National University of Science and Technology POLITEHNICA Bucharest
Faculty of Energy Engineering
Department of Electrical Power Systems

Academic year
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MS16 – IDG

Laboratory task

Discipline **The impact of distributed generation on electrical networks**

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1. Framework

It is considered that the urban electricity distribution network presented in Figure 1 feeds a consumption area.

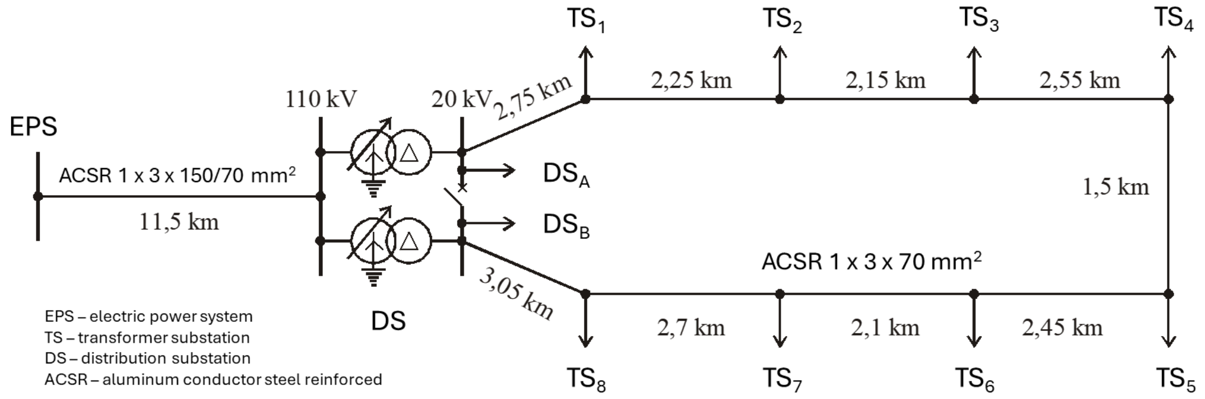


Fig.1.1. Base Looped Configuration Single-wire diagram of the electrical distribution network.

In normal operation, the electrical distribution network is operated in radial configuration. The unlooping of the medium voltage network is done by disconnecting the section between the load **TS2and TS3**. Furthermore, in the medium voltage electrical network, a distributed generation source with an installed capacity of 3.5 MW will be placed, located at a distance of 1.5 km from the **TS6 load**. as showned below in figure 2.

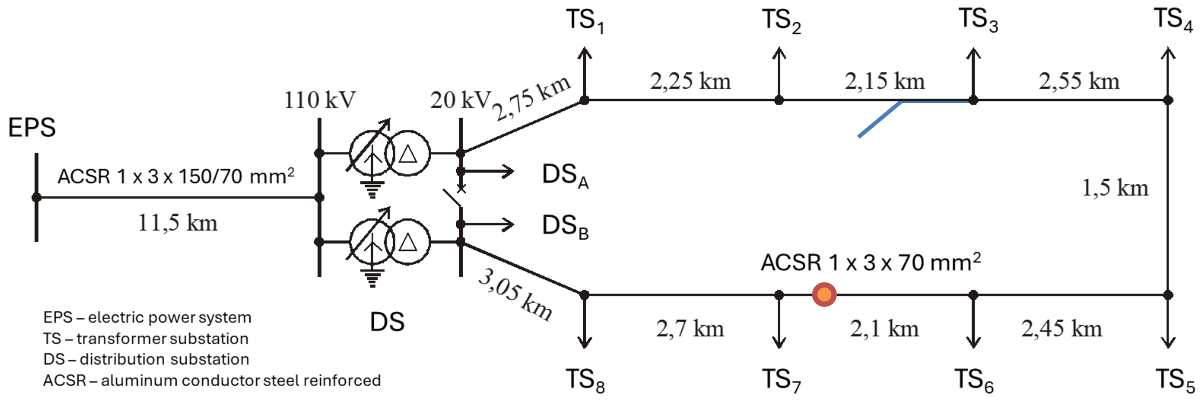


Fig.1.2. Radial Unlopped Configuration Single-wire diagram of the electrical distribution network.

The parameters of the power transformers in the distribution substation are shown in Table 1, and the parameters of the power lines are presented in Table 2. Table 3 shows the maximum powers required by loads.

Table 1. Power Transformer Parameters.

S_n	V^{HV}/V^{MV}	ΔP_{sc}	ΔP_0	u_{kr}	i_0
[MVA]	[kV/kV]	[kW]	[kW]	[%]	[%]
25	(110 ± 9 x 1,78%) / 20	140	20	10.5	1,0

Table 2. Power lines Parameters

U_n	s_n	r	x	b	I_{adm}
[kV]	[mm^2]	[Ω/km]	[Ω/km]	[μS/km]	[A]
110	150/70	0,193	0,417	2,684	425
20	70	0,437	0,343	3,209	265

Table 3. Characteristics of network loads.

Load	***S* [kVA]**	**cos(φ)**	**Location**
L_A	6000	0,89	DS_A
L_B	5000	0,90	DS_B
L_1	2150	0,76	TS3
L_2	2300	0,74	TS5
L_3	2200	0,72	TS7
L_4	600	0,89	TS2
L_5	400	0,88	TS4
L_6	300	0,87	TS6
L_7	600	0,90	TS8
L_8	500	0,91	TS1

The supply busbar represented by the national electric power system (EPS) is characterized by:

- the voltage level is equal to $1.03U_n$;
- short circuit power: 2150 MVA.

2. Objectives

For improving the power flow of the electical distribution network, reactive power compensation is pursued so that the neutral power factor reaches 0.9. Additionally, the optimal configuration of the medium voltage electrical network is aimed to be established through reconfiguration.

In order to integrate the distributed source into the electrical network, two solutions will be developed:

- Solution 1: direct connection to the 20 kV medium voltage line;
- Solution 2: connection to the 20 kV busbars of the electrical transformer station.

For each connection solution, the following aspects will be analysed.:

- Analysis of power flow and power losses through the network branches for different operating modes of the distributed source;
- Analysis of slow and rapid voltage variations during connection and disconnection of the distributed source; in this regard, it is considered that another power source with a power of 5 MW is also connected to the MV busbar of the transformer station to which the distributed source is connected;
- Determination of the optimal power generated by the distributed source to minimize active power losses;
- Determination of the maximum power that can be generated by the distributed source by considering the maximum allowable loading and the voltage level;
- Application of voltage regulation mechanisms to achieve a voltage level of 21 kV on the MV busbar of the power transformer;
- Analysis of the influence of the distributed source on short-circuit currents (considering maximum and minimum operating modes);
- Determination of the optimal configuration of the medium voltage electrical network through reconfiguration in the presence of the distributed source;
- Determination of the optimal number of transformers in parallel, depending on the operating modes of the distributed source;
- Calculation of harmonic emissions at the PCC (Point of Common Coupling);
- Analysis of the operating conditions of the distribution power network for topologies with $N-1$ elements in operation (power line/power transformer loading, voltage level, slow and rapid voltage variations), for Solution 1.

3. Improving power flow of the electrical distribution network

Input data

The study will be carried out considering the electrical distribution network presented in Figure 1.1, which was simulated in the software NEPLAN, as follows:

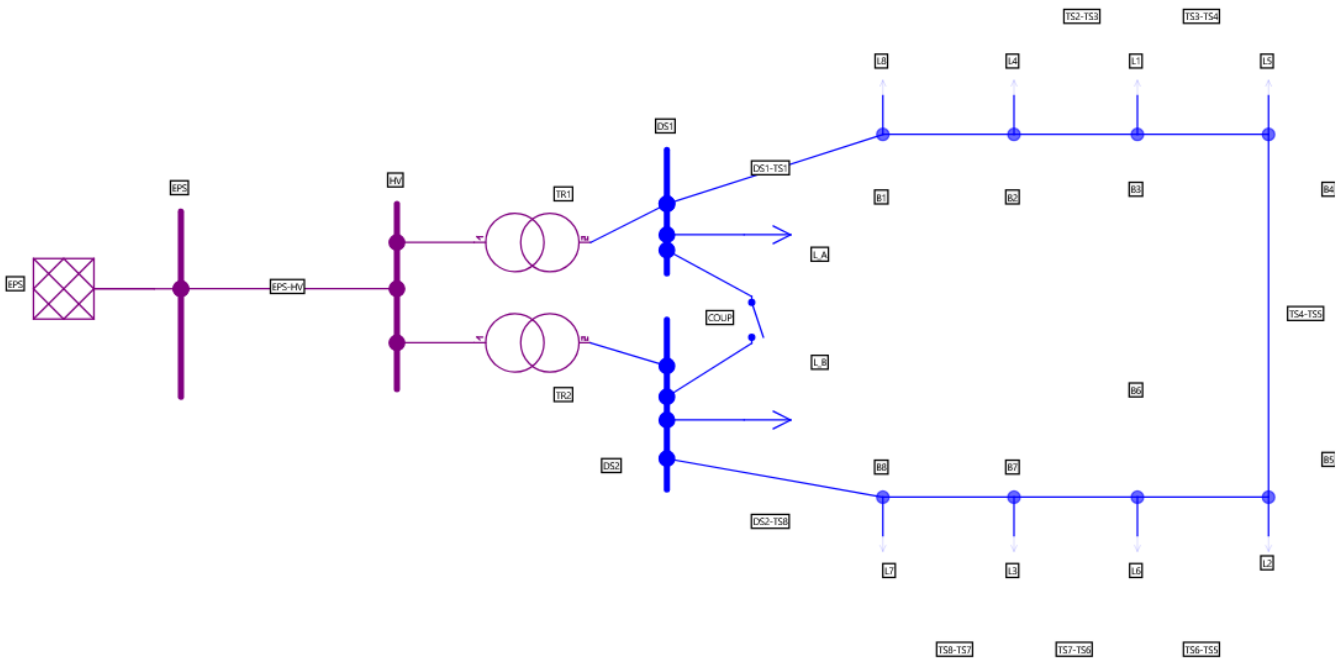


Fig. 3.1. Neplan diagram of the analysed electrical distribution network.

Table 3.1. *Load characteristics (active, reactive, apparent power)*

Load	S [kVA]	cos ϕ	Location	P [kW]	Q [kVAr]
LA	6000	0.89	DSA	5340	2735.763
LB	5000	0.9	DSB	4500	2179.45
L8	500	0.91	TS1	455	207.3041
L4	600	0.89	TS2	534	273.5763
L1	2150	0.76	TS3	1634	1397.335
L5	400	0.88	TS4	352	189.9895
L2	2300	0.74	TS5	1702	1546.996
L6	300	0.87	TS6	261	147.9155
L3	2200	0.72	TS7	1584	1526.743
L7	600	0.9	TS8	540	261.5339

For initial alarms in the operation of the network, measures to eliminate these problems were proposed for the personal load distribution configuration.

- For power lines overloading, it is necessary to modify the section of the conductors for the power line (a larger section was chosen, with a higher permissible current, I_{adm})

Table 3.2. *Parameters of power lines with aluminium conductors*

s_n	r_0	x_0	b_0	I_{adm}
[mm^2]	[Ω/km]	[Ω/km]	[μS/km]	[A]
25	1.400	0.122	58	95
35	1.000	0.112	58	110
50	0.703	0.106	58	135
70	-	-	-	**165**
95	0.389	0.097	58	195
120	0.293	0.095	58	225
150	0.234	0.092	58	250
185*	20KV-VPE-AI-L	20KV-VPE-AI-L	20KV-VPE-AI-L	310

**** To note that the 185mm2 conductor is no longer typically used at distribution level.***

3.1 Enhancement of overloaded lines by conductor sizing

Starting with a network with the power line parameters of Table 1, the conductors start with an initial cross section of 70mm2 and an admissible current of 165 A. Placing the load distribution assigned in this studies, the steady-state power flow was carried out both for the electricity network operated in *radial configuration* (by disconnecting the section between consumers TS2 and TS3) and in *looped configuration*, obtaining the following information in Fig. 3.2 and 3.3.

