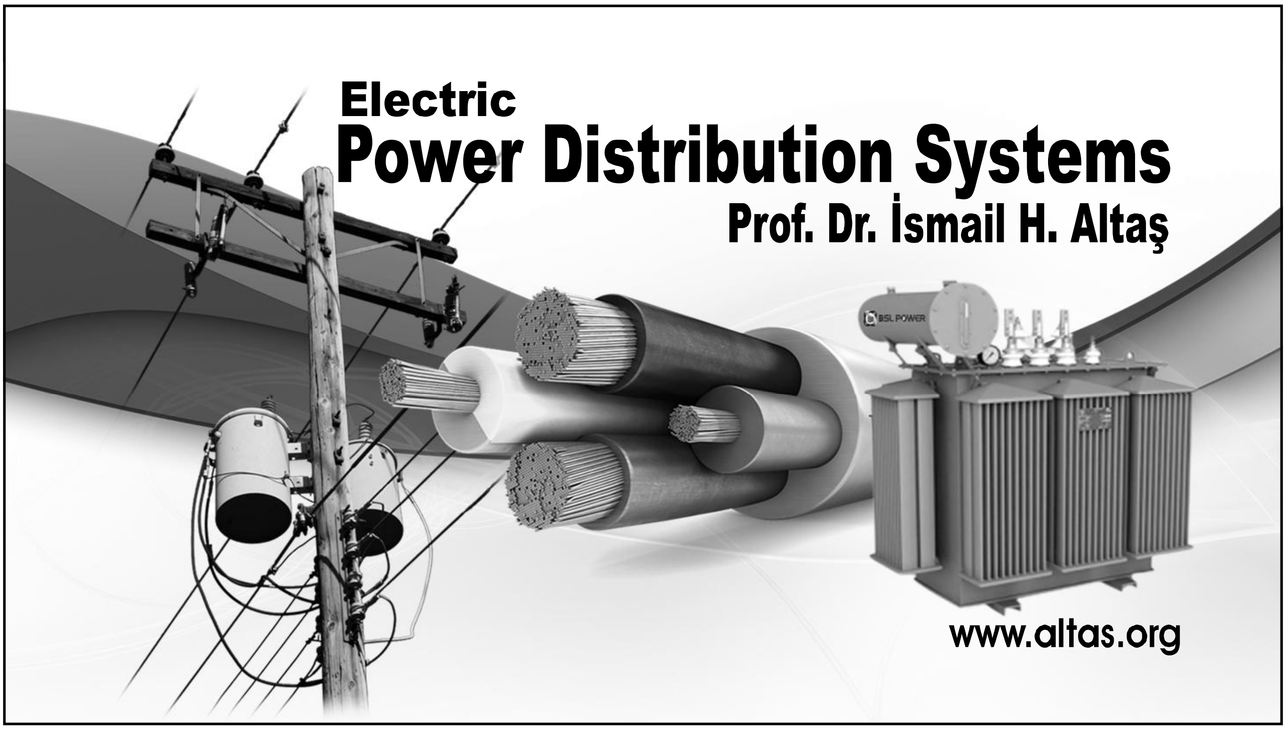

Electric Power Distribution Systems
Chapter 1 – Introduction

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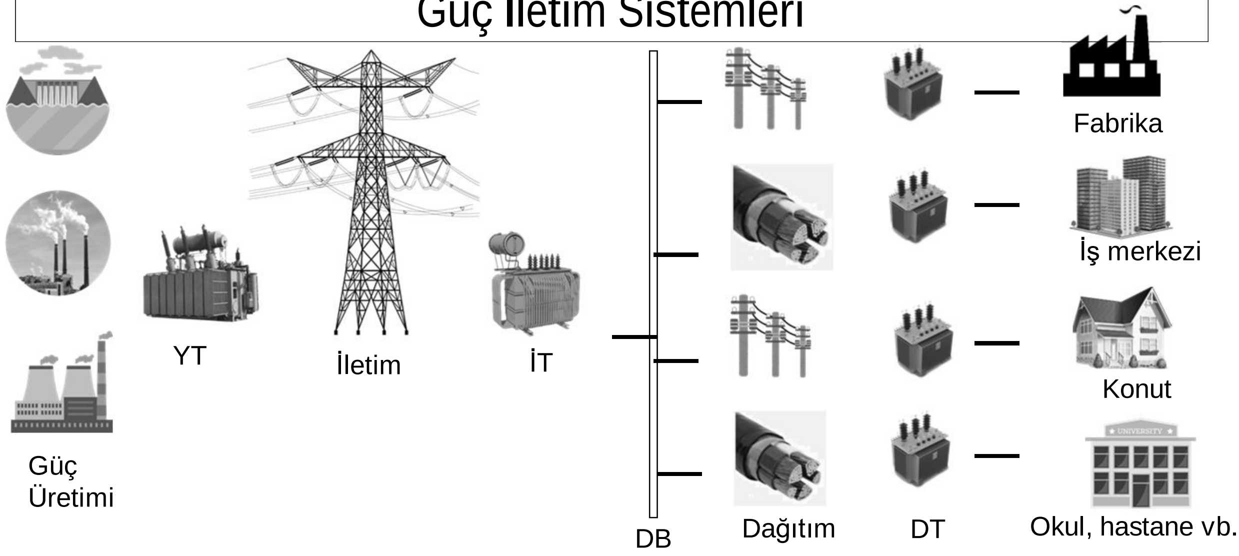
Güç İletim Sistemleri



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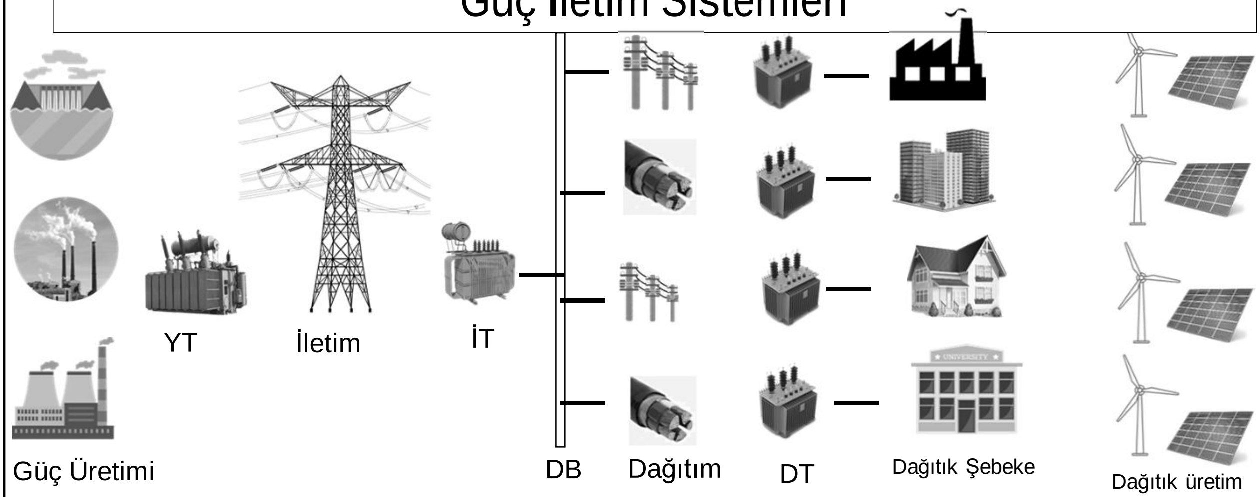
Güç İletim Sistemleri



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Fundamentals of Power Systems

PROBLEMS

QUESTION

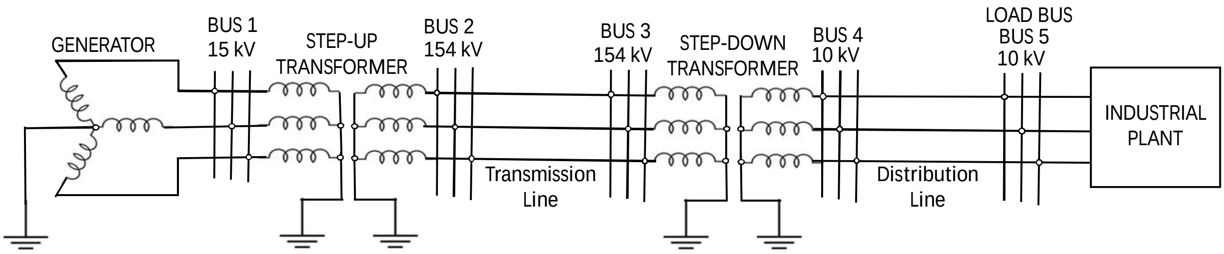
A power transmission system consists of a three-phase 15 kV generator, a step-up transformer, a 154 kV transmission line, a step-down transformer, a 10 kV distribution line, a load bus and an industrial plant. Three-phase stator windings of the generator are connected in wye. Step-up and step-down transformers are also both connected in wye-wye. The neutral points of all wye connections are solidly grounded.

a. Draw a three-phase open circiut connection diagram of the system described above
b. Draw a single line diagram of this system.

