WROCLAW UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF ELECTRICAL ENGINEERING

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Lab1 &2 -Load flow in radial network with DER

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1. Exercise aim

The aim of this project is to acquire knowledge of the preparation of equivalent parameters of lines, cables and transformers which uses for load flow and voltage analysis for the given radial network in fig.1.

2. Exercise description

The given load variation for the given radial Network is 6 motors start (6S)

Induction motor voltage must not be less than 0.8UN and greater than 10.5 KV at the load bus. In each variation, the node load voltage should be changed to obtain the voltage 1.05UN, i.e., 10.5 kV at the feeder point.

3. Scheme of analyzed power system

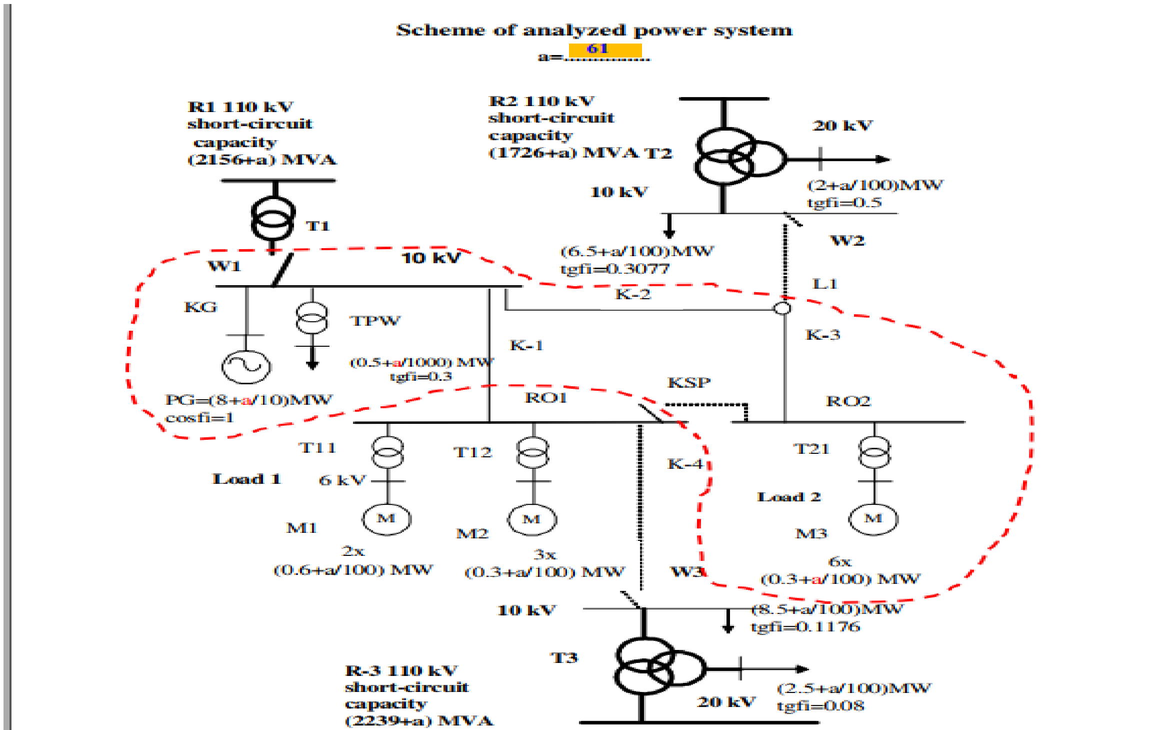


Fig.1 The scheme of MV network which can be supplied in 3 variations.

4. Calculation of system parameters for given a=61

1 Calculation of induction motor Parameters for $a = 61$

6 induction motors - 1 Pair of Poles

$$P_{Nm} = \left(0.3 + \frac{a}{100}\right) MW = \left(0.3 + \frac{61}{100}\right) = 0.91\ MW$$

$$U_{NM} = 0.5\ KV$$

$$\cos\phi_N = \left(0.83 + \frac{a}{1000}\right) = \left(0.83 + \frac{61}{1000}\right) = 0.891$$

$$\cos\phi_K = \left(0.3 + \frac{a}{1000}\right) = \left(0.3 + \frac{61}{1000}\right) = 0.361$$

$$\eta_N = 0.94$$

$$\eta_m = 0.97$$

$$K_{LR} = I_{LR}/I_{Nm} = \left(7 + \frac{a}{100}\right) = \left(7 + \frac{61}{100}\right) = 7.61$$

