ibpu(1,1)/ZLDbpu;
S_cons_b=Ubpu_Ibpu(1,1)*conj(ILDbpu)*Sbase;
P_cons_b=real(S_cons_b);
disp(P_cons_b);

%Consumed active power at Node c
TP_tot_C=((TP_1*TP_2)*TP_3);
Ucpu_Icpu=inv(TP_tot_C)*[Uapu;Iapu];  %power consumption at Load C
disp(Ucpu_Icpu);

ILDcpu=Ucpu_Icpu(1,1)/ZLDcpu;
S_cons_c=Ucpu_Icpu(1,1)*conj(ILDcpu)*Sbase;
P_cons_c=real(S_cons_c);
disp(P_cons_c);

%Total Power consumption
S_tot=Uapu*conj(Iapu)*Sbase;
P_tot=real(S_tot);
disp(P_tot);

%Total Losses
disp((P_tot-(P_cons_b+P_cons_c+P_cons_e))*1E3);

endfunction
```

For PART G

```
vec=[];
for pu=0.8:0.01:1.2
vec=[vec,S1_B73(pu,0.18548)];
end
x=0.8:0.01:1.2;
plot(x,vec);
xlabel("Variation in voltage at Node a")
ylabel("Normalized Power Consumption at Node e")
title("PLOT")
```