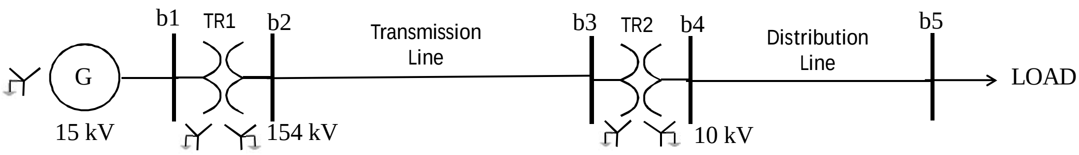
Fundamentals of Power Systems

PROBLEMS

Three-phase open circiut diagram



Single-line diagram



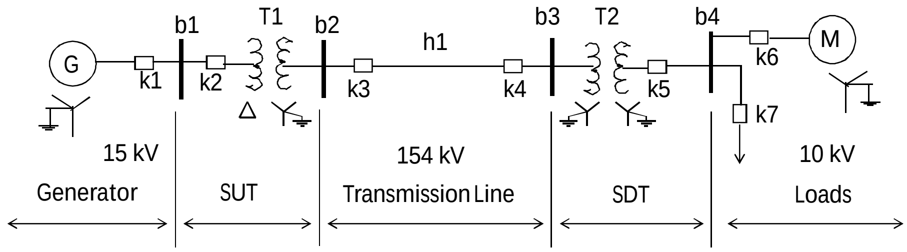
Fundamentals of Power Systems

PROBLEMS

QUESTION

A single line power system shown in Figure consists of main components from generation to dissipation.

Draw an impedance diagram of this system.



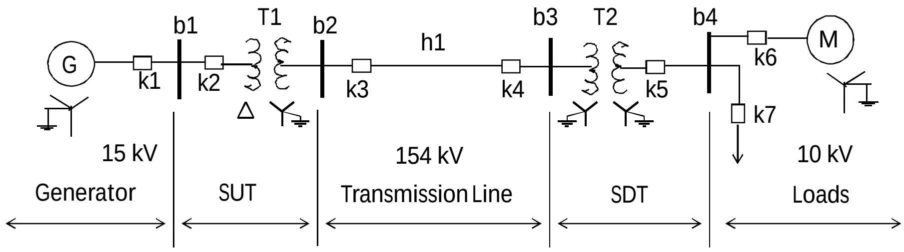
Single-line diagram

Fundamentals of Power Systems

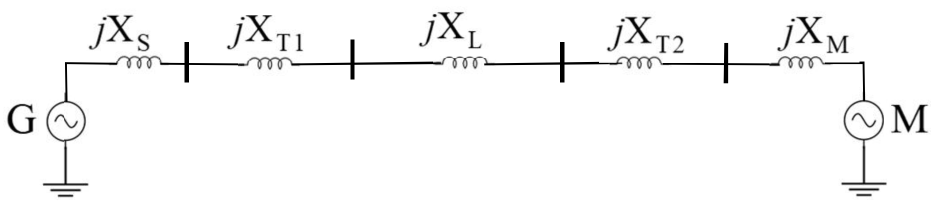
PROBLEMS

ANSWER

Single-line diagram

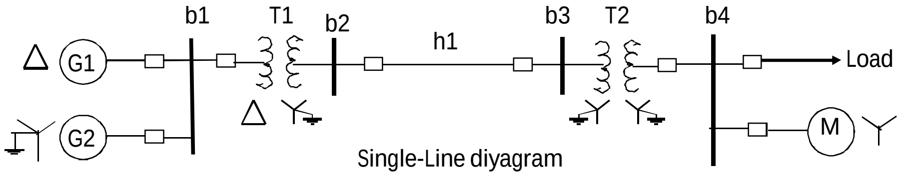


Impedance diagram



Fundamentals of Power Systems

PROBLEMS



Single-Line diyagram

DATA USED IN SINGLE-LINE DIAGRAMS

Generator G1

30 MVA
13,8 kV
X=%8

Generator G2

20 MVA
13,8 kV
X=%10

Transmission Line h1

Z_h=2+j3 Ω/km
l= .... km

Motor M

10 MVAr
6,6 kV
X=%12

Senkron (dinamik) Kondansatör

Transformer T1

50 MVA
13,8 kV Δ / λ 138 kV
X=%5

Transformer T2

20 MVA
79,7 kV λ / λ 3,81 kV
X=%6

Load

40 MW
6,6 kV
0,80 geri

Fundamentals of Power Systems

PROBLEMS

DATA USED IN SINGLE-LINE DIAGRAMS

Generator Data

S_N : Nominal power
U_N : Nominal line voltage
%X : Reactance and resistance of the windings in percentages.
Connection type of the windings

Transmission Lines

Line impedance or total impedance per km.

Load

P_N active power
U_N nominal line-to-line voltage
Power factor

Transformers

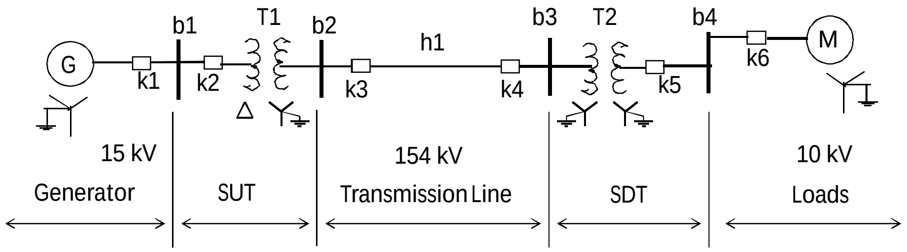
S_N : Nominal 3-phase power
U_{N1} ve U_{N2} : Nominal input/output voltages
%X : Reactance and resistance of the windings in percentages.
Connection type of the windings

Fundamentals of Power Systems

PROBLEMS

QUESTION

Obtain the impedance diagram of the power system represented by following single-line diagram. Show each step.



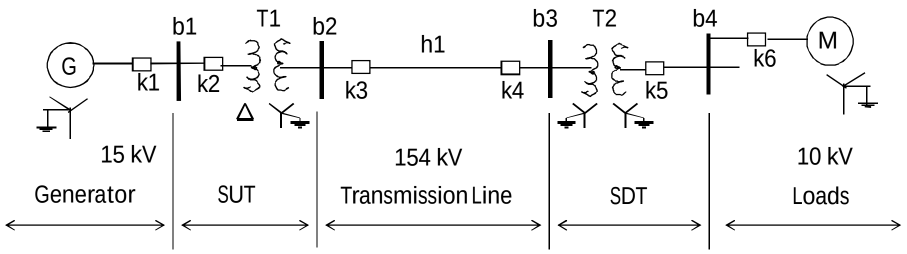
Single-line diagram

Fundamentals of Power Systems

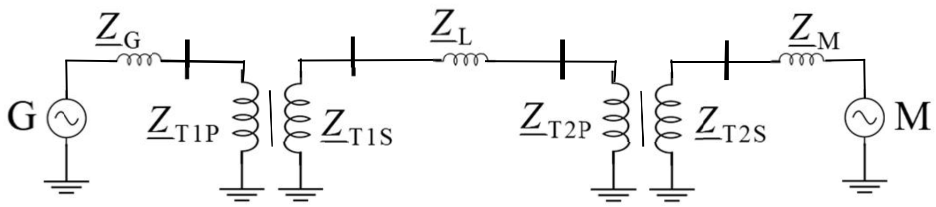
PROBLEMS

ANSWER

Single-line diagram



Impedance diagram

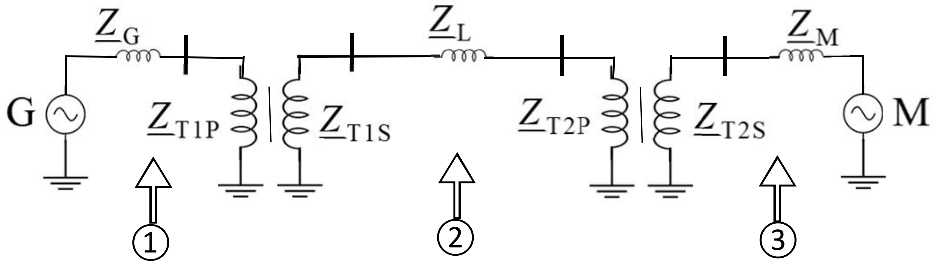


Very complicated?

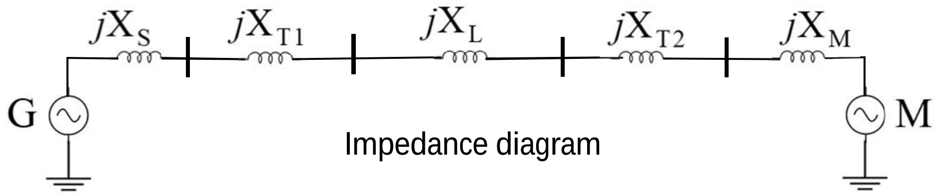
Fundamentals of Power Systems

PROBLEMS

ANSWER



There are three voltage circuits. These different voltage levels must be considered when constructing the impedance diagram given below. This issue will be discussed in next examples.