1 motor nominally loaded

$$P_N = \frac{P_{Nm}}{\eta_m} = \frac{0.91\ MW}{\eta_m} = \frac{0.91 MW}{0.97} = 0.938\ MW$$

$$S_N = \frac{P_N}{\cos\phi_N} = \frac{0.938 MW}{0.891} = 1.053\ MVA$$

1 motor during start

$$\sin\phi_K = \sqrt{1 - \cos^2\phi_K} = \sqrt{1 - 0.361^2} = 0.9326$$

$$P_K = K_{LR} S_N \cos\phi_K = 7.61 \times 1.053 \times 0.361 = 2.892\ MW$$

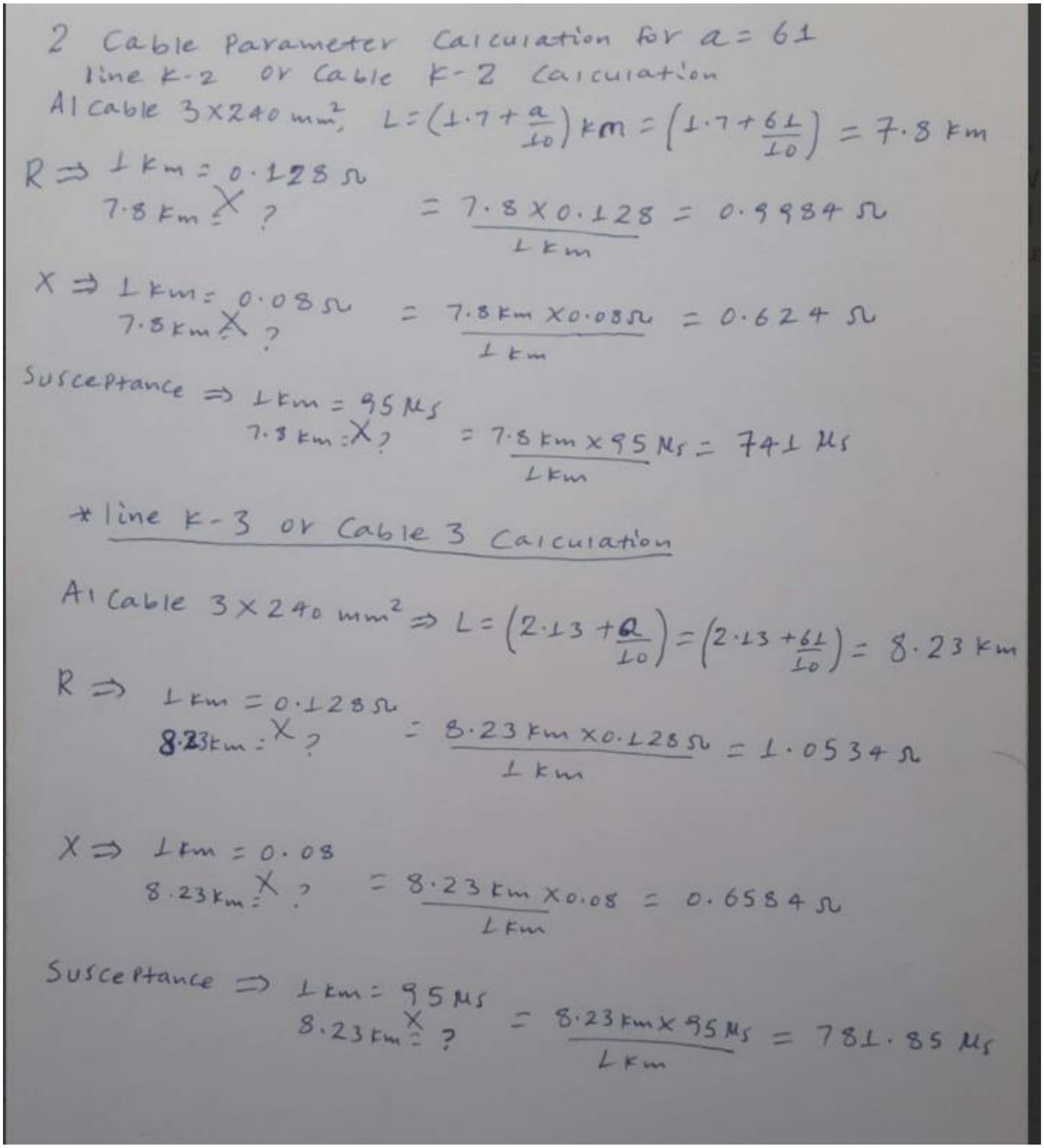
$$Q_K = K_{LR} S_N \sin\phi_K = 7.61 \times 1.053 \times 0.9326 = 7.47\ Mvar$$