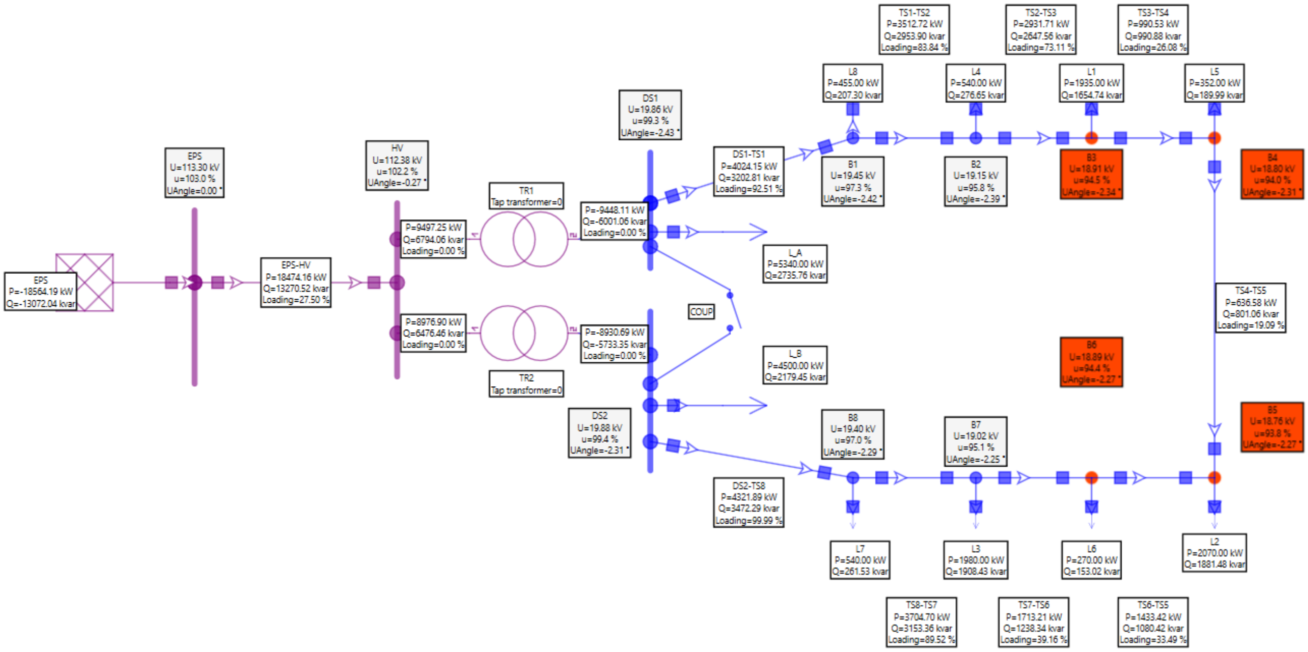


Fig. 3.1.2. Neplan Looped Load Flow Results

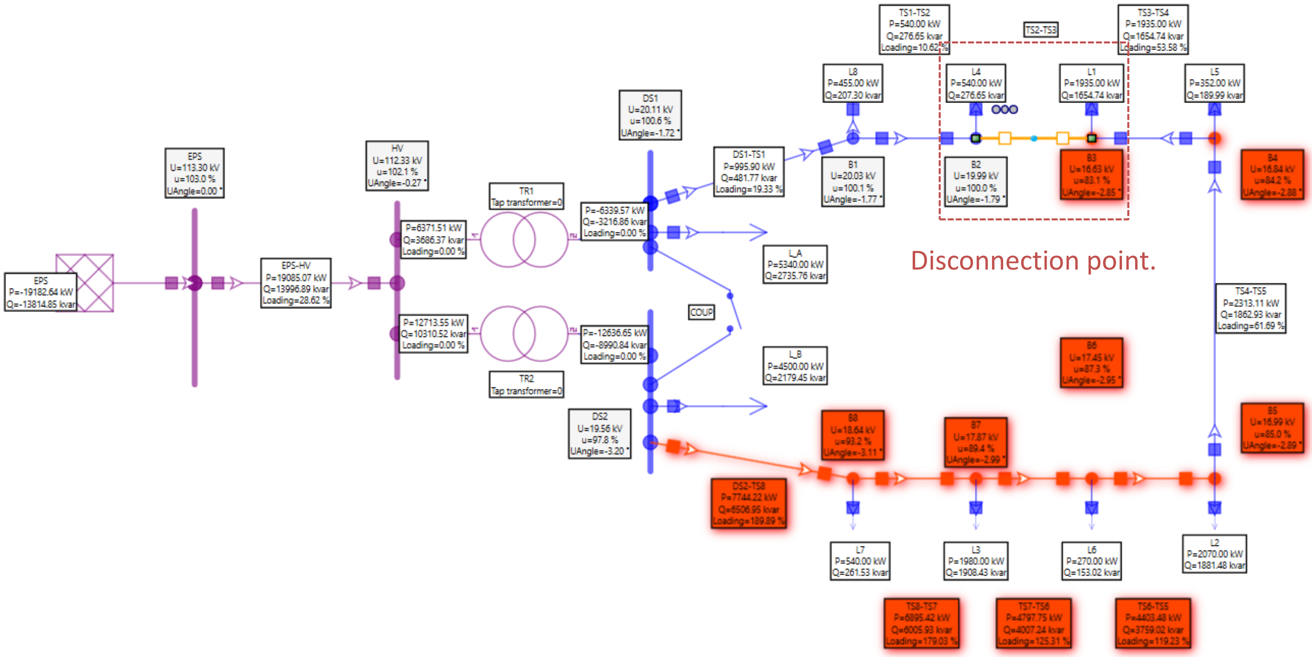


Fig. 3.1.3. Neplan Radial Load Flow Results.

The results obtained from the steady-state calculation were extracted in the form of graphs for the following:

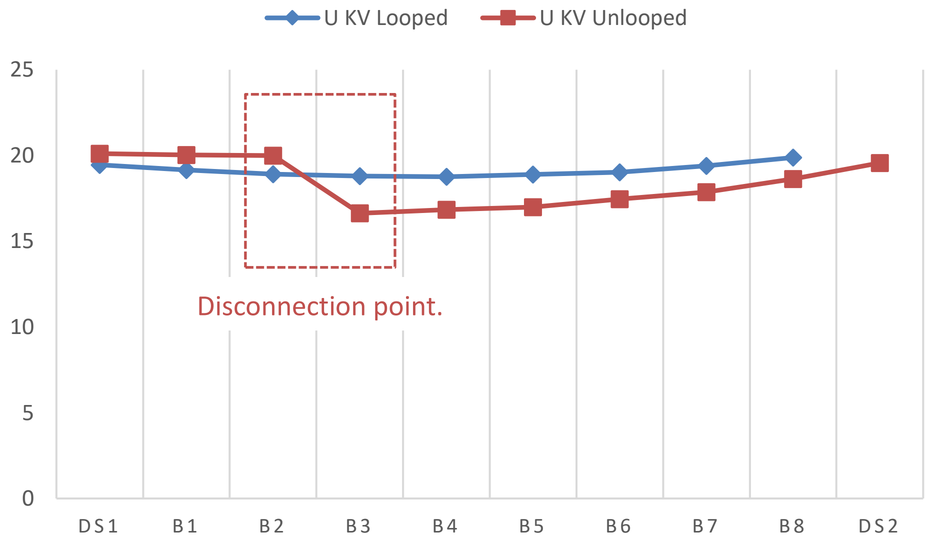


Fig. 3.1.4. Bus voltages on the medium voltage side.

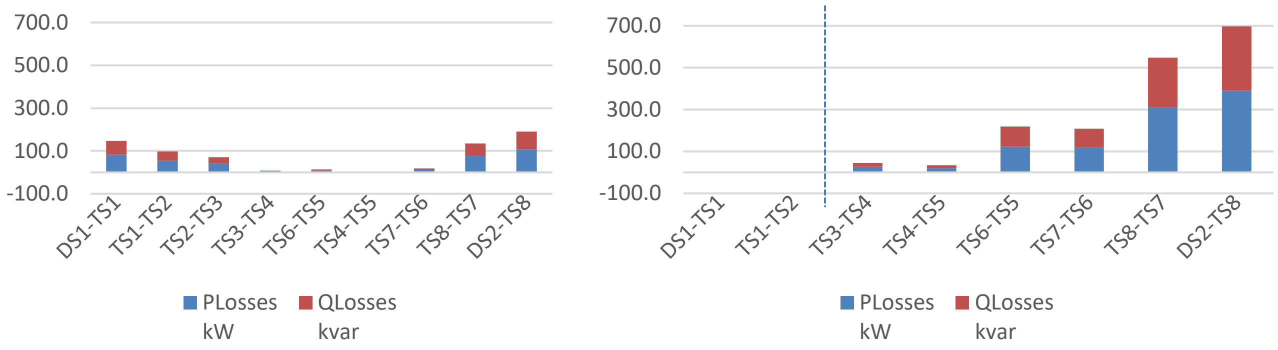


Fig. 3.1.5. Total power losses in the network (a) Looped configuration, (b) Unlopped Radial Configuration.

The comparison was performed in terms of medium-voltage bus magnitudes (in kV and p.u.) and total active and reactive power losses per line section, allowing a direct assessment of voltage profile improvement and loss reduction.

When operating in radial configuration (unlopped), 4 power lines are overloaded, thus, a first enhancement will be increasing progressively the transversal area of the conductor modifying only the overloaded lines with parameters from table 2.2. The following modifications were made until the desired and optimal result was obtained:

- From 70mm2 to 95mm2 in the four overloaded lines, only the line TS5-TS6 was enhanced. From 119.23% to 99.95% loading.
- From 95mm2 to 120mm2 in the three overloaded lines, line TS6-TS7 was enhanced.
- From 120 to 185mm2 from the library 20KV-VPE-AI-L, lines DS2-TS8 and TS8-TS7 were finally enhanced up to complying levels.

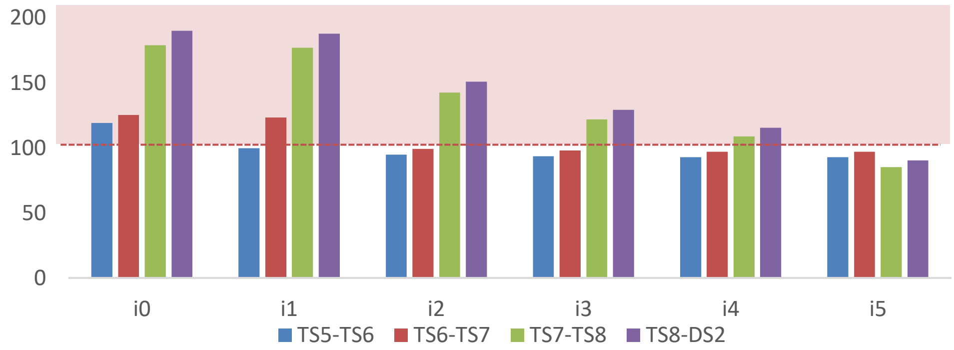


Fig. 3.6. Iterative adjustment of conductors.

With this enhancements, the results of the power flow for radial configuration are as follows:

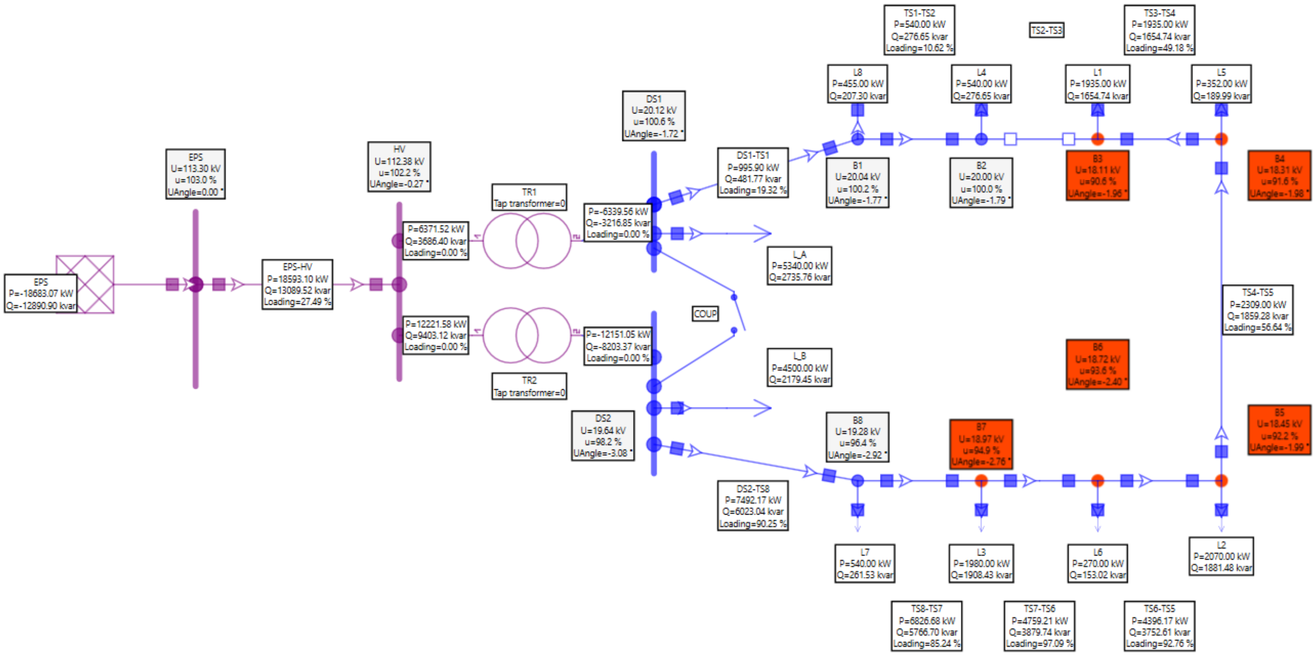


Fig. 3.1.7. Conductor Enhanced Radial Load Flow Results.

In normal operation, the electrical distribution network is operated in a *radial configuration* to reduce the effect of faults and simplify the coordination of protection systems. The purpose of improving the power flow consists of technical measures aimed at reducing active power losses in the network.

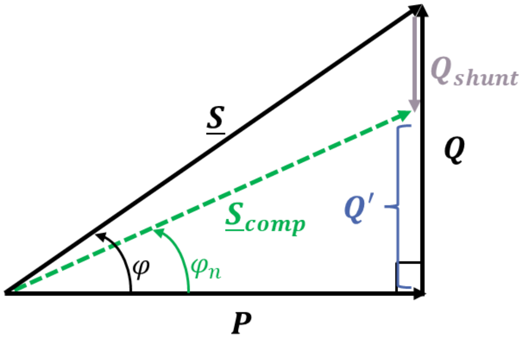
In the initial radial configuration, the following measures to reduce power losses are successively applied

3.2 Enhancement by **reactive power compensation PF>0.9**

Reactive power compensation is performed in order to obtain the neutral power factor ($cos\varphi_n$=0.9). For the purpose of compensating the reactive power, the parameters of a *shunt compensation coil* shall be determined by calculation.

$$\begin{cases} cos\varphi = \frac{P}{S} \\ sin\varphi = \frac{Q}{S} \end{cases} \Rightarrow \ tan\varphi = \frac{Q}{P}$$

$$Q_{shunt} = Q - P \cdot tan\varphi_n$$



$$tan\varphi_n = \frac{Q-Q_{BC}}{P}$$

As $Q = P \cdot tg\varphi \rightarrow Q_{shunt} = P \cdot (tg\varphi - tg\varphi_n)$

Example of calculation for the load L_1

S= 2150 kVA, cos φ = 0.76

P = S x cos ϕ = 2150 x 0.76= 1634 kW

$Q_{shunt} = P \cdot (tg\varphi - tg\varphi_n)$ = 1634 (tan (acos(cosφ))-tan(acos(cosφ_n))) = 605.95 kVAr

$Q_{init} = \sqrt{S^2 - P^2} = \sqrt{2150^2 - 1634^2} = 1397.33\ kVAr$

$Q_{comp} = Q_{init} - Q_{shunt} = 1397.33 - 370.82 = 791.38\ kVAr$

For loads whose power factor, cosφ, exceeds the value 0.9 no measures will be applied.

The power needed to be compensated for each consumer will be calculated individually, and the results will be centralized in Table 3.3.

Table 3.3 Reactive power before and after compensation at load buses

Load	S [kVA]	cos φ [-]	P [kW]	Q_{init} [kVAr]	Q_{shunt} [kVAr]	Q_{comp} [kVAr]
LA	6000	0.89	5340	2735.76	2615.339	120.42
L1	2150	0.76	1634	1397.34	937.163	460.17
L2	2300	0.74	1702	1547.00	1002.547	544.45
L3	2200	0.72	1584	1526.74	958.958	567.79
L4	600	0.89	534	273.58	261.534	12.04
L5	400	0.88	352	189.99	170.481	19.51
L6	300	0.87	261	147.92	130.767	17.15
LB	5000	0.9	4500	2179.45	2179.449	0.00
L7	600	0.9	540	261.53	261.534	0.00
L8	500	0.91	455	207.30	207.304	0.00

*To note that loads LB, L7 and L8 were not compensated since its original power factor is greater or equal to 0.9.