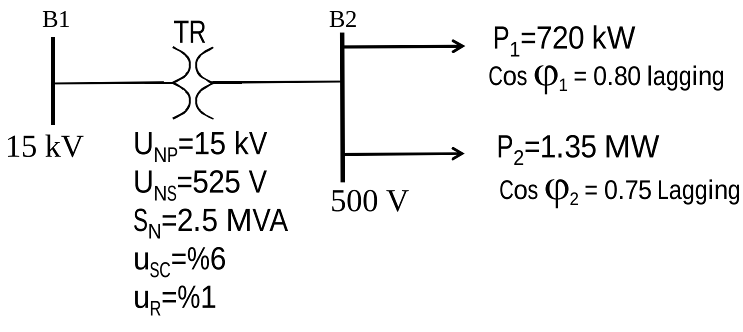
Impedance diagram

Fundamentals of Power Systems

PROBLEMS

QUESTION

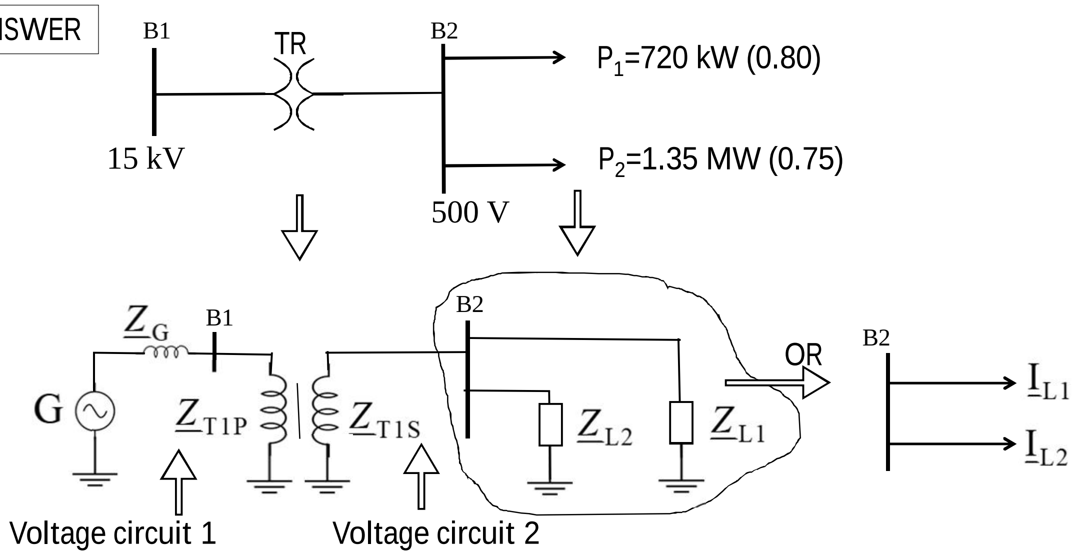
Two separate loads with P_1=720 kW power and 0.75 lagging power factor and P_2=1.35 MW power with 0.80 lagging power factor are fed over a 15/0.525 kV, 2.5 MVA transformer as shown in the figure. The voltage of the busbar B_1 is kept constant at U_{B1}=15 kV. Create the impedance diagram for this system.



Fundamentals of Power Systems

PROBLEMS

ANSWER



Fundamentals of Power Systems

PROBLEMS

ANSWER

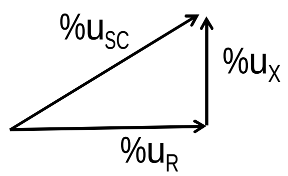
- There are two different voltage circuits in this system.
- One of these voltage circuits should be selected as the operating circuit and the values in the other circuit should be transferred to this operating circuit.
- $\%u_{SC}$ and $\%u_R$ values are given in the figüre as transformer data.

ASIDE What are $\%u_{SC}$ and $\%u_R$

$\%u_{SC}$: Short circuit voltage.

$\%u_R$: The voltage that causes Cooper losses under full load.

$\%u_X$: The voltage that causes magnetizing losses under full load.



$$\%u_X = \sqrt{(\%u_{SC})^2 - (\%u_R)^2}$$

Fundamentals of Power Systems

PROBLEMS

ANSWER

The impedance values of the transformer on LV side:

$$R_{TLV} = \%u_R \frac{U_{NLV}^2}{100S_N} = (1)\frac{0.525^2}{100\times 2.5} = 0.0011\ \Omega$$

$$\%u_X = \sqrt{(\%u_{SC})^2 - (\%u_R)^2} = \sqrt{6^2 - 1^2} = 5.916$$

$$X_{TLV} = \%u_X \frac{U_{NLV}^2}{100S_N} = 5.916\frac{0.525^2}{100\times 2.5} = 0.0065\ \Omega$$

Z @ LV

$$\underline{Z}_{TLV} = R_{TLV} + jX_{TLV} = 0.0011 + j0.0065\ \Omega$$

$$\underline{Z}_{TLV} = Z_{TLV}\underline{|\theta} = 0.006592\underline{|80.39^o}\ \Omega$$

Transformer impedance on 525 V LV side:

Fundamentals of Power Systems

PROBLEMS

ANSWER

The impedance values of the transformer on HV side:

$$R_{THV} = \%u_R \frac{U_{NHV}^2}{100S_N} = (1)\frac{15^2}{100\times 2.5} = 0.9\ \Omega$$

$$\%u_X = \sqrt{(\%u_{SC})^2 - (\%u_R)^2} = \sqrt{6^2 - 1^2} = 5.916$$

$$X_{THV} = \%u_X \frac{U_{NHV}^2}{100S_N} = 5.916\frac{15^2}{100\times 2.5} = 5.3244\ \Omega$$

Z @ HV

$$\underline{Z}_{THV} = R_{THV} + jX_{THV} = 0.9 + j5.3244\ \Omega$$

$$\underline{Z}_{THV} = Z_{THV}\underline{|\theta} = 5.3999\underline{|80.39^o}\ \Omega$$

Transformer impedance on 15 kV HV side:

Fundamentals of Power Systems

PROBLEMS

ANSWER | The impedance values of the loads on LV side:

The loads P1 and P2 given in this problem are shown with their impedance equivalents. These loads could also be represented as load currents. Because these loads will draw constant current with their constant impedance at constant active power and power coefficient.

Power values per phase:

$$P_{1\phi} = \frac{P_{3\phi}}{3} \quad \text{kW/faz}$$

$$P_1 = \frac{720}{3} = 240 \quad \text{kW/faz}$$

$$P_2 = \frac{1.35}{3} = 0.45 \quad \text{MW/faz}$$

If the L-L voltage of the busbar B_2 is kept constant at 500 V, the phase-neutral voltage is then:

$$V_{LN} = \frac{U}{\sqrt{3}} = \frac{500}{\sqrt{3}} = 288.675 \text{ V}$$

Fundamentals of Power Systems

PROBLEMS

ANSWER | The impedance values of the loads on LV side:

LOAD IMPEDANCES

$$Z_{L1LV} = \frac{V_{LN}}{I_{Ph}} = \frac{V_{LN}}{\dfrac{P_{1\phi}}{V_{LN}\cos\varphi_1}} = \frac{V_{LN}^2}{P_{1\phi}}\cos\varphi_1 = \frac{V_{LN}^2}{S_{1\phi}}$$

Z @ LV

$$Z_{L1LV} = \frac{V_{LN}^2}{P_{1\phi}}\cos\varphi_1 = \frac{\left(\frac{500}{\sqrt{3}}\right)^2}{240\ 000} \times 0.80 = 0.277\ \Omega$$

$$Z_{L1LV} = \frac{V_{LN}^2}{P_{1\phi}}\cos\varphi_1 = \frac{\left(\frac{500}{\sqrt{3}}\right)^2}{0.40\times10^6} \times 0.75 = 0.1389\ \Omega$$

Impedances can also be calculated directly from 3-phase power and phase-to-phase voltages.

$$S_{L13\phi} = \frac{P_{L13\phi}}{\cos\varphi_1} = \frac{720}{0.80} = 900 \text{ kVA}$$

$$S_{L23\phi} = \frac{P_{L23\phi}}{\cos\varphi_1} = \frac{1.35}{0.75} = 1.8 \text{ MVA}$$

Z @ LV

$$Z_{L1LV} = \frac{U_{LL}^2}{S_{L13\phi}} = \frac{500^2}{900\times10^3} = 0.277\ \Omega$$

$$Z_{L2LV} = \frac{U_{LL}^2}{S_{L23\phi}} = \frac{500^2}{1.8\times10^6} = 0.1389\ \Omega$$

Fundamentals of Power Systems

PROBLEMS

ANSWER — The current values of the loads on LV side: — I @ LV

Load currents van also be used to represent loads instead of load impedances. Phase currents can be calculated directly using L-N voltages and powers per phase, or using 3-phase circuit values.