* Given Load varation task for me is 6 motors during start (6S) so based on the above datas we can calculate the total active and reactive Power of the load as follows

$$P_{d MW} = 0 * P_N + 6 * P_K = 6 * 2.892 = 17.355\ MW$$

$$Q_{d Mvar} = 0 * Q_N + 6 * Q_K = 6 * 7.47 = 44.834\ Mvar$$

Figure 2: Motor parameter calculation



2 Cable Parameter Calculation for $a = 61$

line K-2 or Cable K-2 Calculation

Al cable $3 \times 240\ mm^2$, $L = (1.7 + \frac{a}{10})\ km = (1.7 + \frac{61}{10}) = 7.8\ km$

$R \Rightarrow 1\ km = 0.128\ \Omega$

$7.8\ km = X\ ?$ $\quad = \frac{7.8 \times 0.128}{1\ km} = 0.9984\ \Omega$

$X \Rightarrow 1\ km = 0.08\ \Omega$

$7.8\ km = X\ ?$ $\quad = \frac{7.8\ km \times 0.08\ \Omega}{1\ km} = 0.624\ \Omega$

Susceptance $\Rightarrow 1\ km = 95\ \mu s$

$7.8\ km = X\ ?$ $\quad = \frac{7.8\ km \times 95\ \mu s}{1\ km} = 741\ \mu s$

* line K-3 or Cable 3 Calculation

Al Cable $3 \times 240\ mm^2 \Rightarrow L = (2.13 + \frac{a}{10}) = (2.13 + \frac{61}{10}) = 8.23\ km$

$R \Rightarrow 1\ km = 0.128\ \Omega$

$8.23\ km = X\ ?$ $\quad = \frac{8.23\ km \times 0.128\ \Omega}{1\ km} = 1.0534\ \Omega$