- The bus LF-type will change from type SC to type PC, maintaining the same value for the active power P. Fill in the cosφ field with the value of the neutral power factor (0.9), and the value calculated by the program for the reactive power Q will represent the reactive power after compensation, Q_{comp};

- Based on the results extracted from the Neplan program, the power required to be compensated will be calculated as the difference between Q_{init} and Q_{comp}.

Following the operation of the compensated power grid, the data for active power losses on the medium voltage side will be extracted and interpreted.

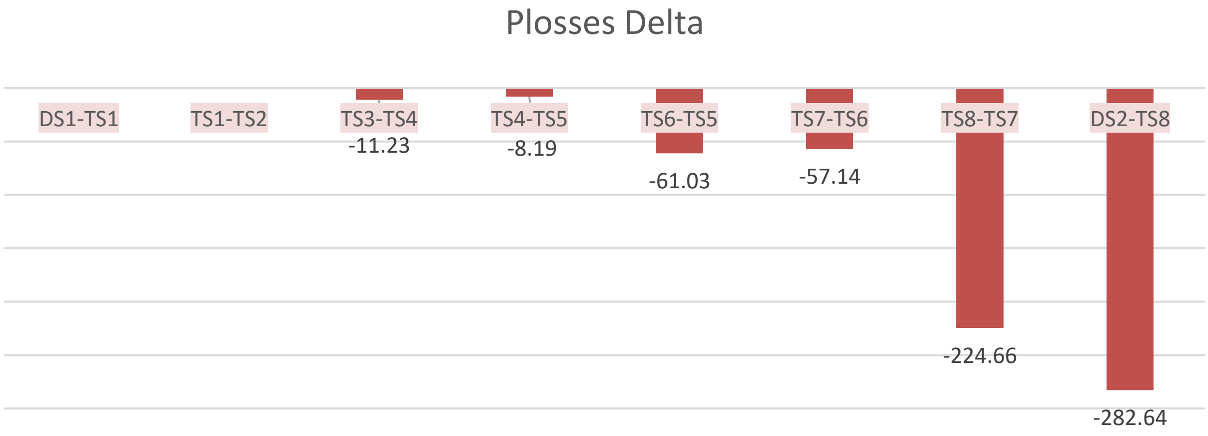


Fig. 3.2.1. Difference of Active Power Losses per line.

After applying reactive power compensation to reach an equivalent power factor of cosϕ ≈ 0.9 at the load buses, the reactive power flow in the network is reduced, leading to lower line currents and a noticeable decrease in active power losses, especially on the downstream feeders supplying highly inductive loads. At the same time, the voltage profile on the MV buses improves, with the lowest bus voltages increasing and remaining closer to the nominal value, particularly at the end of the feeders, confirming the positive impact of PF correction on both losses and voltage levels.

3.3 Determining the optimal configuration of the power grid by reconfiguration

To determine the optimal configuration of the distribution power network, the starting point is considering loop configuration in which the reactive power compensation has been achieved.

This case study aims to determine the section that needs to be disconnected, so that active power losses are minimal. The determination of this section will be done by tests, disconnecting one section at a time and running the power flow analysis for each radial configuration thus obtained. The optimal configuration will involve disconnecting the section that corresponds to the minimum total active power losses.

During the runs, other electrical quantities influenced by the reconfiguration process are also monitored, such as bus voltages and currents through the power line.

Table 3.3.1. Results obtained from the disconnection of a section, from original set (lopped) and no enhancements.

Disconnected section	**ΔP [kW]**	**U_{min} [%] and location**	**U_{max} [%] and location**	**I_{max} [%]**
None (initial radial)	582.19	93.782 – B5	~100.0 – DS1	—
TS1–TS2	1424	80.917 – B2	~100.5 – B1	205.989 – DS2–TS8
TS2–TS3	1189	83.169 – B3	~100.5 – B1	189.829 – DS2–TS8
TS3–TS4	655.62	90.818 – B4	~99.8 – DS1	129.145 – DS2–TS8
TS4–TS5	**621.36**	**91.702 – B5**	**~99.9 – B8**	**120.814 – DS2–TS8**
TS5–TS6	695.45	89.856 – B5	~100.0 – DS1	130.348 – DS1–TS1
TS6–TS7	738.66	89.044 – B6	~100.0 – DS1	137.149 – DS1–TS1
TS7–TS8	1550	79.411 – B7	~100.0 – DS1	207.565 – DS1–TS1
DS2–TS8	1853	76.733 – B8	~100.1 – DS2	225.419 – DS1–TS1
DS1–TS1	1645	78.795 – B1	100.8 – DS1	220.029 – DS2–TS8

Table 3.3.2. Results obtained from the disconnection of a section, from radial unlopped and previous enhancements.

Disconnected section	**ΔP [kW]**	**U_{min} [%] and location**	**U_{max} [%] and location**	**I_{max} [%]**
TS2–TS3 *(lab-required)*	**355.3**	**93.01 – B3**	~101 – DS1	< 100
TS3–TS4	358.2	91.91 – B3	~101 – DS1	< 100
TS4–TS5	**354.3**	**92.94 – B4**	**~101 – DS1**	< 100
TS5–TS6	491.9	92.42 – B5	~101 – DS1	101.9 (TS1–TS2)
TS6–TS7	528.1	91.87 – B5	~101 – DS1	107.7 (TS1–TS2)
TS7–TS8	1004	86.21 – B6	~101 – DS1	166.6 (DS1–TS1)
DS2–TS8	1197	83.80 – B8	~101 – DS2	181.2 (DS1–TS1)
TS1–DS1	698.7	90.44 – B1	~101 – DS1	100.2

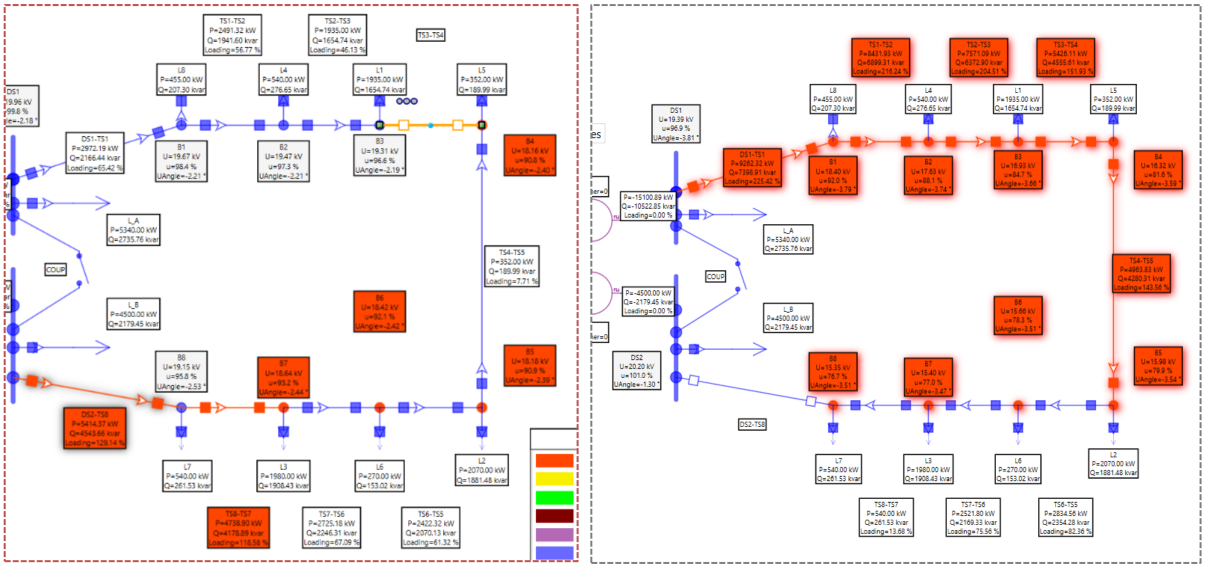


Fig. 3.3.2. Lopped Configuration Disconnection (a) Least power losses over the system. (b) Most Power Losses

over the system.

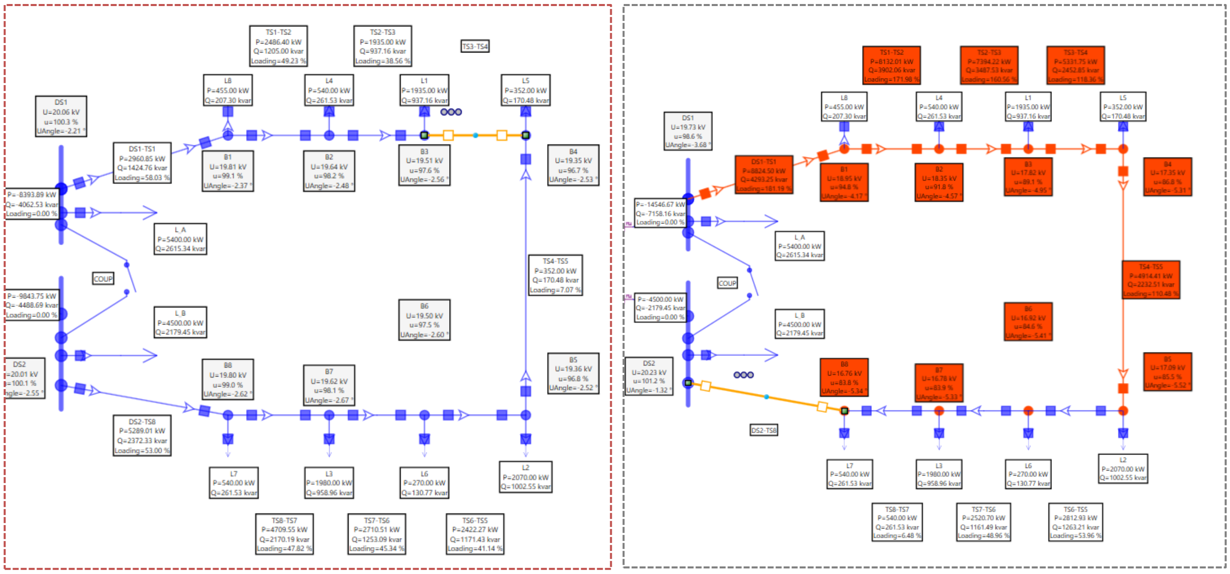


Fig. 3.3.3. Unlopped Configuration Disconnection with enhancements (a) Least power losses over the system. (b) Most Power Losses over the system.

Other configurations such as TS3–TS4 and TS4–TS5 exhibit similar loss levels; however, they are not aligned with the prescribed operating condition. Disconnections farther from the source (e.g., TS7–TS8 and DS2–TS8) result in significantly higher losses, severe overloading, and unacceptable voltage drops, indicating poor power flow distribution and reduced network robustness. Therefore, TS2–TS3 is confirmed as the optimal and compliant radial configuration, achieving a good compromise between loss minimization, thermal limits, and voltage profile, and is selected as the reference case for further analysis.

4. Further Improvement of power flow

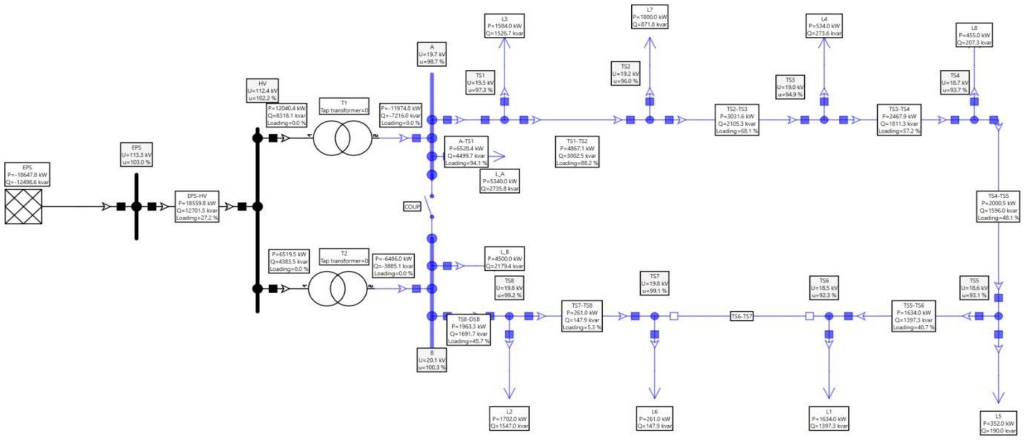


Fig. 4.1 Example of analyzed distribution power network in Neplan.

Further measures to reduce power losses:

4.1 optimal transformer number connected in parallel, to reduce active power losses
4.2 adjustment of transformer taps for a required voltage level
4.3 optimal operating tap to reduce active power losses
4.4 determining the optimal location of a distributed source to reduce active power losses

4.1 Optimal number of transformers in parallel

The technical criterion of the optimal number of transformers is based on the reduction of power losses in the transformer substation.

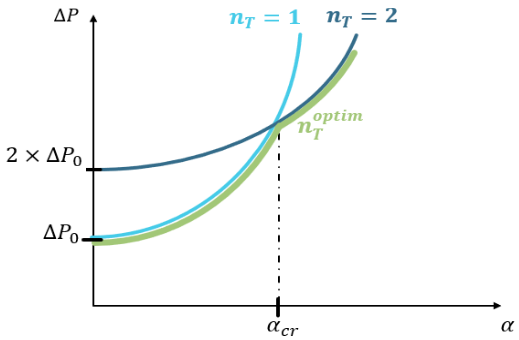


Fig. 4.1.1 Variation of power losses as function of the number of transformers in parallel

After comparing the value of the two coefficients (α and α_{cr}) the optimal number of transformers in parallel operation will be determined based on:

- If $\alpha < \alpha_{cr}$ -> it is more economical to operate with a single power transformer.
- If $\alpha > \alpha_{cr}$ -> it is more economical to operate with two power transformers in parallel.

The optimal number of transformers operating in parallel was evaluated based on the minimization of active power losses in the substation. The analysis was performed considering the **radial configuration obtained by opening the section TS2–TS3**, which divides the distribution network into two independent branches supplied by two transformers.