CURRENT

Using per-phase values:

$$I_{L1} = \frac{P_{L11\phi}}{V_{LN}\cos\varphi_1} = \frac{240\times10^3}{(288.675)(0.80)} = 1039.23\text{ A}$$

$$I_{L2} = \frac{P_{L21\phi}}{V_{LN}\cos\varphi_2} = \frac{0.45\times10^6}{(288.675)(0.75)} = 2078.46\text{ A}$$

Using three-phase values:

$$I_{L1} = \frac{P_{L13\phi}}{\sqrt{3}\ V_{LL}\cos\varphi_1} = \frac{720\times10^3}{\sqrt{3}\ \times500\times0.80} = 1039.23\text{ A}$$

$$I_{L2} = \frac{P_{L23\phi}}{\sqrt{3}\ V_{LL}\cos\varphi_2} = \frac{1.35\times10^6}{\sqrt{3}\ \times500\times0.75} = 2078.46\text{ A}$$

Fundamentals of Power Systems

PROBLEMS

ANSWER — The current values of the loads on LV side: — I @ LV

CURRENT

Angles related to power coefficients given for loads:

$$\varphi_1 = \cos^{-1}(0.80) = 36.86^0$$

$$\varphi_2 = \cos^{-1}(0.75) = 41.4^0$$

Thus, the load currents can be expressed as phasors.

I @ LV

$$\underline{I}_{L1LV} = 1039.23\angle{-36.86^o}\text{ A}$$

$$\underline{I}_{L2LV} = 2078.42\angle{-41.4^o}\text{ A}$$

These are the load currents at low voltage side of the transformer.

These current values calculated for the 500 V low voltage circuit must be transferred to 15 kV circuit so that they can be used together with the $\underline{Z}_{THV}$ in the 15 kV high voltage circuit. This transfer can be accomplished using the transformer's turn ratio.

Fundamentals of Power Systems

PROBLEMS

ANSWER

The current values of the loads on HV side:

I @ HV

$$\frac{N_1}{N_2}=\frac{U_{NHV}}{U_{NLV}}=\frac{15\text{ kV}}{0.525\text{ kV}}=\frac{I_{NLV}}{I_{NHV}} \Rightarrow I_{NHV}=I_{NLV}\frac{0.525\text{ kV}}{15\text{ kV}}$$

Ignoring the losses, we can assuming that the power on both sides of the transformer would be equal.

$$U_{NHV}I_{NHV}=U_{NLV}I_{NLV}$$

$$\underline{I}_{L1HV}=\underline{I}_{L1LV}\frac{U_{NLV}}{U_{NHV}}=1039.23\angle{-36.86^o}\left(\frac{0.525}{15}\right)=36.373\angle{-36.86^o}\text{ A}$$

$$\underline{I}_{L2HV}=\underline{I}_{L2LV}\frac{U_{NLV}}{U_{NHV}}=2078.42\angle{-41.4^o}\left(\frac{0.525}{15}\right)=72.7447\angle{-41.4^o}\text{ A}$$

I @ HV

$$\underline{I}_{L1HV}=36.373\angle{-36.86^o}\text{ A}$$

$$\underline{I}_{L2HV}=72.7447\angle{-41.4^o}\text{ A}$$

Fundamentals of Power Systems

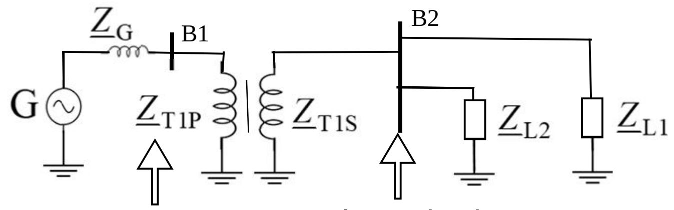
PROBLEMS

ANSWER

Configuring the impedance diagrams as separate circuits according to the voltage levels (lower and hiher voltage sides) of the transformers makes the operations complicated and difficult. Therefore it is better to configure the impedance diagrams as a whole circuit instead of separating them into the lower and upper voltage circuits.

The impedance diagram can also be formed as a single circuit without using the per-unit values. However, in this case, all values in the circuit must be transferred to either the lower voltage circuit or the higher voltage circuit.

The next examples explain this issue.



Voltage circuit 1 Voltage circuit 2

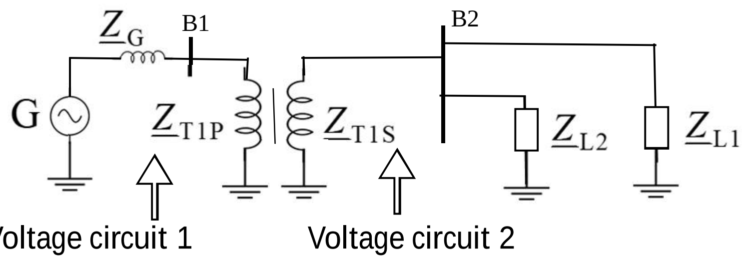
Fundamentals of Power Systems

PROBLEMS

QUESTION

Obtain and draw the Impedance diagram of the power system given in the previous example for the following voltage circuits.

a. For low voltage circuit
b. For the upper voltage circuit.

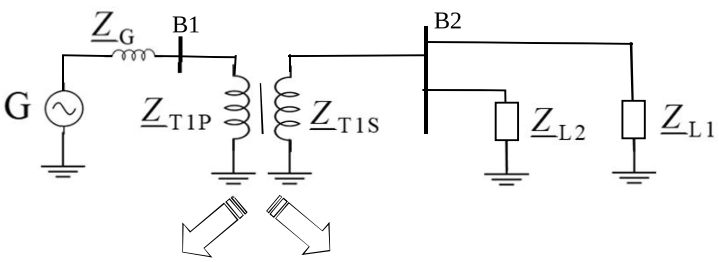


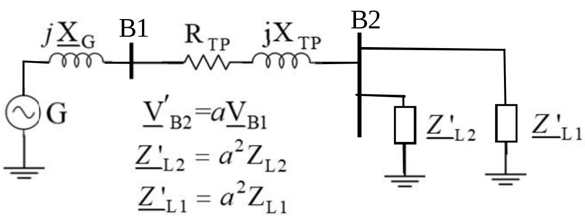
Fundamentals of Power Systems

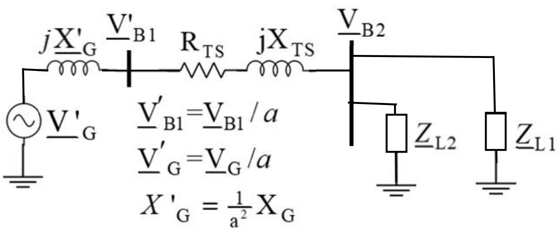
PROBLEMS

ANSWER

$$a=\frac{N_P}{N_S}=\frac{U_{NHV}}{U_{NLV}}=\frac{15}{0.525}$$







@ HV — Impedance diagram with all values at primary side (HV side for this examle)

@ LV — Impedance diagram with all values at secondary side (LV side for this examle)

Fundamentals of Power Systems

PROBLEMS

ANSWER

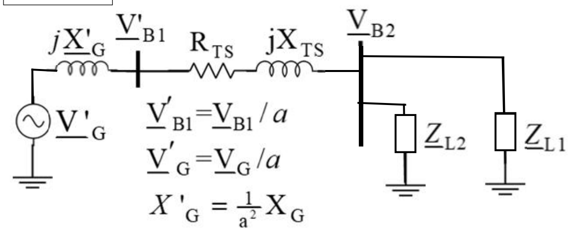
Obtain and write down all of the required circuit elemnts shown in the curcuit @LV side.