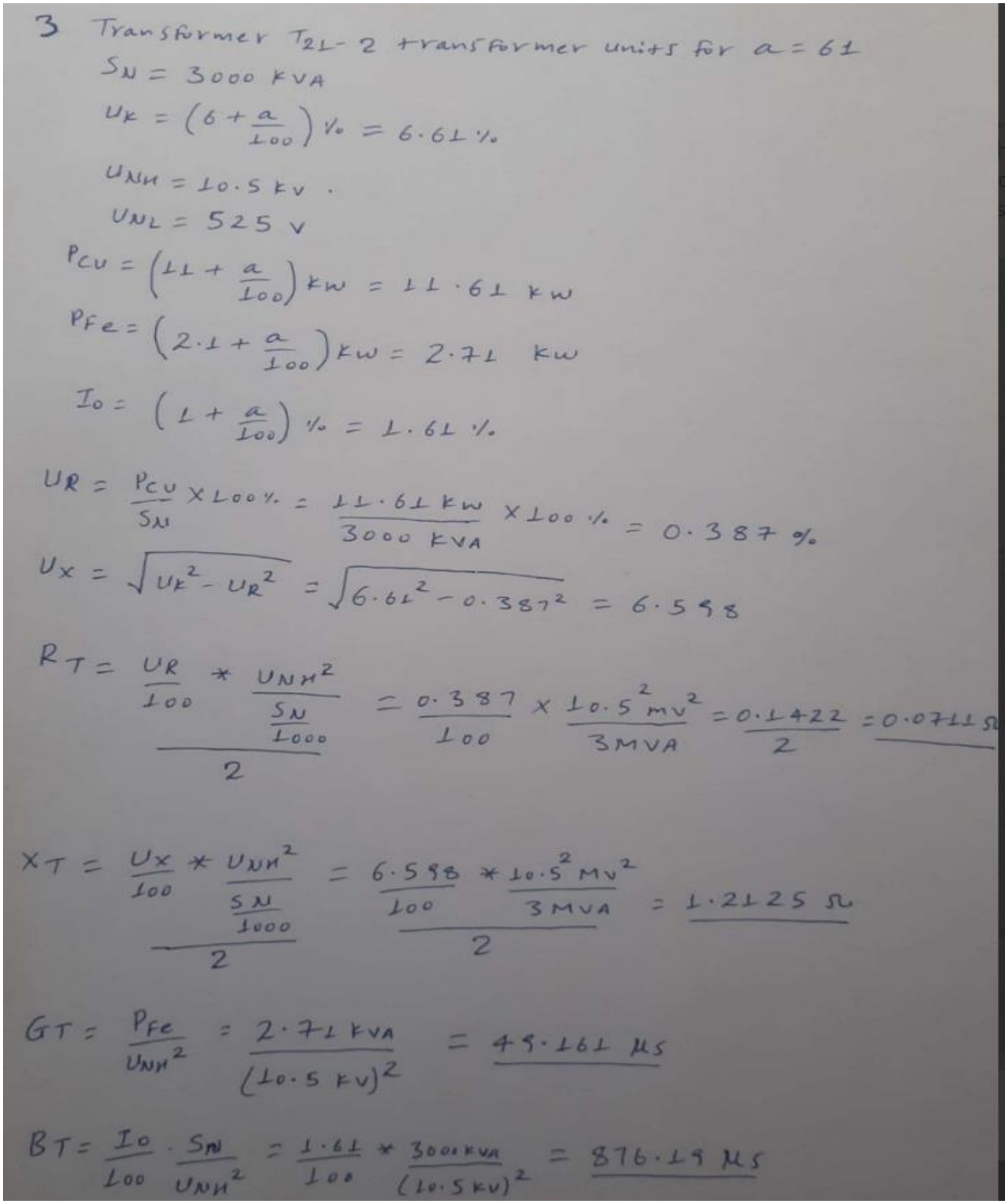
$X \Rightarrow 1\ km = 0.08$

$8.23\ km = X\ ?$ $\quad = \frac{8.23\ km \times 0.08}{1\ km} = 0.6584\ \Omega$

Susceptance $\Rightarrow 1\ km = 95\ \mu s$

$8.23\ km = X\ ?$ $\quad = \frac{8.23\ km \times 95\ \mu s}{1\ km} = 781.85\ \mu s$

Figure 3: Cable parameter calculation



3 Transformer T_{21} - 2 transformer units for $a = 61$

$S_N = 3000\ kVA$

$U_K = \left(6 + \frac{a}{100}\right)\% = 6.61\%$

$U_{NH} = 10.5\ kV$.

$U_{NL} = 525\ V$

$P_{CU} = \left(11 + \frac{a}{100}\right) kW = 11.61\ kW$

$P_{Fe} = \left(2.1 + \frac{a}{100}\right) kW = 2.71\ kW$

$I_0 = \left(1 + \frac{a}{100}\right)\% = 1.61\%$

$U_R = \frac{P_{CU}}{S_N} \times 100\% = \frac{11.61\ kW}{3000\ kVA} \times 100\% = 0.387\%$

$U_X = \sqrt{U_K^2 - U_R^2} = \sqrt{6.61^2 - 0.387^2} = 6.598$

$$R_T = \frac{\frac{U_R}{100} * \frac{U_{NH}^2}{\frac{S_N}{1000}}}{2} = \frac{\frac{0.387}{100} \times \frac{10.5^2\ MV^2}{3MVA}}{} = \frac{0.1422}{2} = \underline{0.0711\ \Omega}$$

$$X_T = \frac{\frac{U_X}{100} * \frac{U_{NH}^2}{\frac{S_N}{1000}}}{2} = \frac{\frac{6.598}{100} * \frac{10.5^2\ MV^2}{3MVA}}{2} = \underline{1.2125\ \Omega}$$

$$G_T = \frac{P_{Fe}}{U_{NH}^2} = \frac{2.71\ kVA}{(10.5\ kV)^2} = \underline{49.161\ \mu s}$$

$$B_T = \frac{I_0}{100} \cdot \frac{S_N}{U_{NH}^2} = \frac{1.61}{100} * \frac{3000\ kVA}{(10.5\ kV)^2} = \underline{876.19\ \mu s}$$