After disconnecting the line **TS2–TS3**, the network is separated as follows:

- **Branch A (Transformer TR1)** supplies the loads connected from **DS1 to TS2**, namely:
  - LA (DSA)
  - L8 (TS1)
  - L4 (TS2)

The total apparent power of branch A is: $S_A = 6000 + 500 + 600 = 7100$ kVA

- **Branch B (Transformer TR2)** supplies the loads connected from **TS3 to DS2**, namely:
  - LB (DSB)
  - L1 (TS3)
  - L5 (TS4)
  - L2 (TS5)
  - L6 (TS6)

- L3 (TS7)
- L7 (TS8)

The total apparent power of branch B is: $S_B = 5000 + 2150 + 400 + 2300 + 300 + 2200 + 600 = 12950$ kVA

The total apparent power of the distribution network is therefore:

$$S_{net} = S_A + S_B = 7100 + 12950 = 20050 \text{ kVA}$$

The substation loading coefficient is calculated as:

$$\alpha = \frac{S_{net}}{S_{nT}} = \frac{20050}{25000} = 0.802$$

Using transformer parameters from Table 1, the critical loading coefficient is:

$$\alpha_{cr} = \sqrt{n_T(n_T - 1)\frac{\Delta P_0}{\Delta P_{sc}}} = 0.5345$$

Since $\alpha > \alpha_{cr}$, operating the substation with **two transformers in parallel** is more economical in terms of active power losses. Consequently, the network is operated with both transformers in parallel for the subsequent voltage regulation and power flow improvement analyses.

4.2 Voltage regulation using transformer taps to obtain a voltage level of 21 kV

By increasing the voltage at the transformer level, the active power losses in the distribution power network will be reduced. The aim is to identify the operating tap of the transformer(s) in the substation so that the voltage on the MV busbars (A and B) is as closes to 21 kV as possible.

Transformers equipped with voltage regulation taps are the main means of voltage control at the level of electrical distribution networks. Constructively, they can be on-load tap changers or no-load tap changers.

The decreasing or increasing of the voltage level is based on the increasing or decreasing of the transformation ratio by changing the number of turns of a winding. Adjusting the winding or changing the number of turns is carried out by a switch capable of connecting or disconnecting taps. MV/LV transformers are mostly equipped with no-load tap changers, while higher power transformers are equipped with a larger number of on-load taps, that can be controlled either manually or automatically (automatic voltage regulator).

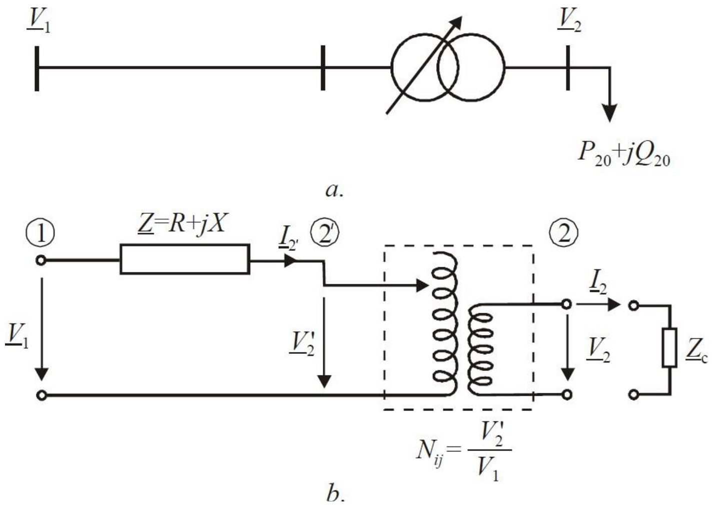


Fig. 4.2 Equivalent single line diagram of a power grid with a transformer supplying a load

The determination of the operating tap of the transformers, to obtain the required voltage level of 21 kV (V^{req}) is based on the following equation:

$$n_t = \frac{100}{\Delta u}\left[\frac{V^{MV}}{2\cdot V^{HV}\cdot V^{req}}\left(V_1+\sqrt{{V_1}^2-4(R_T\cdot P_2+X_T\cdot Q_2)}\right)-1\right]$$

$$n_t = \frac{100}{1{,}78}\left[\frac{20}{2\cdot 110\cdot 21}\left(112{,}52+\sqrt{112{,}52^2-4(R_T\cdot P_2+X_T\cdot Q_2)/1000}\right)-1\right]$$

where:

- n_t is the tap number
- $\Delta u = 1{,}78\ \%$ – voltage variation when switching between two consecutive taps
- V_1 – primary winding voltage (in Neplan is HV busbar)
- $V^{req} = 21\ kV$ – required voltage for secondary winding
- $R_T = \Delta P_{sc}\cdot\frac{U^2_{n,MV}}{S^2_n} = 140\ \cdot\frac{20^2}{25^2} = \cdots$ [Ω] – transformer resistance
- $Z_T = \frac{u_{sc}}{100}\cdot\frac{U^2_{n,MV}}{S_n}$ = ... [Ω] – transformer impedance
- $X_T = \sqrt{(Z_T^2 - R_T^2)}$ = ... [Ω] – transformer reactance
- $P_2 = Re\{\underline{S}_A\}\ or\ Re\{\underline{S}_B\}$ – the sum of the active powers in the secondary of the considered transformer
- $Q_2 = Im\{\underline{S}_A\}\ or\ Im\{\underline{S}_B\}$ – the sum of the reactive powers in the secondary of the considered transformer

If the network is operated with a single transformer, a single tap is calculated, if the substation operates with two transformers, two taps will be calculated: a tap for the transformer supplying the upper branch (A) and a tap for the transformer supplying the lower branch (B).

Initial Verification:

- Base case without OLTC: run LF and record MV voltages at DS1 and DS2.
- OLTC was enabled and Uset=105% wich means 21 KV was assigned to the secondary controlled node.
- For the current study case, since most of the loads are connected to the lower transformer #2, its voltage requires higher support to take it close to 21 Kv.

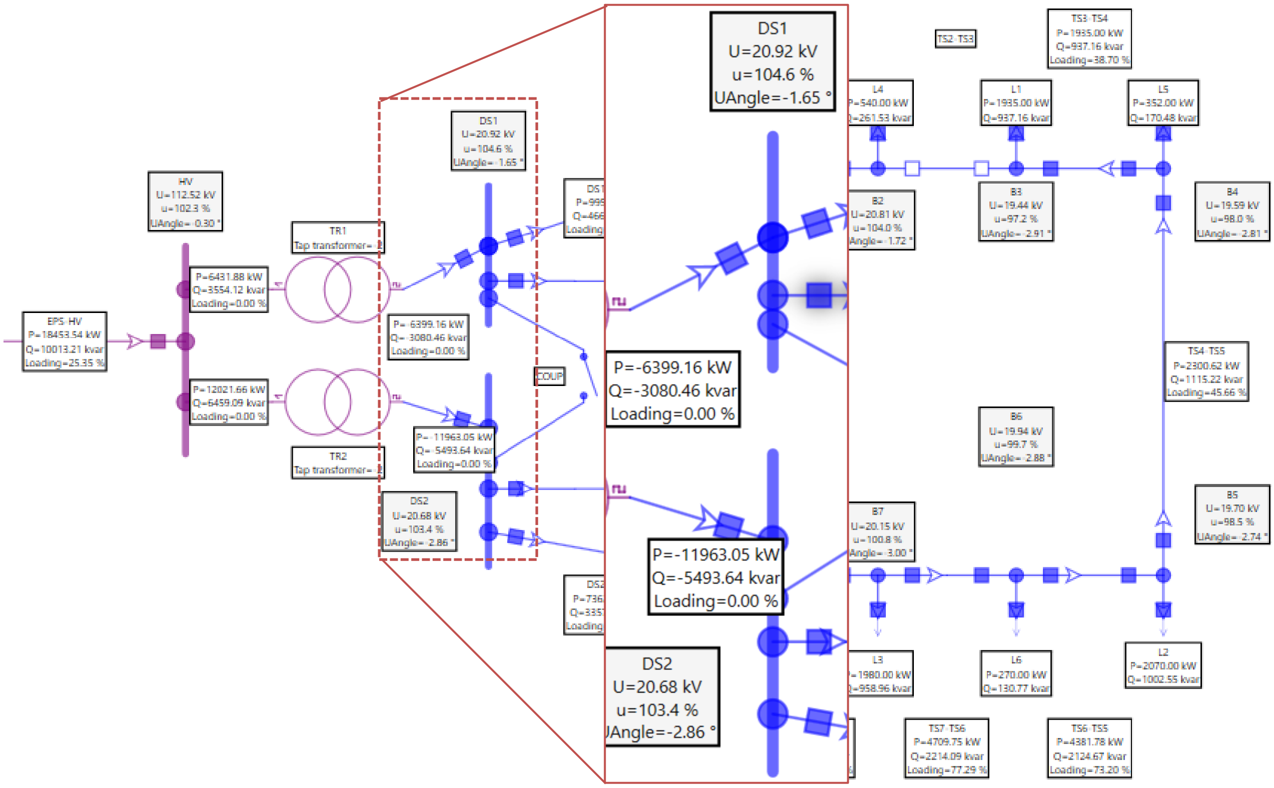


Fig. 4.3. Voltage enhancement, OLTC effect.

A change in MV voltage was observed only when modifying the transformer rated secondary voltage (Ur2) from 20 kV to 21 kV, which effectively changes the base voltage of the transformer model and does not represent OLTC action. Therefore, for Section 2.4 the transformer rated voltages were kept at 110/20 kV and voltage regulation was performed using OLTC tap control (Uset=105%).

Identification of the operating tap with the help of the Neplan program is done by checking the *On-load tapchanger* and setting in the *Regulation window* the value of *Uset* at 105%. For the student version of NEPLAN, this process is not made automatically.

For the radial configuration with the **TS2–TS3** opening, the transformer secondary (MV side) powers are $\mid P_{2A} \mid = 6.40$ MW, $\mid Q_{2A} \mid = 3.08$ MVArand $\mid P_{2B} \mid = 11.99$ MW, $\mid Q_{2B} \mid =$ 5.53 MVAr; using $V_1 = 112.51$ kV, $u_{sc} = 10.5\%$, $\Delta P_{sc} = 140$ kWand $V_{req} = 21$ kV, the OLTC equation yields $n_t \approx -1.5$for both branches, therefore an operating tap **between −1 and −2 (≈ −2)** is selected to obtain $V_{MV} \approx 21$ kV.

Table 4.1. Voltage level variation corresponding to the operating tap

n_t	V_A **[kV]**	V_B **[kV]**
1	19.79	19.53
0	20.15	19.9
−1	20.53	20.29
−2	20.92	20.68
−3	21.33	21.09
−4	21.75	21.52

After the observations, the optimal taps for transformer VA its 30, giving a value of 20.92 for A and 20.68 to B. Which was also compared to the theoretical calculation above in section 4.2 and do not over passes the 105% established.

4.3 Setting the optimal tap to minimize active power losses

In certain situations, the automatic adjustment of voltage at transformer level is no longer used in the operation of power grids and the tap changer is set on manual operation. The operating tap is determined so that the power losses are at a minimum level within the distribution network.

In this assignment the determination of this tap will be carried out heuristically. In this regard, the *on-load tap changer option is unchecked at the transformer* (the transformer will no longer be with automatic adjustment), and the reference tap is set as the middle one (tap 0). The operating tap values are then set from -1 to -9 and from 1 to 9 and the network active power losses is read for each tap setting. Since the change of the operating tap also changes the voltage level, the values of the nodal voltages and line loadings will be registered, so that they will not exceed the admissible limits:

- $\boldsymbol{V_{max}}$ = 1,1·20 = 22 kV
- $\boldsymbol{V_{min}}$ = 0,9·20 =18 Kv
- $\boldsymbol{I_{max} < I_{adm}}$

Table 4.2. Variation of losses according to the operating plot

Tap	**ΔP_{net} [kW]**	**V_{min} [%] B3**	**V_{max} [%] DS1**	**I_{max} [%] DS2-TS8**
~~-5~~	~~447~~	~~104.0~~	~~110.9~~	~~67.18~~
-4	460	101.7	108.7	68.71
-3	473	99.4	106.6	70.26
-2	488	97.2	104.6	71.82

-1	503	95.1	102.7	73.39
0	518	93	100.8	74.89
1	534	91	99.0	76.59
~~2~~	~~551~~	~~89.1~~	~~97.2~~	~~78.21~~

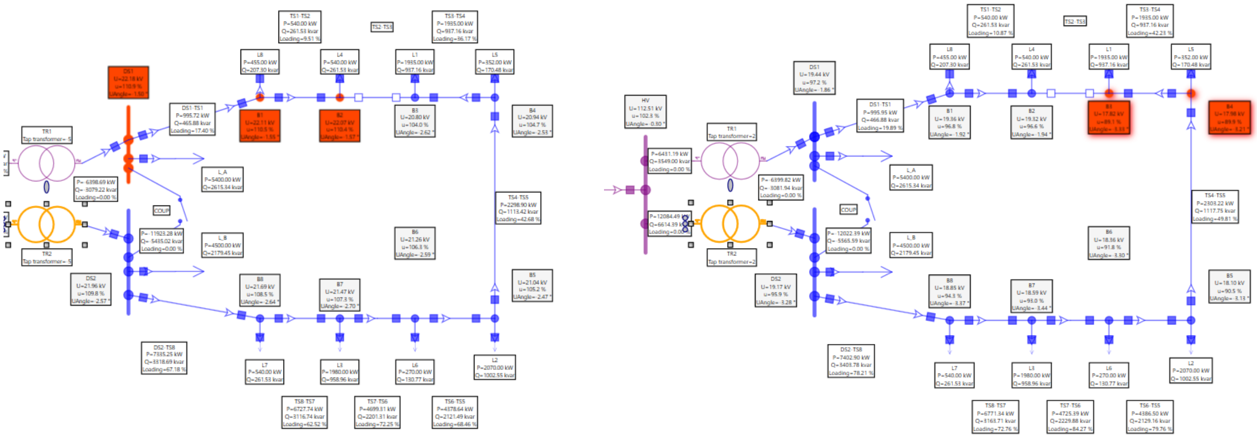


Fig. 4.4. Limit violations (a) Vmax Violation at *tc*=-5. (b) Vmin Violation at *tc*=2.

The tap sweep shows that active power losses decrease as the MV voltage is raised, but operational limits constrain the range; taps beyond $n_t = 2$approach the upper voltage limit, while $n_t \geq +2$lead to undervoltage in the most remote bus of branch B. Therefore, the optimal operating tap is the highest one that remains within voltage limits, achieving reduced losses without violating $V_{\min}$or $V_{\max}$.