From previous example:

$$\underline{Z}_{TS} = \underline{Z}_{TLV} = 0.0011 + j0.0065\ \Omega$$

$$\underline{Z}_{TS} = \underline{Z}_{TLV} = 0.006592\angle 80.39^o\ \Omega$$

@ LV



$$\underline{I}_{L1} = 1039.23\angle -36.86^o\ A$$

$$\underline{I}_{L2} = 2078.42\angle -41.4^o\ A$$

@ LV

Assume V_{B2} at reference

$$\underline{V}_{B2} = \frac{500}{\sqrt{3}}\angle 0^o\ V$$

@ LV

$$\underline{Z}_{L1} = 0.277\angle 36.86^o\ \Omega$$

$$\underline{Z}_{L2} = 0.1389\angle 41.4^o\ \Omega$$

@ LV

$$\underline{V}'_{B1} = \underline{V}_{B2} + (\underline{I}_{L1} + \underline{I}_{L2})\underline{Z}_{TS}\ \text{Volt}$$

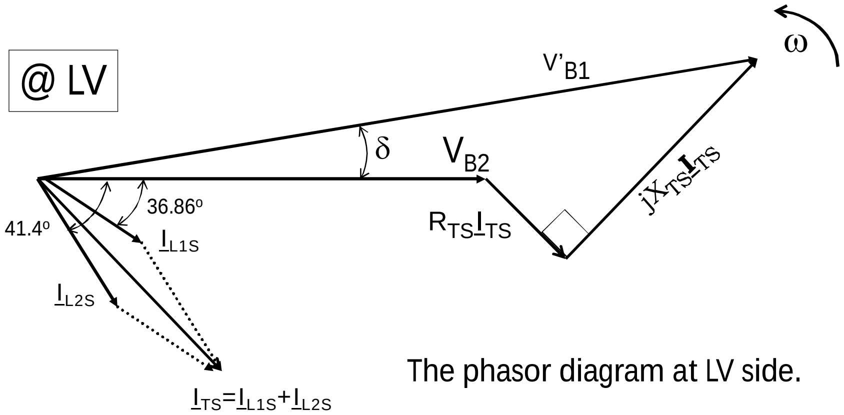
Fundamentals of Power Systems

PROBLEMS

ANSWER

Obtain and write down all of the required circuit elemnts shown in the curcuit @LV side.

@ LV



The phasor diagram at LV side.

Fundamentals of Power Systems

PROBLEMS

QUESTION

Obtain and write down all of the required circuit elemnts shown in the curcuit @HV side. The PRIMARY.

$\underline{I}_{L1HV} = 36.373\angle{-36.86^o}$ A

$\underline{I}_{L2HV} = 72.7447\angle{-41.4^o}$ A

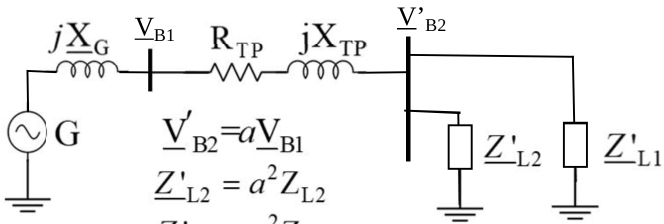
@ HV

$a = \frac{15}{0.525}$

$\underline{Z}_{THV} = R_{THV} + jX_{THV} = 0.9 + j5.3244\ \Omega$

$\underline{Z}_{THV} = Z_{THV}\angle\theta = 5.3999\angle 80.39^o\ \Omega$

$\underline{Z}_{TP} = \underline{Z}_{THV}\angle\theta$



$\underline{V}'_{B2} = a\underline{V}_{B1}$

$\underline{Z}'_{L2} = a^2 Z_{L2}$

$\underline{Z}'_{L1} = a^2 Z_{L1}$

$\underline{V}'_{B2} = \frac{500}{\sqrt{3}}\angle 0^o$ V reference

$\underline{Z}'_{L1H} = a^2 0.277\angle 36.86^o\ \Omega$

$= 226.122\angle 36.86^o\ \Omega$

$\underline{Z}'_{L2} = a^2 0.1389\angle 41.4^o\ \Omega$

$= 113.38\angle 41.4^o\ \Omega$

@ HV

$\underline{V}_{B1} = \underline{V}'_{B2} + (\underline{I}'_{L1} + \underline{I}'_{L2})\underline{Z}_{TP}$ Volt

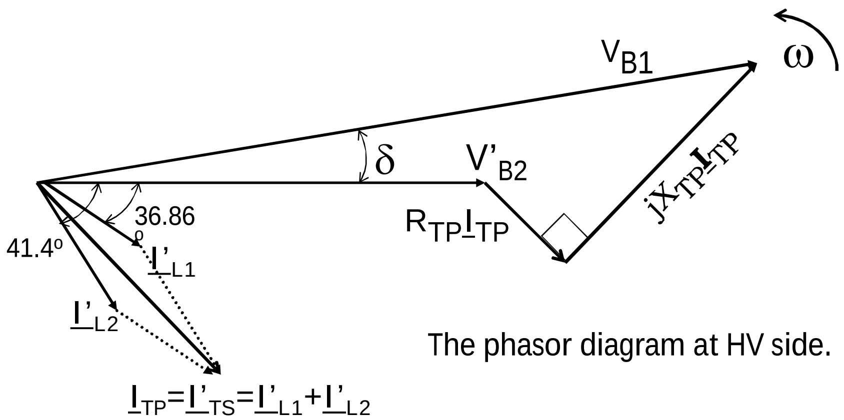
Fundamentals of Power Systems

PROBLEMS

ANSWER

@ HV

Obtain and write down all of the required circuit elemnts shown in the curcuit @HV side.

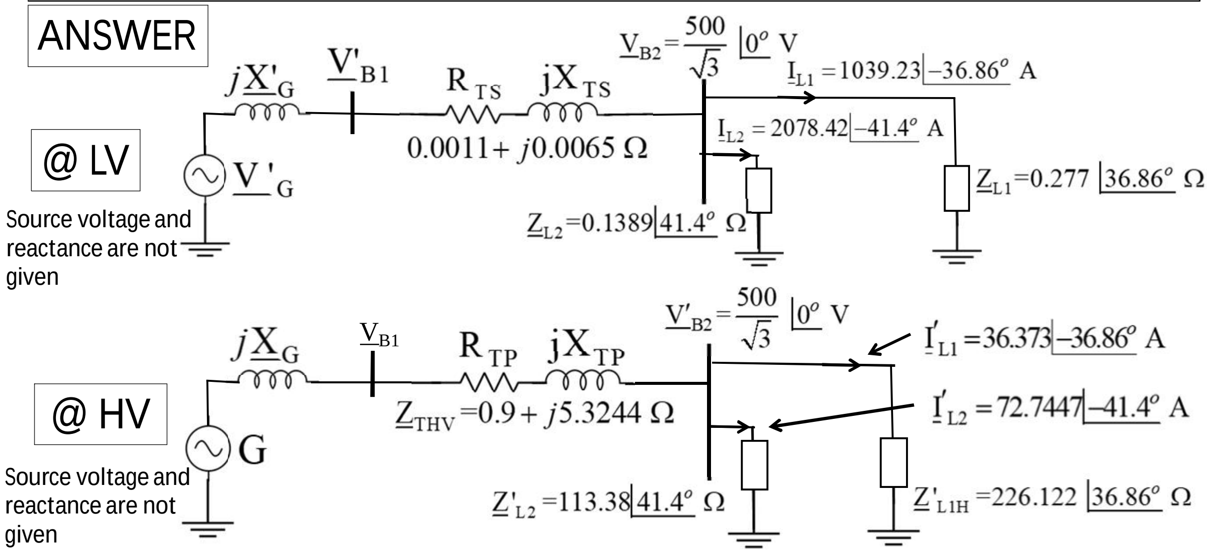


The phasor diagram at HV side.

Fundamentals of Power Systems

PROBLEMS

ANSWER



Fundamentals of Power Systems

PROBLEMS

QUESTION

In the system whose impedance diagram is obtained in the previous example, if the voltage of the busbar B1 is kept constant at 15 kV, answer the following.

a. What will be the voltage value of the B1 busbar?

b. What is the power factor in the B1 and B2 busbars?

NOTE : Take the voltage of the B2 busbar as reference.

HINT: Since V_2 voltage is not known, I_1 and I_2 load currents can be written as dependent on V_2 voltage.

Fundamentals of Power Systems

PROBLEMS

ANSWER

$$\underline{I}_{L1}=\frac{P_{L13\phi}}{\sqrt{3}\ V_{LLS}\cos\varphi_1}=\frac{720\times10^3}{\sqrt{3}\ \times\sqrt{3}V_{LNS}\times0.80}=\frac{300\ 000}{V_{LNS}}\ \text{A}$$

$$\underline{I}_{L1}=\frac{300\ 000}{V_{LNS}}\angle{-36.87^o}\ \text{A}$$ @ LV

$$\underline{I}_{L2}=\frac{P_{L23\phi}}{\sqrt{3}\ V_{LLS}\cos\varphi_2}=\frac{1.35\times10^6}{\sqrt{3}\ \times\sqrt{3}V_{LNS}\times0.75}=\frac{600\ 000}{V_{LNS}}\ \text{A}$$

$$\underline{I}_{L2}=\frac{600\ 000}{V_{LNS}}\angle{-41.4^o}\ \text{A}$$ @ LV

$$\underline{Z}_{TS}=R_{TS}+jX_{TS}=0.0011+j0.0065\ \Omega$$ @ LV

$$\underline{I}_{TS}=\underline{I}_{L1}+\underline{I}_{L2}=\frac{300\ 000}{V_{LNS}}\angle{-36.87^o}+\frac{600\ 000}{V_{LNS}}\angle{-41.4^o}\ \text{A.}$$

$$\underline{I}_{TS}=\underline{I}_{L1}+\underline{I}_{L2}=\frac{1}{V_{LNS}}\left(690\ 000-j576\ 780\right)\ \text{A.}$$