Figure 4: Transformer parameter calculation

5. Input data for a = 61

```
function [nodes,branches,UN,U]=erlfd61
UN=10.0; % nominal voltage of equivalent network
U =10.0; % voltage set at the load bus
%
 nodes=[
```

```
%   Pd(+)  - active load at node,
%   Pd(-)  - active injection at node
%   Qd(+)  - reactive load at node (inductive),
%   Qd(-)  - reactive injection at node (capacitive)
%   Un_kV  - nominal voltage of equivalent network
%   Uk_st  - voltage angle / zero before cload flow computing/
%Node   Un_kV    Uk_st      Pd_MW   Qd_Mvar
%   1       2    3           4      5
    1   10.00    0          17.355    44.834
    2   10.00    0          0          0
    3   10.00    0          0          0
    4   10.00    0          0          0
];
%
%
%
 branches=[
%   k - node number at pi-end, p - node number at pi-begin
%   Sp=Pp+jQp--->p____R____X____k----> Sk=Pk+jQk
%   Up/Ukp       |              |      Uk/Ukk
%                Yp             Yk
%                |              |
%   -------------------------------------------
%
%   R - resistance, X - reactance
%   Yp=G/2+jB/2 - shunt admittance at pi-begin
%   Yk=G/2+jB/2 - shunt admittance at pi-end
% NOTE! B>0 for line and B<0 for transformer
% Give G,B w mikrosimens with proper sign:
%  (-)minus for transformer,
%  (+)plus for line
% Program creates pi-circuit with G/2 and B/2 so give G nad B.
%   p   k   R_om         X_om        G_mikroS       B_mikroS
%   1   2    3             4           5              6
    2   1  0.071111     1.2125      49.161         -876.19
    3   2  1.0534       0.6584          0          781.85
    4   3  0.9984        0.624          0          741
];
 %

 return;
```

6. Load variations results

6.1 Load variation for 10 kv at the load bus

>> erlf

plikdat =

'erlfd61'

% Calculation stop: 2022- 5- 2 godz. 12h, 41min, 18.75s
Number of pi-circuits   npi =   3
Total bus number   n =   4
Nominal voltage of equivalent network UN =   10.000 kV
Voltage set at load bus   U =   10.000 kV

czwornik   2 -   1
Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar   Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar
15.656 6.6 19.0043 0.0060   72.661 -0.1074   10.000 0.0 17.3550 0.0025   44.834 -0.0438

czwornik   3 -   2
Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar   Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar
20.399 -5.0 43.1850 0.0000   87.516 -0.1627   15.656 6.6 19.0043 0.0000   72.661 -0.0958

czwornik   4 -   3
Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar   Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar
25.358-11.7 65.9701 0.0000 101.364 -0.2382   20.399 -5.0 43.1850 0.0000   87.516 -0.1542

node	UN_kV	U_kV	dU_%	Uk_st	P_MW	Q_MW
1	10.000	10.000	0.0	0.0	17.3550	44.8340
2	10.000	15.656	56.6	6.6	19.0043	72.6605
3	10.000	20.399	104.0	-5.0	43.1850	87.5155
4	10.000	25.358	153.6	-11.7	65.9701	101.3638

Active losses   Pstr =   48.615 MW
Transmission efficiency eta =   26.307 %

End of calculation by erlf.m - see results in file erlfout.m>>

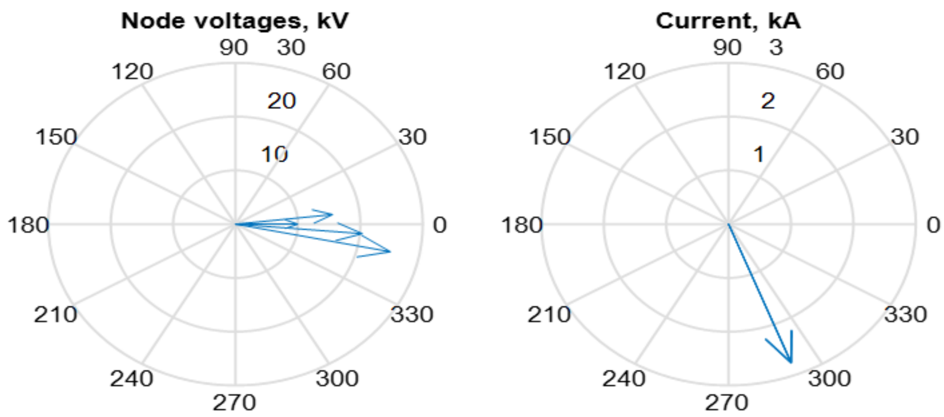


Figure 5: Node voltage and current results for 10 KV

6.2 Load variation for 10.5Kv at load bus

>> erlf

plikdat =

'erlfd61'