For simplicity, the plots of the two transformers will be changed simultaneously to the same value. There is a possibility that the real optimal solution will not be found, given the operation of the network in radial configuration.

4.4 Determination of the optimal placement location for reducing active power losses

The distributed generation source will be modelled in the Neplan program through an "AC disperse generator" generator, having the following parameters (in the Parameters window):

- U_r = 20 kV – rated voltage
- S_r = 5 MVA – rated apparent power
- cosφ r = 0,85 – power factor

Next, the analysis will be done with the compensated, reconfigured network, in which the voltage on the busbars of the MV station is maintained at 21 kV with the help of the tap changer.

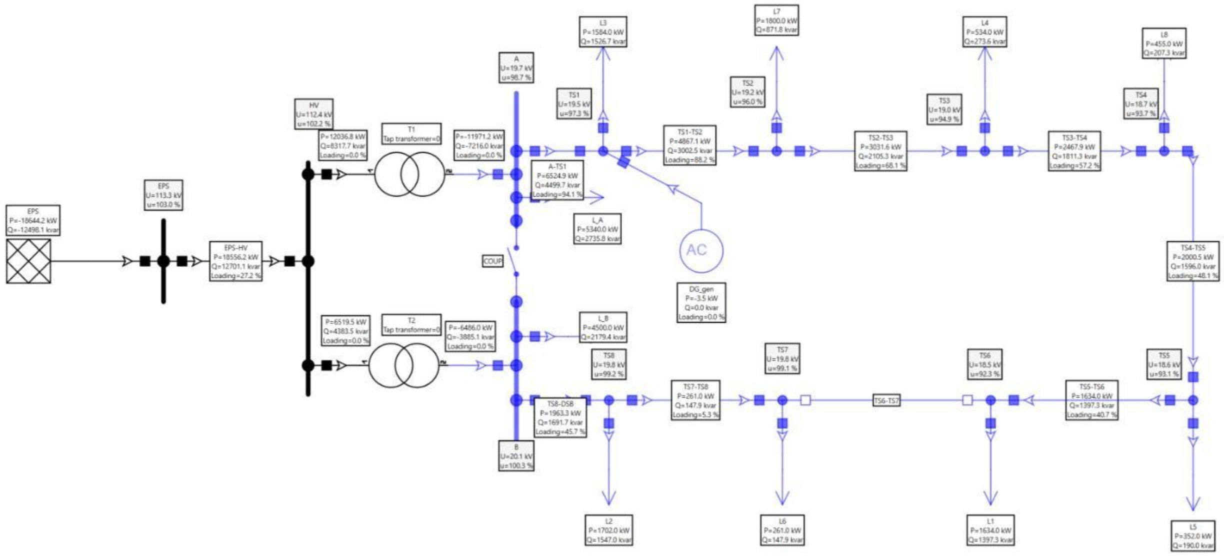


Fig. 4.5 Location of the distributed generation source *(example)*

For determining of the location of the distributed generator, both transformers are considered in operation.

The distributed source will be connected to all nodes of the network, one by one, monitoring power losses and centralizing the values in Table 3.

The active power generated will be entered in the *LF Analysis* section by selecting *PC* as LF-type and filling in the P =... and cosφ = 1).

Table 4.3. *Power losses following the connection of the distributed source*

Distributed Source Connection Bus	$\mathbf{\Delta P}_{net}$ **[kW]**
TS_1	474
TS_2	493
TS_3	232
TS_4	237
TS_5	244
TS_6	290
TS_7	334
TS_8	385

Based on the results obtained, the location node of the distributed source with the lowest losses is recommended to be chosen.

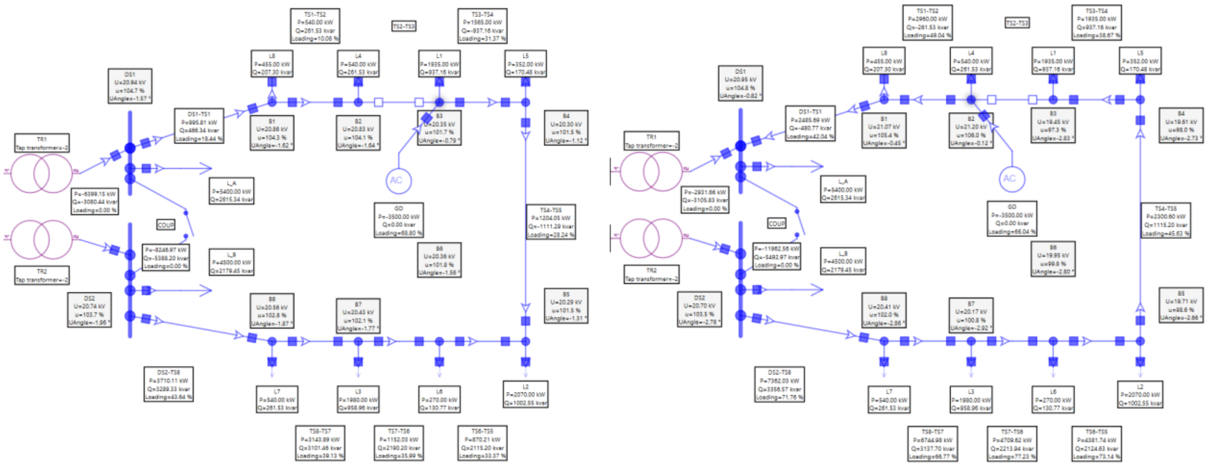


Fig. 4.6 Location of the distributed generation (a) Optimal allocation with less losses. (b) Sub-optimal allocation with higher losses.

Based on the loss variation ΔPnet, TS3 is the optimal bus for DG connection, yielding the minimum increase in network losses (232 kW), while TS2 is the least favorable option, producing the highest losses (493 kW). From a purely technical, loss-minimization perspective, TS3 is therefore the preferred location. However, in practice, DG siting is constrained by land availability, permitting, and renewable resource potential, which may prevent installation at the technically optimal node. For this reason, subsequent analysis considers alternative DG locations from an owner-oriented and practical deployment perspective.

5. Impact of a distributed source on network operating regimes

5.1 Analysis of power flow and power losses through the network branches

Considering the distributed generation source (DG) modelled in Neplan according to the parameters presented in the previous chapter Parameters window and LF Analysis window. The DG following the solutions specified in the homework (Fig. 5.1) and (Fig.5.2), was connected.

For each solution, the *Load-Flow* analysis was run and extracted the total power losses in the network, the voltage profile and the power losses through the network branches. Identify the branch with the highest load for each solution and draw conclusions.

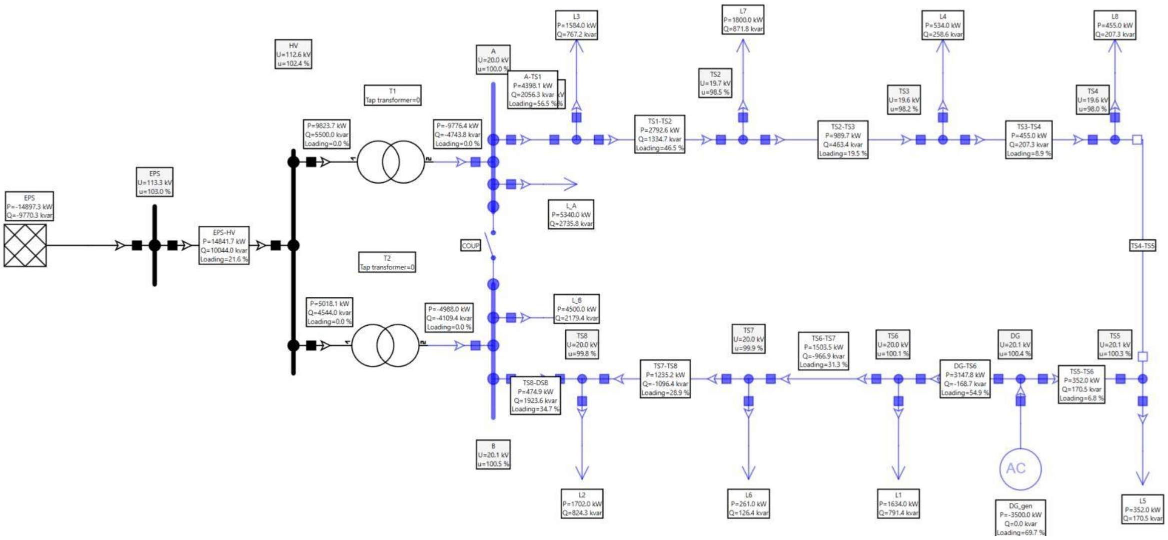


Fig. 5.1. Solution 1 – direct connection to the 20 kV medium voltage line

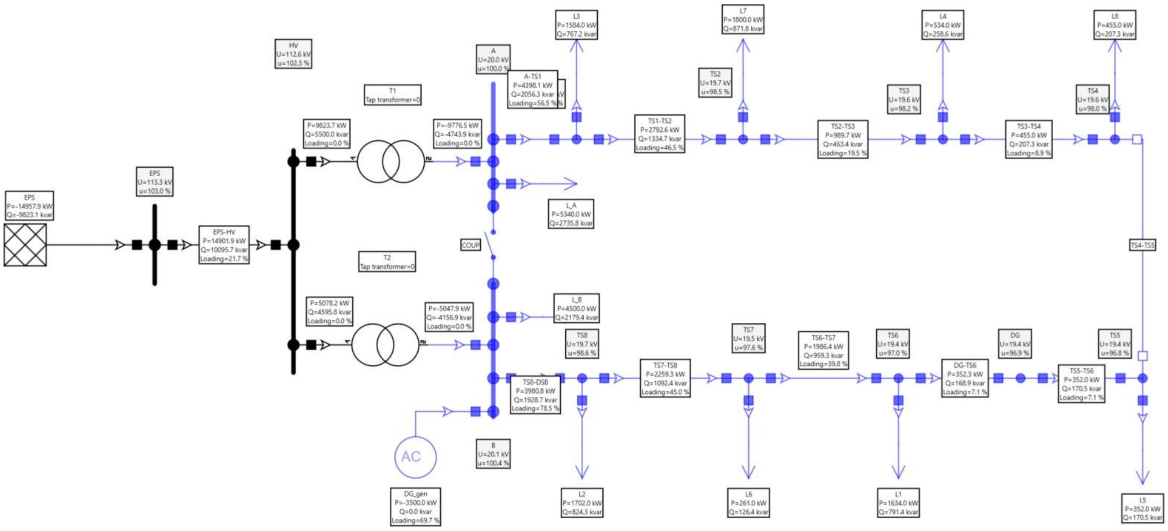


Fig. 5.2. Solution 2 – connection to the 20 kV busbars of the electrical transformer station

In order to identify for each solution, the power losses through the network branches for different operating modes of the DG source it is necessary to modify the power factor values (cosφ = 0.9 inductive and capacitive). These values can be changed in the *LF Analysis* window (generator parameters check or not the "*Capacitive*")

For solution 1, it was stated to allocate the distributed generation at 1.5 km from TS6, hence, the following setup is adopted:

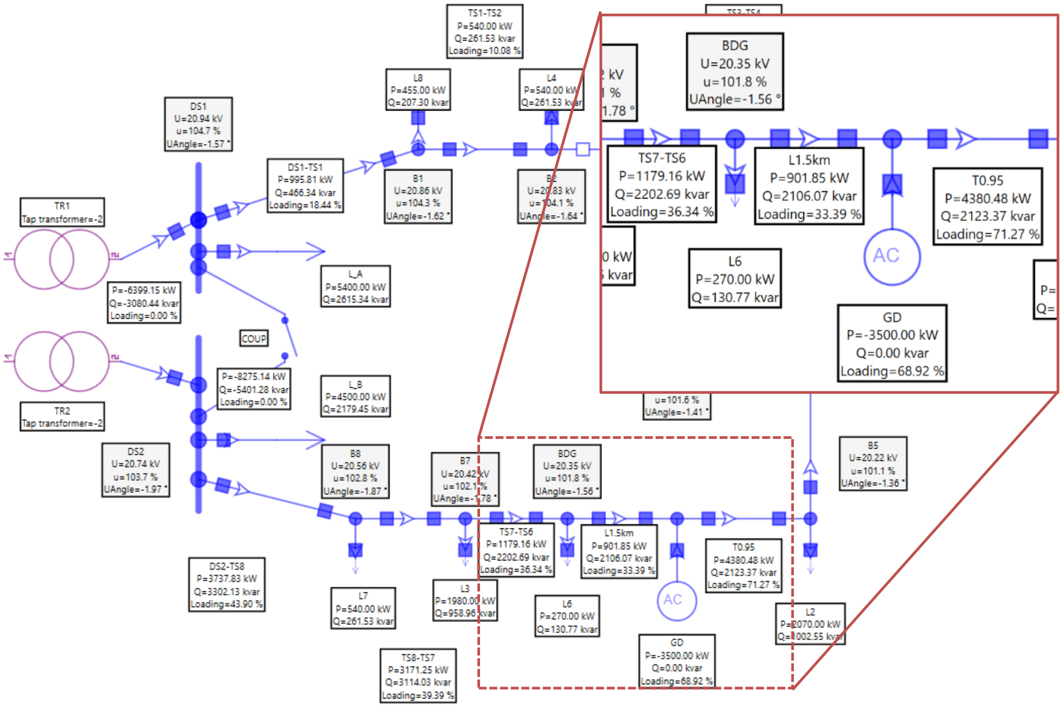


Fig. 5.3. Solution 1 – connection to the 20 kV busbars of the electrical transformer station.