@ LV

$$\underline{I}_{TS}=\frac{899\ 319.2806}{V_{LNS}}\angle{-39.89^o}\ \text{A.}$$

Fundamentals of Power Systems

PROBLEMS

ANSWER

Details

$$\underline{I}_{TS}=\underline{I}_{L1}+\underline{I}_{L2}$$

$$=\frac{300\ 000}{V_2}\left(\cos 36.87^\circ-j\sin 36.87^\circ\right)+\frac{600\ 000}{V_2}\left(\cos 41.4^\circ-j\sin 41.4^\circ\right)$$

$$=\frac{300\ 000}{V_2}\left(0.80-j0.60\right)+\frac{600\ 000}{V_2}\left(0.75-j0.6613\right)$$

$$=\frac{240\ 000}{V_2}-j\frac{180\ 000}{V_2}+\frac{450\ 000}{V_2}-j\frac{396\ 780}{V_2}$$

$$=\frac{690\ 000}{V_2}-j\frac{576\ 780}{V_2}$$

$$\underline{I}_{TS}=\frac{1}{V_{LNS}}\left(690\ 000-j576\ 780\right)\ \text{A.}$$

Fundamentals of Power Systems

PROBLEMS

ANSWER

@ LV

Voltage drop on transformer:

$$\underline{\Delta V}_{TS} = \underline{Z}_{TS}\underline{I}_{TS} = \left(0.00659\underline{|80.39^o}\right)\left(\frac{899\ 319.2806}{V_{LNS}}\underline{|-39.89^o}\right)$$

$$\underline{\Delta V}_{TS} = \frac{5926.514}{V_{LNS}}\underline{|40.5^o}$$ @ LV

The value of the busbar B1 voltage transferred to the low voltage circuit

$$\underline{\Delta V'}_{TP} = \underline{V}_{TS} + \underline{\Delta V}_{TS}$$ @ LV

Since the B1 busbar voltage is constant at U1=15 kV,

$$V_{TP} = \frac{15}{\sqrt{3}} = 8.66\ \text{kV}$$ @ HV

This value will remain constant. Its transferred value to the low voltage circuit:

Fundamentals of Power Systems

PROBLEMS

ANSWER

$$V'_{TP} = V_{TP}\left(\frac{U_{NS}}{U_{NP}}\right) = \frac{15}{\sqrt{3}}\left(\frac{0.525}{15}\right) = 0.3031\ \text{kV}$$

$$\underline{V'}_{TP} = 0.3031\underline{|\delta}\ \text{kV}$$

$$\underline{V'}_{TP} = 303.1\underline{|\delta}\ \text{V}$$

@ LV

$$\underline{\Delta V'}_{TP} = \underline{V}_{TS} + \underline{\Delta V}_{TS}$$

$$303.1\underline{|\delta} = \underline{V}_{TS} + \frac{5956.514}{V_{TS}}\underline{|40.5^o}$$

$$303.1\underline{|\delta} = \underline{V}_{TS} + \frac{5956.514}{V_{TS}}\left(\cos 40.5^o + j\sin 40.5^o\right)$$

$$303.1\underline{|\delta} = \frac{V_{TS}^2 + 4504.15}{V_{TS}} + j\frac{3848.96}{V_{TS}}$$

Fundamentals of Power Systems

PROBLEMS

ANSWER

$$303.1\angle\delta = \frac{V_{TS}^2 + 4504.15}{V_{TS}} + j\frac{3848.96}{V_{TS}}$$

$$303.1 = \sqrt{\left(\frac{V_{TS}^2 + 4504.15}{V_{TS}}\right)^2 + \left(\frac{3848.96}{V_{TS}}\right)^2}$$

$$(303.1)^2 = \left(\frac{V_{TS}^2 + 4504.15}{V_{TS}}\right)^2 + \left(\frac{3848.96}{V_{TS}}\right)^2$$

$$(303.1)^2\, V_{TS} = \left(V_{TS}^2 + 4504.15\right)^2 + (3848.96)^2$$

$$(303.1)^2\, V_{TS} = V_{TS}^4 + 2\times 4504.15 V_{TS}^2 + (4504.15)^2 + (3848.96)^2$$

$$V_{TS}^4 + \left(2\times 4504.15 - (303.1)^2\right)V_{TS}^2 + (4504.15)^2 + (3848.96)^2 = 0$$

$$V_{TS}^4 + (82861.31)V_{TS}^2 + 35101860.3 = 0$$

Fundamentals of Power Systems

PROBLEMS

ANSWER

$$V_{TS}^4 + (82861.31)V_{TS}^2 + 35101860.3 = 0$$

Let: $x = V_{TS}^2$

$$x^2 + (82861.31)x + 35101860.3 = 0$$

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{82861.31 \pm \sqrt{(82861.31)^2 - 4(1)(35101860.3)}}{2(1)}$$

$$x_{1,2} = \frac{82861.31 \pm 82009.69}{2} \Rightarrow x_1 = 82435.5, \quad x_2 = 425.81$$

Since $x = V_{TS}^2$

@ LV

$V_{TS1} = \sqrt{x_1} \Rightarrow V_{TS1} = 287.115\ V$ — SUITABLE

$V_{TS2} = \sqrt{x_2} \Rightarrow V_{TS2} = 20.635\ V$ — NOT SUITABLE

Fundamentals of Power Systems

PROBLEMS

ANSWER

Since $\underline{V}_{TS} = 287.115\angle 0^o$ V

$$303.1\angle\delta = \frac{(287.115)^2 + 4504.15}{287.115} + j\frac{3848.96}{287.115}$$

$$\left.\begin{array}{l} 303.1\angle\delta = 302.8 + j13.4 \\ 303.1\angle\delta = 303.1\angle 2.5^o \end{array}\right\} \quad \delta = 2.5^o$$

Thus, if the busbar B1 voltage is kept constant at 15 kV, the relevant busbar voltages according to the lower voltage circuit are obtained as follows.

@ LV

$\underline{V}'_{TP} = 303.1\angle 2.5^o$ V.

$\underline{V}_{TS} = 287.115\angle 0^o$ V.

$\underline{I}_{TS} = 3132.26\angle -39.89^o$ A.

The power factor at busbar B1

$\cos\varphi_{B1} = \cos(39.89+2.5) = 0.738$

The power factor at busbar B2

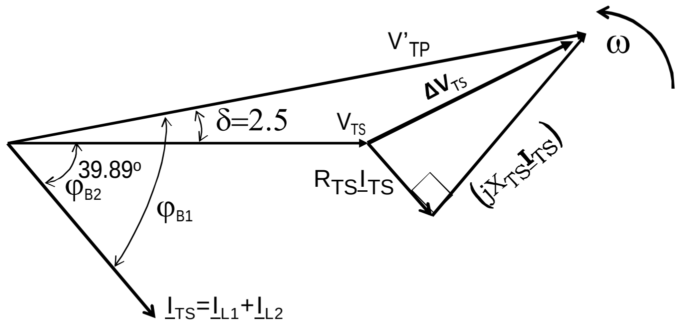
$\cos\varphi_{B2} = \cos(39.89) = 0.767$

Fundamentals of Power Systems

PROBLEMS

ANSWER

Fasor diagram @ LV



Fundamentals of Power Systems

PROBLEMS

QUESTION

The sub-transient synchronous reactance of a generator with a nominal value of 18 kV, 500 MVA is given as X"=0.25 pu. If the operations will be carried out at 20 kV, 100 MVA base values, what will be the pu value of the X" reactance at this new base?

ANSWER

First find actual value in Ohm

$$X''_{\Omega}=X''_{pu}Z_{B1} \Rightarrow X''_{\Omega}=0.25\left(\frac{18^2}{500}\right)$$

Calculate new pu value with the new base $Z_{B2}=\frac{20^2}{100}$

$$X''_{pu}=\frac{X''_{\Omega}}{Z_{B2}}=\frac{0.25\left(\frac{18^2}{500}\right)}{\frac{20^2}{100}}=0.25\left(\frac{18^2}{500}\right)\times\frac{100}{20^2}=0.0405$$

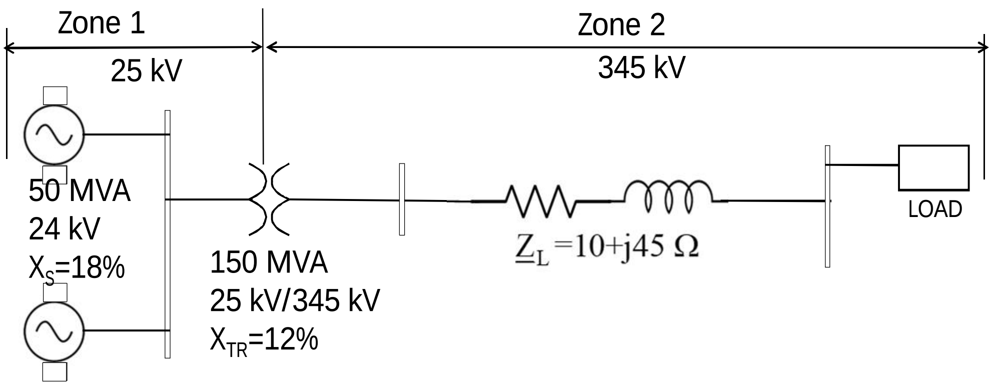
Fundamentals of Power Systems

PROBLEMS

QUESTION

A power system section with two voltage zones is given in the figure.