% Calculation stop: 2022- 5- 7 godz. 13h, 41min, 5.06s

Number of pi-circuits npi = 3

Total bus number n = 4

Nominal voltage of equivalent network UN = 10.000 kV

Voltage set at load bus U = 10.500 kV

czwornik 2 - 1

Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar

15.881 6.1 18.8520 0.0062 70.048 -0.1105 10.500 0.0 17.3550 0.0027 44.834 -0.0483

czwornik 3 - 2

Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar   Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar

20.399 -4.8 40.7736 0.0000   83.488 -0.1627   15.881 6.1 18.8520 0.0000   70.048 -0.0986

czwornik   4 -   3

Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar   Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar

25.104-11.2 61.4238 0.0000   96.006 -0.2335   20.399 -4.8 40.7736 0.0000   83.488 -0.1542

node	UN_kV	U_kV	dU_%	Uk_st	P_MW	Q_MW
1	10.000	10.500	0.0	0.0	17.3550	44.8340
2	10.000	15.881	58.8	6.1	18.8520	70.0475
3	10.000	20.399	104.0	-4.8	40.7736	83.4878
4	10.000	25.104	151.0	-11.2	61.4238	96.0065

Active losses   Pstr =   44.069 MW

Transmission efficiency eta =   28.255 %

End of calculation by erlf.m - see results in file erlfout.m>>

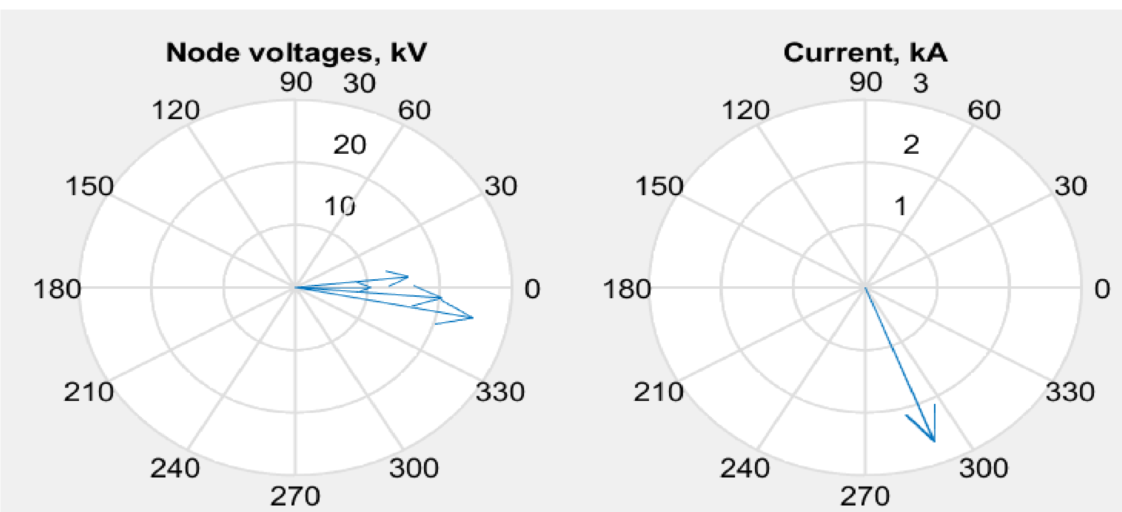


Figure 6: Node voltage and current results for 10.5 KV

6.3. Using the generator in bus 4 to increase transmission efficiency

In this case unlike the above two cases the generator in bus 4 will operate at power factor 1 (cosfi=1). The input data in this case will look like as shown below

```
 %Node    Un_kV     Uk_st       Pd_MW    Qd_Mvar

%    1        2     3            4          5
     1    10.00     0         17.355    44.834
     2    10.00     0           0          0
     3    10.00     0           0          0
     4    10.00     0          14.1        0
```

Because of this the transmission efficiency increase to a great extent comparing with the other two cases. The result is shown below.