Table 5.1. Solution 1 *Power losses and voltage values in the connection point for different operating modes*

cosφ	**Power Generated P_{DG}[MW]**	**Power losses ΔP[kW]**	**U [kV]**	**I_{max} [%]**
0,9 - Inductive	3,5	353.63	20.06	0.77
1	3,5	261.37	20.31	0.71
0,9 - Capacitive	3,5	212.09	20.56	0.75

Table 5.2 Solution 1 - Loading and Losses Profile per Branch

Nodes	***Loading %***	***PLosses kW***	***QLosses kvar***	***ΔPLosses Capacitive***	***ΔPLosses Inductive***
B1	18.43143	3.32949	-1.24672	0.00	0.00
B2	10.07414	0.81317	-2.50284	0.00	0.00
B3	37.19847	12.58538	6.50686	0.32	-0.35
B4	43.89112	10.3102	6.08488	0.26	-0.28
B5	70.38765	20.84296	-17.9983	0.53	-0.57
B6	18.34549	3.08745	-50.99669	9.00	-21.19
B7	30.30848	15.78668	-81.3985	10.78	-19.63
B8	35.22075	24.09668	-89.59645	13.21	-23.32
BDG	14.24841	1.33101	-36.50162	5.98	-14.65

Table 5.3 Solution 1 - *Voltage Profiles as follows:*

Name	***U kV***	***UAngle °***	***u %***	***ΔU Capacitive***	***ΔU Capacitive***
B1	20.86033	-1.62272	104.30167	-0.015	0.015
B2	20.8252	-1.64397	104.12601	-0.015	0.015
B3	19.97115	-1.5174	99.85573	-0.253	0.263
B4	20.12011	-1.42473	100.60057	-0.251	0.261
B5	20.22353	-1.36089	101.11765	-0.250	0.259
B6	20.35414	-1.56411	101.77071	-0.236	0.245
B7	20.4234	-1.77617	102.11699	-0.218	0.226
B8	20.56087	-1.8731	102.80435	-0.189	0.196
BDG	20.31321	-1.41345	101.56604	-0.249	0.258
DS1	20.93871	-1.57272	104.69355	-0.015	0.015
DS2	20.73609	-1.96855	103.68045	-0.156	0.161

Fig. 5.3. Solution 2 – connection to the 20 kV busbars of the electrical transformer station

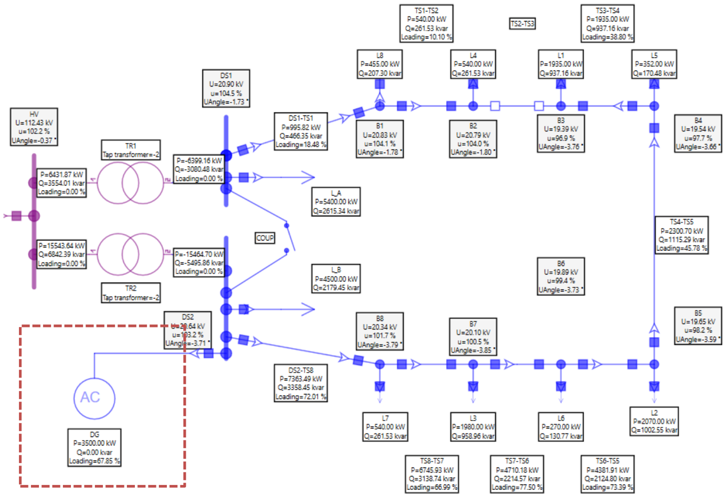


Table 5.4. Solution 2 *Power losses and voltage values in the connection point for different operating modes*

cosφ	**Power Generated P_{DG}[MW]**	**Power losses ΔP[kW]**	**U [kV]**	**I_{max} [%]**
0,9 - Inductive	3,5	554.85	20.48	1.04
1	3,5	536.58	20.64	0.77
0,9 - Capacitive	3,5	521.15	20.79	1.04

Table 5.4 Solution 2 - Loading and Losses Profile per Branch

Nodes	***Loading %***	***PLosses kW***	***QLosses kvar***	*ΔPLosses* ***Capacitive***	*ΔPLosses* ***Inductive***
B1	18.475	3.34528	-1.21629	0.005	-0.005
B2	10.09793	0.81702	-2.48505	0.001	-0.001
B3	38.80391	13.69591	7.64972	0.232	-0.242
B4	45.78307	11.21852	6.95733	0.190	-0.198
B5	73.38734	58.26701	-40.99231	0.979	-1.021
B6	77.49571	55.74562	-34.78829	0.942	-0.983
B7	66.99146	77.56712	-41.82719	1.294	-1.349
B8	72.00532	101.20647	-42.04271	1.693	-1.765
BDG	18.475	3.34528	-1.21629	0.005	-0.005

Table 5.5 Solution 2 - *Voltage Profiles as follows:*

Name	***U kV***	***UAngle °***	***u %***	***ΔU Capacitive***	***ΔU Capacitive***
B1	20.82613	-1.77571	104.13065	-0.015	0.015
B2	20.79094	-1.79704	103.9547	-0.015	0.015
B3	19.38735	-3.75802	96.93675	-0.166	0.169
B4	19.54081	-3.65974	97.70405	-0.165	0.168
B5	19.64734	-3.5921	98.23671	-0.164	0.167
B6	19.88533	-3.73252	99.42664	-0.162	0.165
B7	20.10131	-3.85149	100.50653	-0.160	0.163
B8	20.34256	-3.78947	101.71278	-0.158	0.161

Results show that Solution 1, for this network configuration, leads to significantly lower active power losses (2x), with minimum losses of 212.09 kW under capacitive operation, compared to 521.15 kW for Solution 2, due to reduced current flows along heavily loaded downstream branches. Voltage profiles in Solution 1 remain within admissible limits (≈99.9–104.7%), while Solution 2 exhibits lower voltages at remote buses (down to ≈96.9%), indicating weaker voltage support. The highest branch loadings are also more evenly distributed in Solution 1, whereas Solution 2 concentrates higher loadings in the lower feeder branches.

An additional comparison was performed by connecting the DG at the upper MV busbar (DS1), resulting in only a marginal loss reduction of approximately 1.9% (≈10.3 kW) from 526.24 kW, compared to 536.58 kW at PF=1, confirming that the physical location of the DG along the feeder has a much stronger influence on losses than the specific MV busbar chosen.

5.2 Analysis of slow and rapid voltage variations

Consider an additional power source with a power of 5 MW (specified in the *LF Analysis* window) connected to the MV busbar of the substation.

5.2.1 To analyze slow voltage variations, it is necessary to save the network voltage profile before integrating the analyzed DG source (the 3.5 MW one) and the existing DG source (5 MW). Then, the existing 5 MW source is connected, and nodal voltage values are recorded. Next, the source under analysis (the 3.5 MW one) is connected in increments of 25% of its installed capacity up to 100%, recording the nodal voltages at each step. The objective is to ensure that, in the end, the differences between the recorded voltage levels do not exceed 3% of the nominal voltage.

Table 5.2.1. Voltage profile reference, solution 1 at feeder.

Name	***U kV***	***UAngle °***	***u %***
DS1	20.9387	-1.5727	104.69
B1	20.8603	-1.6227	104.3
B2	20.8252	-1.644	104.13
B3	19.9711	-1.5174	99.86
B4	20.1201	-1.4247	100.6
B5	20.2235	-1.3609	101.12
B6	20.3541	-1.5641	101.77
B7	20.4234	-1.7762	102.12
B8	20.5609	-1.8731	102.8
BDG	20.3132	-1.4134	101.57
DS2	20.7361	-1.9685	103.68

Table 5.2.2. Voltage profile diference, solution 1, upper MVBB (DS1) connection.

Name	5MW only		25%		50%		75%		100%	
DS1	20.916	0.11%	20.9206	0.09%	20.925	0.07%	20.9293	0.04%	20.9334	0.03%
B1	20.8376	0.11%	20.8422	0.09%	20.8466	0.07%	20.8509	0.05%	20.855	0.03%
B2	20.8024	0.11%	20.807	0.09%	20.8114	0.07%	20.8157	0.05%	20.8199	0.03%
B3	19.436	2.68%	19.5734	1.99%	19.7079	1.32%	19.8397	0.66%	19.9689	0.01%

B4	19.5891	2.64%	19.7254	1.96%	19.8588	1.30%	19.9896	0.65%	20.1179	0.01%
B5	19.6954	2.61%	19.8309	1.94%	19.9636	1.29%	20.0937	0.64%	20.2213	0.01%
B6	19.9328	2.07%	20.041	1.54%	20.1469	1.02%	20.2505	0.51%	20.3519	0.01%
B7	20.1482	1.35%	20.2191	1.00%	20.2882	0.66%	20.3555	0.33%	20.4212	0.01%
B8	20.3889	0.84%	20.4334	0.62%	20.4765	0.41%	20.5183	0.21%	20.5587	0.01%
BDG	19.7875	2.59%	19.9224	1.92%	20.0545	1.27%	20.184	0.64%	20.311	0.01%
DS2	20.6808	0.27%	20.6955	0.20%	20.7092	0.13%	20.722	0.07%	20.7339	0.01%

Table 5.2.3. Voltage profile difference, solution 1, lower MVBB (DS2) connection.

Name	5MW only		25%		50%		75%		100%	
DS1	20.919	0.09%	20.9236	0.09%	20.9281	0.05%	20.9324	0.03%	20.9365	0.01%
B1	20.8405	0.09%	20.8452	0.09%	20.8496	0.05%	20.854	0.03%	20.8581	0.01%
B2	20.8054	0.10%	20.81	0.10%	20.8145	0.05%	20.8188	0.03%	20.823	0.01%
B3	19.4314	2.70%	19.569	2.70%	19.7037	1.34%	19.8357	0.68%	19.9652	0.03%
B4	19.5845	2.66%	19.721	2.66%	19.8547	1.32%	19.9857	0.67%	20.1142	0.03%
B5	19.6908	2.63%	19.8265	2.63%	19.9595	1.31%	20.0898	0.66%	20.2176	0.03%
B6	19.9283	2.09%	20.0367	2.09%	20.1428	1.04%	20.2466	0.53%	20.3483	0.03%
B7	20.1438	1.37%	20.2149	1.37%	20.2842	0.68%	20.3517	0.35%	20.4176	0.03%
B8	20.3845	0.86%	20.4292	0.86%	20.4725	0.43%	20.5144	0.23%	20.5551	0.03%
BDG	19.783	2.61%	19.918	2.61%	20.0504	1.29%	20.1801	0.66%	20.3073	0.03%
DS2	20.6765	0.29%	20.6913	0.29%	20.7052	0.15%	20.7182	0.09%	20.7303	0.03%

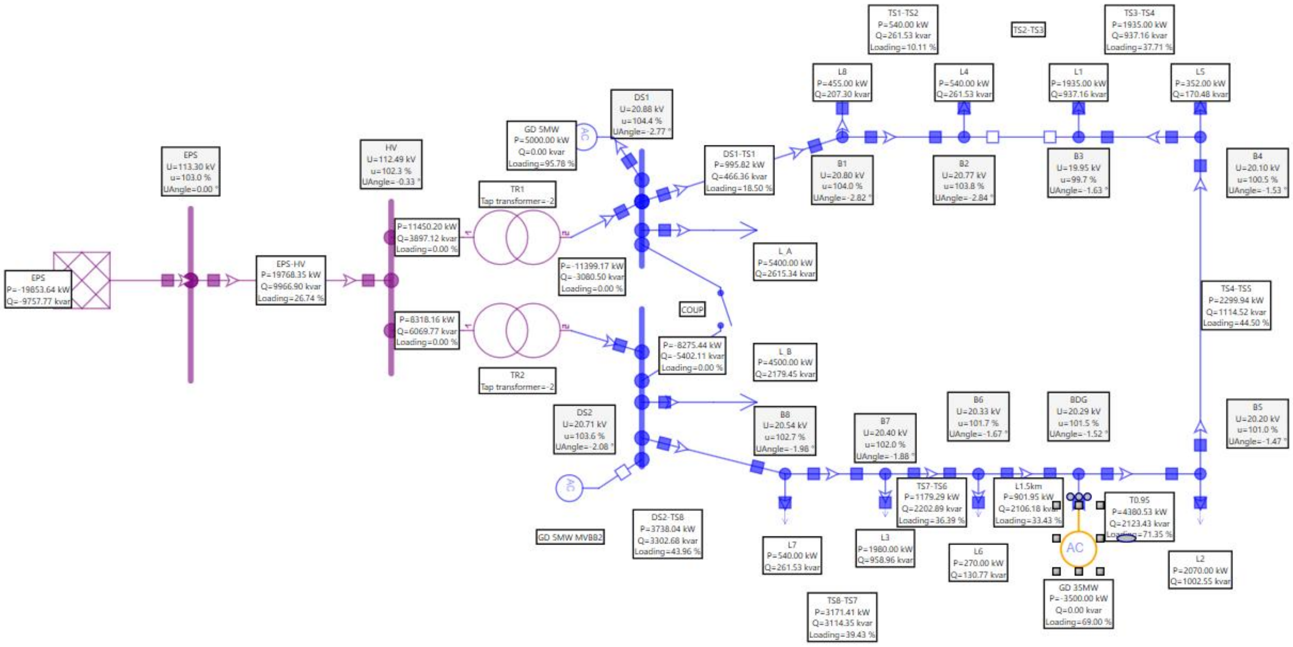


Figure 5.2.1. Schematic setup of interconnection solution 1.

Table 5.2.4. Voltage profile reference, solution 2 at MVBB.

Name	***U*** ***kV***	***UAngle*** ***°***	***u*** ***%***
DS1	20.92133	-1.65105	104.60663
B1	20.84288	-1.70113	104.21442
B2	20.80772	-1.72242	104.03862
B3	19.43837	-2.9072	97.19184
B4	19.59142	-2.80943	97.95712
B5	19.69768	-2.74213	98.48838
B6	19.93504	-2.88182	99.67522
B7	20.15046	-3.00014	100.75231
B8	20.39108	-2.93838	101.95542
DS2	20.68299	-2.858	103.41496

Table 5.2.5 Voltage limit sanity per case, connection at MVBB (upper) DS1.

name	5 MW only		25%		50%		75%		100%	
DS1	20.916	0.03%	20.9065	0.07%	20.8967	0.12%	20.8866	0.17%	20.8762	0.22%
B1	20.8376	0.03%	20.828	0.07%	20.8182	0.12%	20.808	0.17%	20.7975	0.22%
B2	20.8024	0.03%	20.7928	0.07%	20.783	0.12%	20.7728	0.17%	20.7623	0.22%
B3	19.436	0.01%	19.4319	0.03%	19.4278	0.05%	19.4235	0.08%	19.4193	0.10%
B4	19.5891	0.01%	19.585	0.03%	19.5809	0.05%	19.5767	0.08%	19.5725	0.10%
B5	19.6954	0.01%	19.6913	0.03%	19.6872	0.05%	19.683	0.07%	19.6788	0.10%
B6	19.9328	0.01%	19.9288	0.03%	19.9247	0.05%	19.9206	0.07%	19.9164	0.09%
B7	20.1482	0.01%	20.1443	0.03%	20.1402	0.05%	20.1362	0.07%	20.132	0.09%
B8	20.3889	0.01%	20.385	0.03%	20.381	0.05%	20.377	0.07%	20.3729	0.09%
DS2	20.6808	0.01%	20.677	0.03%	20.6731	0.05%	20.6691	0.07%	20.6651	0.09%

Table 5.2.6 Voltage limit sanity for case a: only 5MW source and full connection 5MW + 35MW DG.