The base values to be studied can be chosen randomly. However, choosing one of the nominal label values or values close to one that will make the calculations easier.



Fundamentals of Power Systems

PROBLEMS

ANSWER

Select voltage and power base values for each zone.

ASIDE

Zone 1: S_{B1} = 100 MVA, V_{B1} = 25 kV

Zone 2: S_{B2} = 100 MVA, V_{B2} = 345 kV

Based on these base values, current and impedance base values can also be calculated.

For ZONE 1

$$I_{B1} = \frac{S_{B1}}{\sqrt{3}\ V_{B1}} = \frac{100\ \text{MVA}}{\sqrt{3}\ 25\ \text{kV}} = 2309\ \text{A} \qquad Z_{B1} = \frac{V_{B1}^2}{S_{B1}} = \frac{25^2}{100} = 6.25\ \Omega$$

For ZONE 2

$$I_{B2} = \frac{S_{B2}}{\sqrt{3}\ V_{B2}} = \frac{100\ \text{MVA}}{\sqrt{3}\ 345\ \text{kV}} = 167.3\ \text{A} \qquad Z_{B2} = \frac{V_{B2}^2}{S_{B2}} = \frac{345^2}{100} = 1190\ \Omega$$

Fundamentals of Power Systems

PROBLEMS

ANSWER

Converting pu or % values to Ohms

ASIDE

Generator and transformer impedances are given in % or pu. Their base values are calculated on the basis of nominal voltage and apparent power.

$$Z_B = \frac{V_N}{I_N} = \frac{V_N^2}{S_N} \quad \text{where} \quad S_N = I_N V_N$$

It is important to remember that the pu value is calculated by dividing actual value to the base value.

$$Z_{pu} = \frac{Z_{ACTUAL}}{Z_B} = Z_{ACTUAL}\left(\frac{S_N}{V_N^2}\right)$$

This equation can be arranged to obtain the actual value in Ohms from the pu value.

$$Z_{ACTUAL} = Z_{pu} Z_B = Z_{pu}\left(\frac{V_N^2}{S_N}\right)$$

Fundamentals of Power Systems

PROBLEMS

ANSWER

The impedance of the transmission line given in the question can be divided by Z_{B2} and converted to pu value. The impedance of the transmission line can be divided by Z_{B2} and converted to pu value.

$$Z_{pu} = \frac{Z_{ACTUAL}}{Z_B} = \frac{(10 + j45)\ \Omega}{1190\ \Omega}$$

$$Z_{pu} = (0.0084 + j0.0378)\ \text{pu} = (0.84 + j3.78)\ \%$$

Generator and transformer impedances are already given as % or pu. Their base values are the nominal values of the relevant unit. For example, the generator has an impedance of 18% with a base of 50 MVA and 25 kV. These values must be transferred to the new base.

One way to perform this transfer is to first convert the pu values to Ohm values and then divide them by the new base value.

Fundamentals of Power Systems

PROBLEMS

ANSWER

Ohm values of generator and transformer impedances:

$$Z_{G\Omega} = Z_{Gpu}\left(\frac{V_{GN}^2}{S_{GN}}\right) = j0.18\left(\frac{24^2}{50}\right) = j2.07\ \Omega$$

$$Z_{TR\Omega} = Z_{TRpu}\left(\frac{V_{TRN}^2}{S_{TRN}}\right) = j0.12\left(\frac{25^2}{150}\right) = j0.5\ \Omega$$

Now, these Ohm values are converted to pu values using the new bases;

$$Z_{Gpu} = \left(\frac{Z_{G\Omega}}{Z_{B1}}\right) = \frac{j2.07\ \Omega}{6.25} = j0.3312\ \text{pu} = j33.12\%$$

$$Z_{TRpu} = \left(\frac{Z_{TR\Omega}}{Z_{B1}}\right) = \frac{j0.5\ \Omega}{6.25\ \Omega} = j0.08\ \text{pu} = j8\%$$

Fundamentals of Power Systems

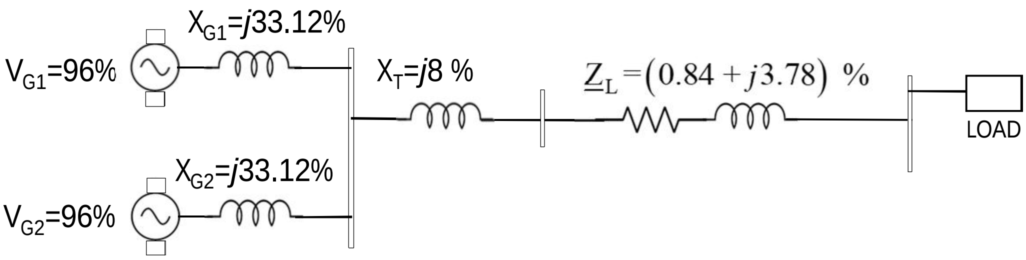
PROBLEMS

ANSWER

Pu value of generator voltage according to new base:

$$V_{Gpu} = \left(\frac{V_{GN}}{V_{B1}}\right) = \frac{24}{25} = 0.96 \text{ pu} = 96\%$$

New equivalent impedance circuit with pu and/or % values



Fundamentals of Power Systems

PROBLEMS

QUESTION

A large generator is connected to the grid via a transformer. This type of system is called a unit-linked system. The System data is given as:

Generator:	**450 MVA**	**25 kV**	**X_G= 85%**
Transformer:	**500 MVA**	**25 kV /120 kV**	**X_{TR}= 13 %**

Generator and transformer reactances are given in % at their nominal values. These need to be converted to Ohm values.

(a) Draw a single-line diagram of this system.

(b) Draw the equivalent circuit of this system by showing the impedances in Ohms.

(c) Draw the equivalent circuit of this system by showing the impedances with pu values at the base of 500 MVA .

(d) If a three-phase symmetrical short circuit occurs on the high voltage side of the transformer, what will be the value of the current flowing through the generator windings?

Elektrik Mühendisliğinin Genel Konuları

BAĞLANTI ŞEMALARI

Elektrik Mühendisliğinin Genel Konuları

BAĞLANTI ŞEMALARI

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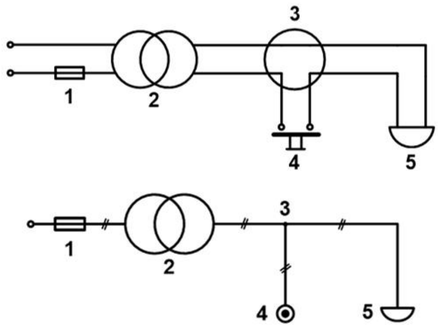
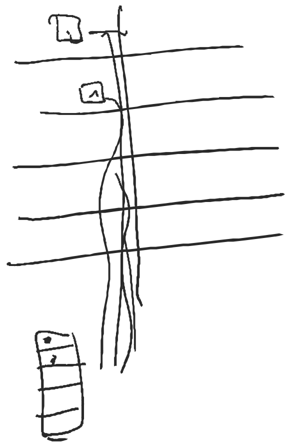


1. Sigorta
2. Zil transformatörü
3. Buat
4. Buton
5. Zil



Şekil. Zil Transformatörü üzerinden beslenen bir zil devresi

İç tesisat yönetmeliğine göre zil devresi, aydınlatma ve priz devresinden ayrı bir sigorta üzerinden beslenmelidir.