\>> erlf

plikdat =

'erlfd61'

% Calculation stop: 2022- 5- 4 godz. 9h, 31min, 22.93s

Number of pi-circuits npi = 3

Total bus number n = 4

Nominal voltage of equivalent network UN = 10.000 kV

Voltage set at load bus U = 10.500 kV

czwornik 2 - 1

Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar

15.881 6.1 18.8520 0.0062 70.048 -0.1105 10.500 0.0 17.3550 0.0027 44.834 -0.0483

czwornik 3 - 2

Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar

20.399 -4.8 40.7736 0.0000 83.488 -0.1627 15.881 6.1 18.8520 0.0000 70.048 -0.0986

czwornik 4 - 3

Up_kV Ukp_st Pp_MW dPp_MW Qp_Mvar dQp_Mvar Uk_kV Ukk_st Pk_MW dPk_MW Qk_Mvar dQk_Mvar

25.104-11.2 61.4238 0.0000 96.006 -0.2335 20.399 -4.8 40.7736 0.0000 83.488 -0.1542

node	UN_kV	U_kV	dU_%	Uk_st	P_MW	Q_MW
1	10.000	10.500	0.0	0.0	17.3550	44.8340
2	10.000	15.881	58.8	6.1	18.8520	70.0475
3	10.000	20.399	104.0	-4.8	40.7736	83.4878
4	10.000	25.104	151.0	-11.2	75.5238	96.0065

Active losses Pstr = 44.069 MW

Transmission efficiency eta = 41.649 %

End of calculation by erlf.m - see results in file erlfout.m>>

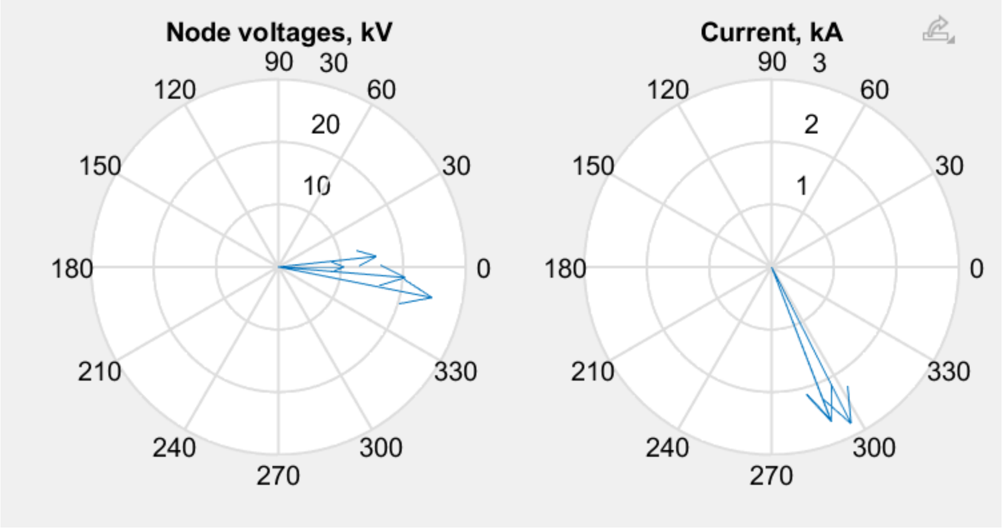


Figure 7: Node voltage and current results for 10.5 KV

7.Conclusion

Three different cases are selected to perform this task at the given load.

- The first case is performed at 10Kv at the load bus. At this voltage level, the active power losses is 48.615 MW, and transmission efficiency is 26.307 %
- The second case is performed for 10.5Kv load bus. At this voltage level, the active power losses is 44.069 MW and transmission efficiency is 28.255 %
- The third case is performed with the generator in bus 4 operating to increase the transmission efficiency. While the active power losses is still the same (44.069 MW) because the generator is operating at power factor 1, but the transmission efficiency is this time 41.649 %. Which is big improvement compared with the above two cases in which the generator was not operating.

An important point to note is, as the voltage in the load bus increases the transmission efficiency increases and the active power loss decreases. Moreover, the transmission efficiency increases when the generator in bus 4 operates at good power factor as it was demonstrated in case 3.

In summary, it is observed that as the load varies the receiving end voltage varies. Moreover, getting a 10.5Kv supply voltage is impossible due to the very high reactive power demand since all 6 motors are starting in this case, which requires 17.355Mw active and 44.834 Mvar reactive power. This very high reactive power demand shows that a very high voltage is required to increase the transmission efficiency and decrease the active losses. However, we cannot increase the voltage in the load bus as we want since it demands a high voltage. Which is above the nominal, in the supply.