MVBB B	0%		100%	
DS1	20.919	0.01%	20.8993	0.11%
B1	20.8405	0.01%	20.8208	0.11%
B2	20.8054	0.01%	20.7856	0.11%
B3	19.4314	0.04%	19.385	0.27%
B4	19.5845	0.04%	19.5385	0.27%
B5	19.6908	0.03%	19.645	0.27%
B6	19.9283	0.03%	19.883	0.26%
B7	20.1438	0.03%	20.0991	0.25%
B8	20.3845	0.03%	20.3403	0.25%
DS2	20.6765	0.03%	20.633	0.24%

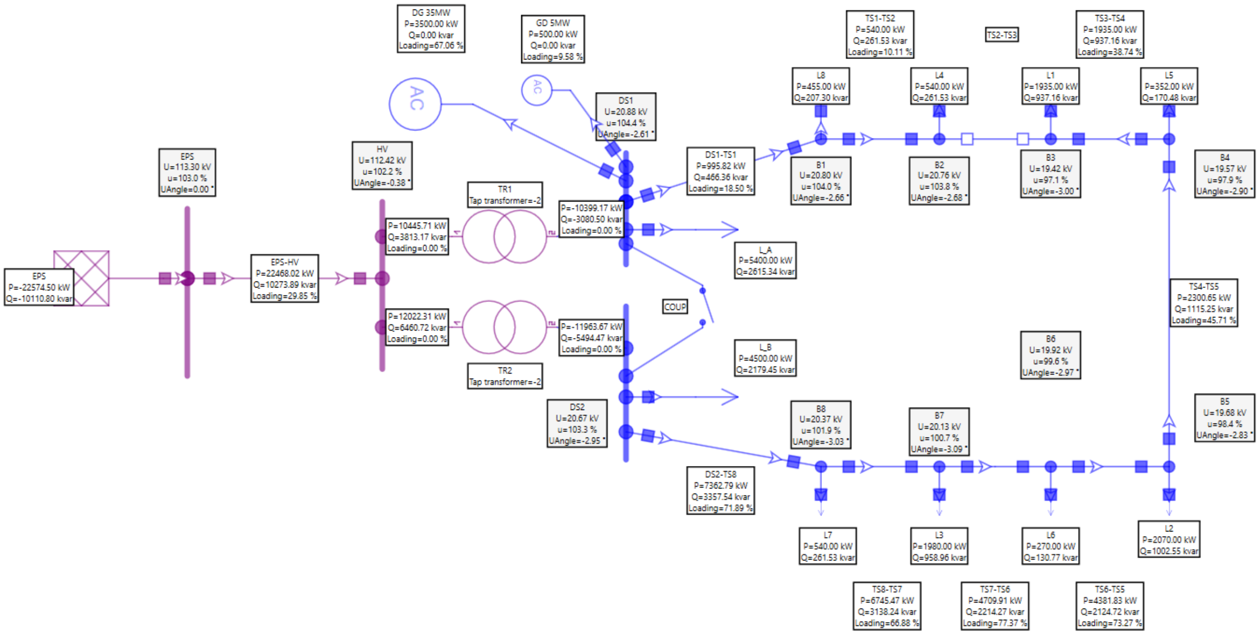


Figure 5.2.2. Schematic setup of interconnection solution 2.

A supplementary sensitivity check was performed by modifying the injection levels of the distributed sources; however, it was later observed that intermediate simulations were conducted using reduced power levels (500 kW and 3.5 MW) instead of the nominal 5 MW, nevertheless the qualitative conclusions regarding the relative performance of the two connection solutions remain valid.

To analyze rapid voltage variations, it is necessary to save the nodal voltage profile values of the electrical network considering the following cases: without any distributed generation source, with the existing source (the 5 MW one), and with the analysed source (the 3.5 MW one). In this situation, the variations must not exceed 4% of the nominal voltage.

Table 5.2.7 Rapid Voltage Variation Sanity per case – Solution 1

Name	*No Gen*	*5MW*	*Delta ramp 1*	*8.5MW*	*Delta ramp 2*
DS1	20.9213	20.8639	0.27%	20.8814	0.19%
B1	20.8429	20.7852	0.28%	20.8028	0.19%
B2	20.8077	20.75	0.28%	20.7676	0.19%
B3	19.4384	19.4143	0.12%	19.9479	-2.62%
B4	19.5914	19.5675	0.12%	20.097	-2.58%
B5	19.6977	19.6739	0.12%	20.2006	-2.55%
B6	19.935	19.9116	0.12%	20.3313	-1.99%
B7	20.1505	20.1273	0.12%	20.4007	-1.24%
B8	20.3911	20.3682	0.11%	20.5383	-0.72%

BDG	19.7898	19.7661	0.12%	20.2903	-2.53%
DS2	20.683	20.6604	0.11%	20.7137	-0.15%

Table 5.2.8 Rapid Voltage Variation Sanity per case – Solution 2

Name	*No Gen*	*5MW*	*Delta ramp 1*	*8.5MW*	*Delta ramp 2*
DS1	20.9213	20.8639	0.27%	20.8178	0.22%
B1	20.8429	20.7852	0.28%	20.7389	0.22%
B2	20.8077	20.75	0.28%	20.7036	0.22%
B3	19.4384	19.4143	0.12%	19.3963	0.09%
B4	19.5914	19.5675	0.12%	19.5497	0.09%
B5	19.6977	19.6739	0.12%	19.6561	0.09%
B6	19.935	19.9116	0.12%	19.894	0.09%
B7	20.1505	20.1273	0.12%	20.1099	0.09%
B8	20.3911	20.3682	0.11%	20.351	0.08%
DS2	20.683	20.6604	0.11%	20.6436	0.08%

No limits were crossed for rapid voltage variations.

6 Impact of a distributed source on network operating regimes (continuation)

6.1. Determination of the optimal power generated by the distributed source to minimize active power losses

Initial conditions:

- DG will be connected one by one in both configurations (solution 1 and solution 2)
- The power factor cosφ = 1

The required power output from the DG source to minimize active power losses is determined through a heuristic method. For this

The power generated by the DG source is gradually increased by 0.5 MW (500 kW) in *LF Analysis* window until maximum apparent power set in subchapter 2.6 (*Determination of the optimal placement location for reducing active power losses*) is reached.

Table 6.1. *Optimal DG value in terms of power losses variartion until 5.0MW.*

P_{DG} [MW]	**Δ*P* [kW] - solution 1 -**	**Δ*P* [kW] - solution 2 -**
0.5	443.766	492.975
1	403.547	498.013
1.5	367.382	503.253
2	335.172	508.695
2.5	306.826	513.4973

3	282.255	518.6363
3.5	261.375	523.7753
4	244.106	528.9143
4.5	230.368	534.0533
5	**220.089**	**539.1923**

Table 6.1. *Optimal DG value in terms of power losses 5MW variartion + steady 3.5MW connected.*

P_{DG} [MW]	**Δ*P* [kW] - solution 1 -**	**Δ*P* [kW] - solution 2 -**
0.5	**265.495**	**532.502**
1	269.815	538.966
1.5	274.337	545.634
2	279.059	552.509
2.5	283.983	559.591
3	289.109	566.879
3.5	294.437	574.375
4	299.969	582.079
4.5	305.704	589.993
5	311.643	598.115

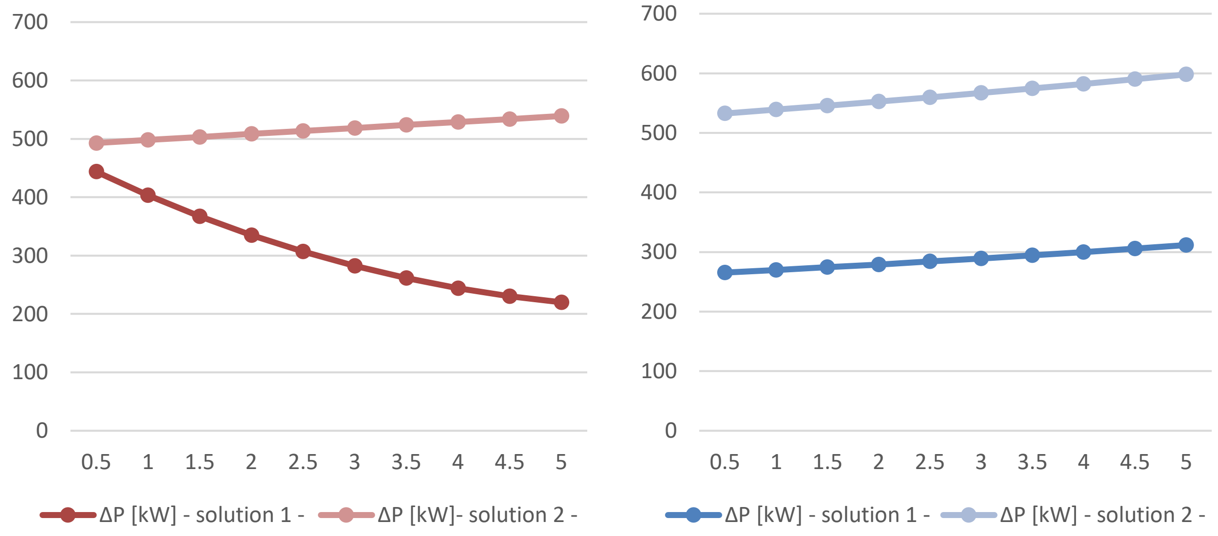


Fig. 6.1 Variation of power losses as a function of the power generated at cosφ = 1, for Solution 1 and 2. (a) solely generator from 0.5MW to 5MW, (b) generator 3.5MW and increased 0.5 until 5MW additional generation.

The heuristic analysis shows that, for both connection solutions and at unity power factor, the active power losses increase monotonically as the injected DG power is raised. Consequently, the optimal DG power in terms of loss minimization corresponds to the lowest tested value, namely 0.5 MW. This behavior is explained by the appearance of reverse power flows and increased current levels in the radial MV network when the DG penetration increases, which leads to higher I^2Rlosses despite local generation.

6.2. Determination of the maximum power that can be generated by the DG source by considering the maximum permissible loading and the voltage level

To determine the maximum power, the DG source connected in both solutions configurations should fulfil the following requirements:

- Not to exceed the maximum transmission capacity of the network branches:

$$I_i \leq I_{adm}$$

- The voltages must be within the range of permissible limits (± 10% U_n):

$$U_{min} \leq U_i \leq U_{max}$$

Recommendation. When you run the analysis for 3.3 subchapter, you should also save values for voltage and load.

Table 6.2.1. Solution 1 - *Results obtained for different DG source power values*

P_{DG} [MW]	ΔP [kW]	U_{max} [%]	U_{min} [%]	I_{max} [%]
0.5	443.766	104.62	97.59	72.91
1	403.547	104.63	99.26	72.62
1.5	367.382	104.65	98.36	72.34
2	335.172	104.66	98.74	72.06
2.5	306.826	104.67	99.12	71.79
3	282.255	104.68	99.49	71.53
3.5	261.375	104.69	99.86	71.27
4	244.106	104.71	100.22	78.49
4.5	230.368	104.72	100.58	88
5	220.089	104.73	100.94	97.44
6 (maximum value)	209.624	104.75	101.64	116.15
6.5	209.305	104.76	101.98	125.41

Table 6.2.2. Solution 2 - *Results obtained for different DG source power values*

P_{DG} [MW]	ΔP [kW]	U_{max} [%]	U_{min} [%]	I_{max} [%]
0.5	492.975	104.58	97.18	77.3
1	498.013	104.55	98.47	77.31
1.5	503.253	104.53	97.16	77.32
2	508.695	104.5	97.14	77.33
2.5	513.4973	104.4783	97.57333	77.34
3	518.6363	104.4533	97.56333	77.35

3.5	523.7753	104.4283	97.55333	77.36
4	528.9143	104.4033	97.54333	77.37
4.5	534.0533	104.3783	97.53333	77.38
5	539.1923	104.3533	97.52333	77.39
6 (maximum value)	559.591	104.26	97.05	115.1
6.5	566.879	104.22	97.03	124.73

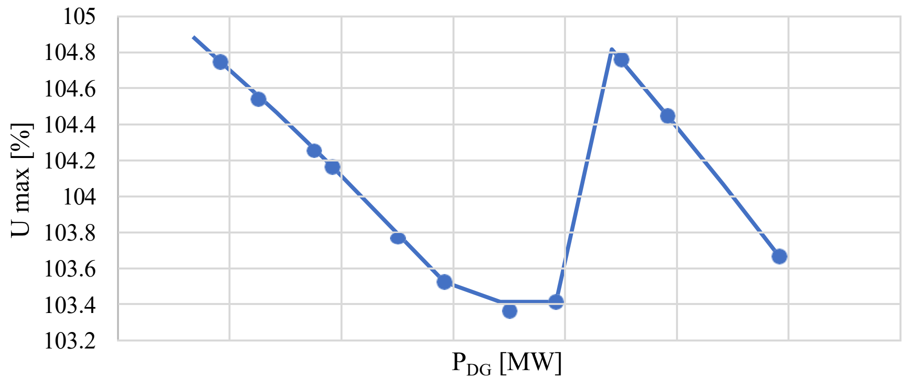


Fig.6. 2.1 Maximum voltage for different source power values, considering cosφ = 1

Observation! In Figure 2, the voltage jump is due to the automatic plot adjustment of the transformers. Depending on the input data, this jump may be missing.