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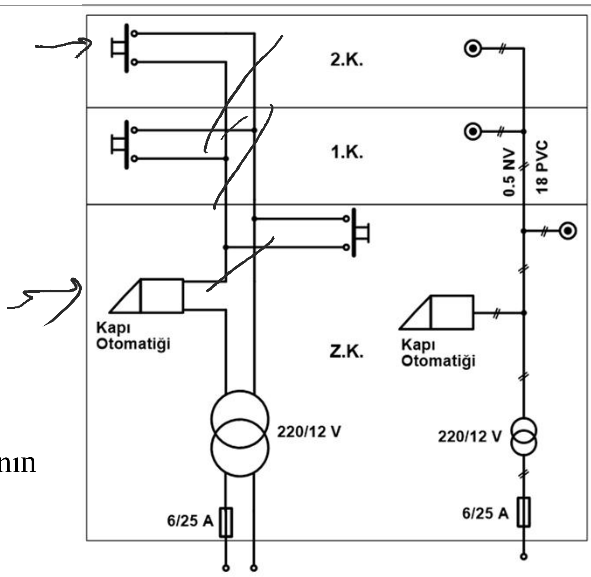

Şekil. Kapı otomatiği tesisatının açık ve kapalı şeması

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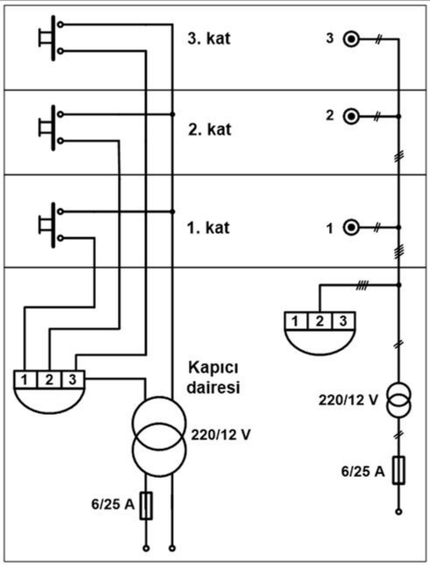

Şekil. Üç katlı bir evde kapıcıyı çağırmak için yapılan numaratör tesisatının açık ve kapalı şeması

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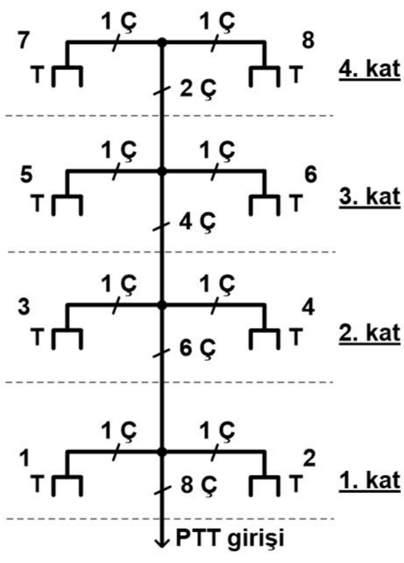

Şekil. Dört katlı çift daireli (8 aboneli) bir binanın telefon tesisatı

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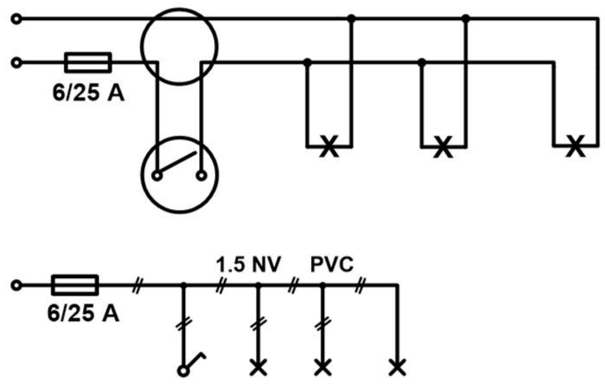

Şekil. Bir lambanın ve 3'lü bir grup lambanın adi anahtarla kumandasının açık ve kapalı şemaları

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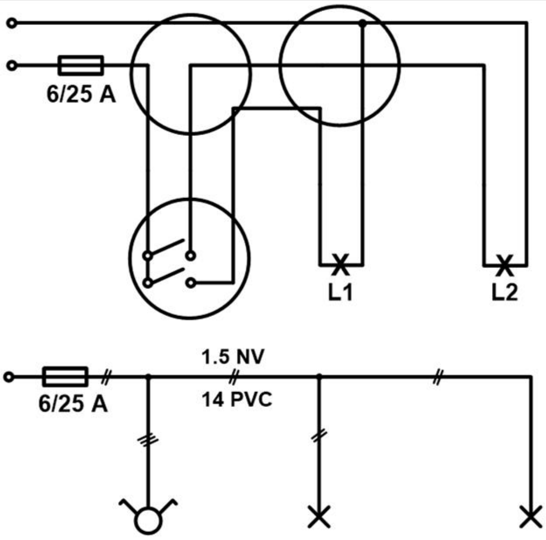

Şekil. Komütatör anahtarla yapılan tesisatın açık ve kapalı şeması

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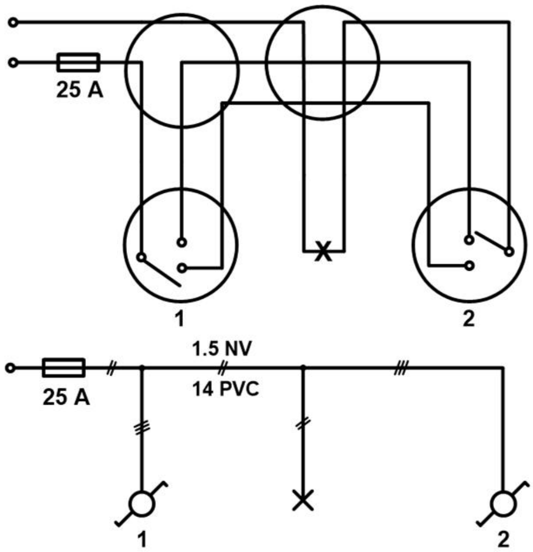

Şekil. Vaviyen anahtar tesisatının açık ve kapalı şeması

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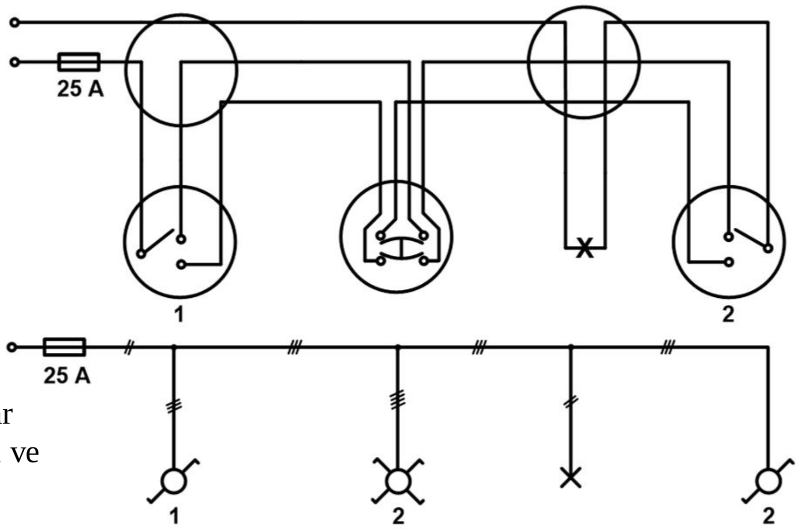

Şekil. Aravaviyen anahtar (Deviyatör) tesisatının açık ve kapalı şeması

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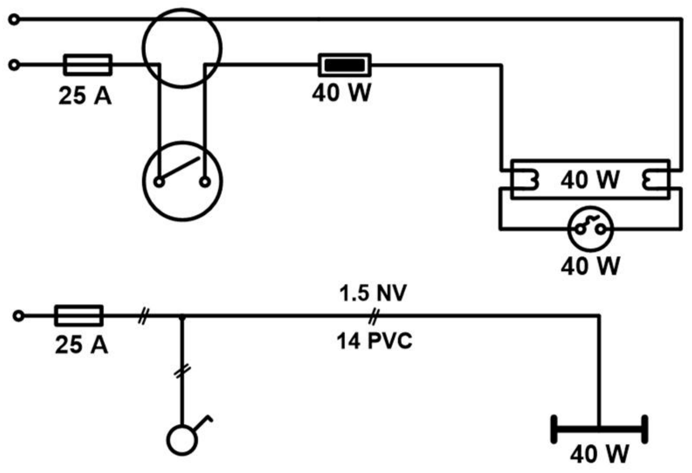

Şekil. Tek flüoresan lamba tesisatı

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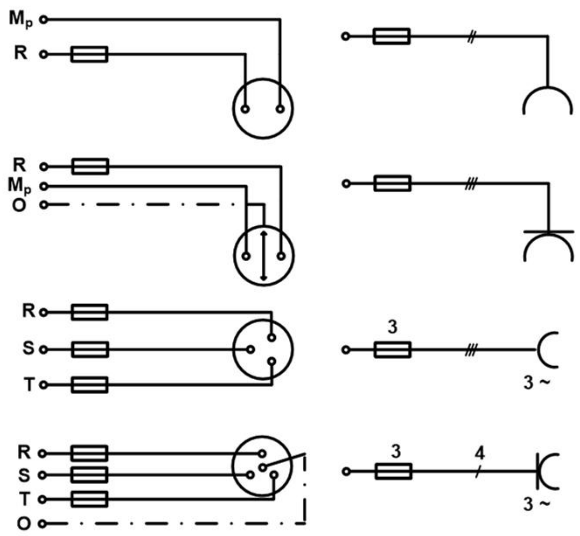

Şekil. Bir ve üç fazlı priz devrelerine ait topraksız ve topraklı şemalar

End of the Chapter:

Introduction