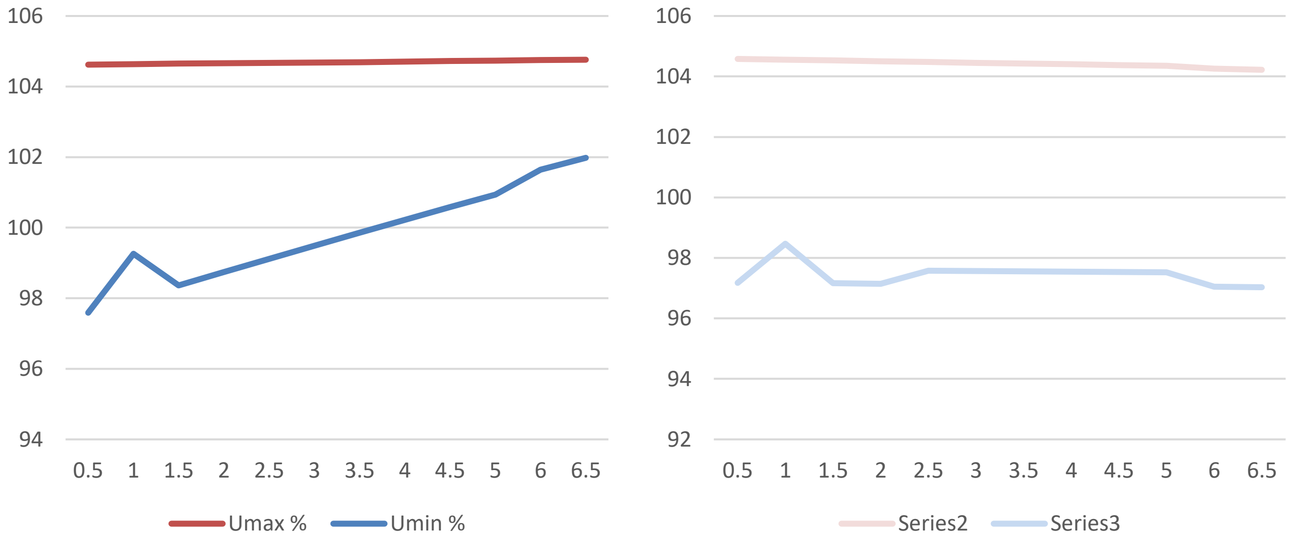


Fig. 6.2.1 Maximum voltage for different source power values, considering cosφ = 1, (a) Solution 1, (b) Solution 2

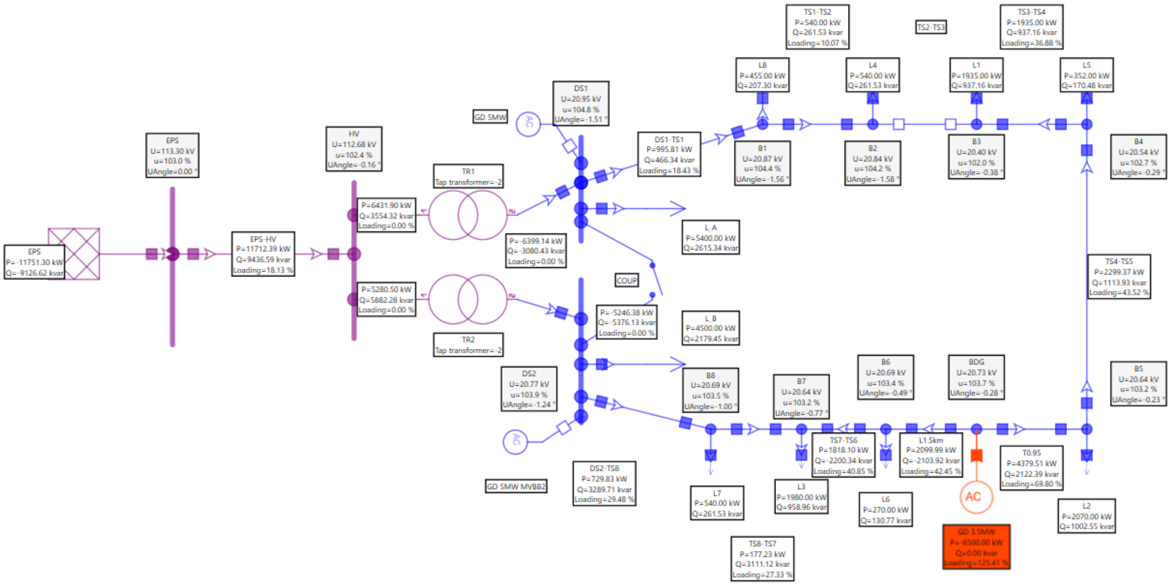


Fig. 6.2.1 Schematic solution 1.

6.3 Voltage level analysis for different types of distributed source generators

Initial conditions:

- DG will be connected one by one in both configurations (solution 1 and solution 2)
- The power of the source is the power corresponding to the minimum losses in the network, $\boldsymbol{P}_{\mathbf{DG,optimal\ value}}$.

For the tap changer control system of power transformers, the value U_{set}=100%.

The variation of voltage levels in MV nodes with or without the connection of the DG source will be analyzed, for a capacitive power factor of 0.9 and an inductive power factor of 0.9.

Table 3. *Voltage levels with and without connection of the distributed source for capacitive operating mode*

cosφ	**U_{set}[%]**	**Bus**	**U[kV] without DG**	**U_{DG}[kV] with DG**	**Δu[%]**
0.9 capacitive	100	1	19.835	19.749	0.43
		2	19.714	19.705	0.05
		3	19.58	19.68	-0.51
		…	…	…	…

$$\Delta \boldsymbol{u} = \frac{\boldsymbol{U_{without\ DG}} - \boldsymbol{U_{with\ DG}}}{\boldsymbol{U_{without\ DG}}} \cdot \mathbf{100} = \cdots [\%]$$

Table 4. Voltage levels with and without connection of the distributed source for inductive mode of operation

cosϕ	**U_{set}[%]**	**Bus**	**U[kV] without DG**	**U_{DG}[kV] with DG**	**u[%]**
0.9 inductive	100	1	19.835	19.833	0.01
		2	19.714	19.746	-0.16
		3	19.58	19.662	-0.42
		…	…	…	…

- U_{set} for power transformers: 100%, 105%, 107.5%
- cosϕ = 0.9 inductive/capacitive
- Power of the distributed source: 20%, 40%, 60%, 80%, 100%

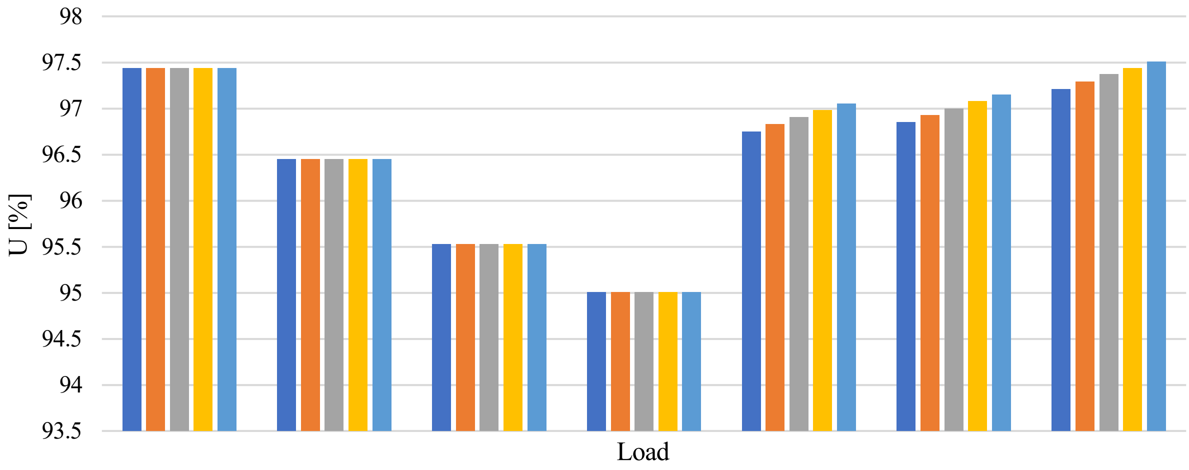


Fig. 3 Voltage level in consuming nodes for Uset=100%, cosϕ=0.9 and 20% to 100% $P_{DG,opt}$

Table 5. *Voltage variation in distributed source connection node and transformer plot for different transformer and power supply settings (cos φ = 0.9 capacitive)*

	P_{DG} [MW]	U_{bus} [%]	TapT2
U set=100%	20% $P_{DG,optimal\ value}$	98.89	0
	40% $P_{DG,optimal\ value}$	97.2	1
	60% $P_{DG,optimal\ value}$	97.62	1
	80% $P_{DG,optimal\ value}$	98.04	1
	100% $P_{DG,optimal\ value}$	98.45	1
U set= 105%	20% $P_{DG,optimal\ value}$	103.33	-2
	40% $P_{DG,optimal\ value}$	103.73	-2
	60% $P_{DG,optimal\ value}$	104.13	-2
	80% $P_{DG,optimal\ value}$	104.52	-2
	100% $P_{DG,optimal\ value}$	104.91	-2
U set = 107.5%	20% $P_{DG,optimal\ value}$	105.66	-3
	40% $P_{DG,optimal\ value}$	106.06	-3
	60% $P_{DG,optimal\ value}$	106.44	-3
	80% $P_{DG,optimal\ value}$	106.82	-3
	100% $P_{DG,optimal\ value}$	107.2	-3

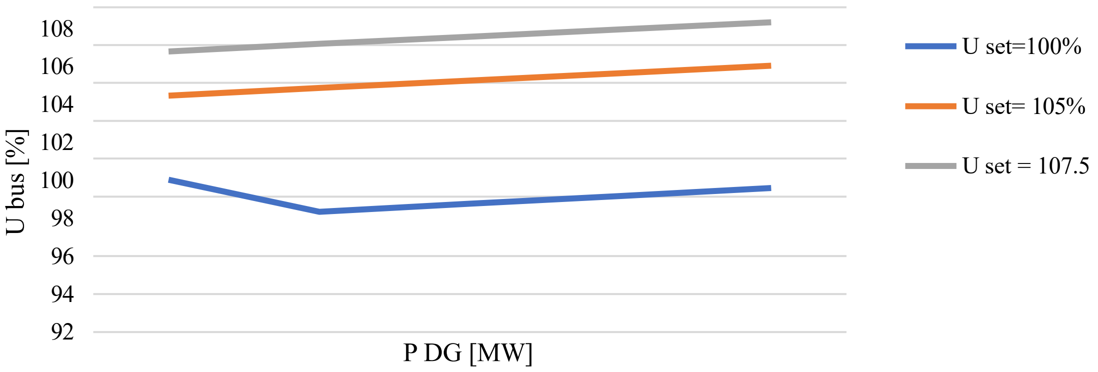


Fig. 4 Voltage variation in the connected node of the distributed source (cosϕ = 0.9 capacitive)

7. Impact of a distributed source on network operating regimes (continuation 2)

7.1. Determining the optimal configuration in the presence of the DG source

Steps:

- DG will be connected one by one in both configurations (solution 1 and solution 2)
- The power of the DG source is the power corresponding to the minimum losses in the network, $P_{DG,optimal\ value}$ (from 3.5) and the power factor is cosφ = 0.9 capacitive
- Uset of 105% - Tap act (in power transformers *Parameters*).

  ! *Make sure you have 21 kV on the MV busbar of the substation.*
- Reactive power compensation – identify Q_{comp} for $cos\varphi_n$=0.9 (similar to 2.1, considering the impact of the DG)
- Reconfiguration of the power grid – identify ***the disconnected section*** for which the active power losses are minimum and the U_{min}, U_{max}, I_{max}, criteria are respected (similar to 2.2, considering the impact of the DG)
- Optimal number of transformers in parallel – identify ***the number of power transformers*** in operation (similar to 2.3, considering the impact of the DG)

7.2. Influence on short-circuit currents for various operating modes

The influence of the DG source on the short-circuit currents on the medium voltage busbar of the substation and in the connection bus will be studied.

In this regard, the voltage of 21 kV at the MV busbar and the optimal configuration determined before are considered.

A three-phase short circuit will be simulated, due to the fact that it is the fault with the highest impact.

The calculation of the short-circuit power will be made with the help of the:

$$S'' = \sqrt{3}U_nI''$$

Table 1. Influence of Current and Short-Circuit Power Following DG source Integration

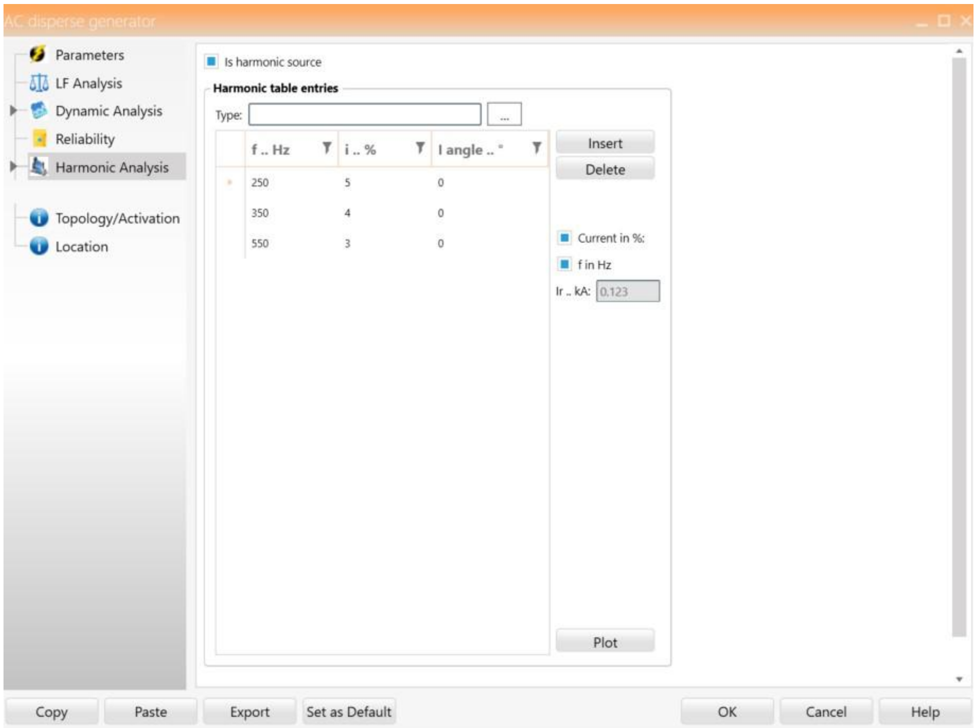
	DG disconnected		**DG connected (cosφ = 0.9 capacitive)**	
Bus	**Ik'' [kA]**	**Sk'' [MVA]**	**Ik'' [kA]**	**Sk'' [MVA]**
MV busbar				
DG connection point				

8. Impact of a distributed source on network operating regimes (continuation 3)

8.1 Calculation of harmonic emission at the common connection point

The following are the steps required to calculate THD at a point in the network:

a. The sources of harmonics are defined in the *AC disperse generator* -> Harmonic Analysis window:



☑ Is harmonic source

Harmonic table entries

Type:

f .. Hz	i .. %	I angle .. °
250	5	0
350	4	0
550	3	0

☑ Current in %:

☑ f in Hz

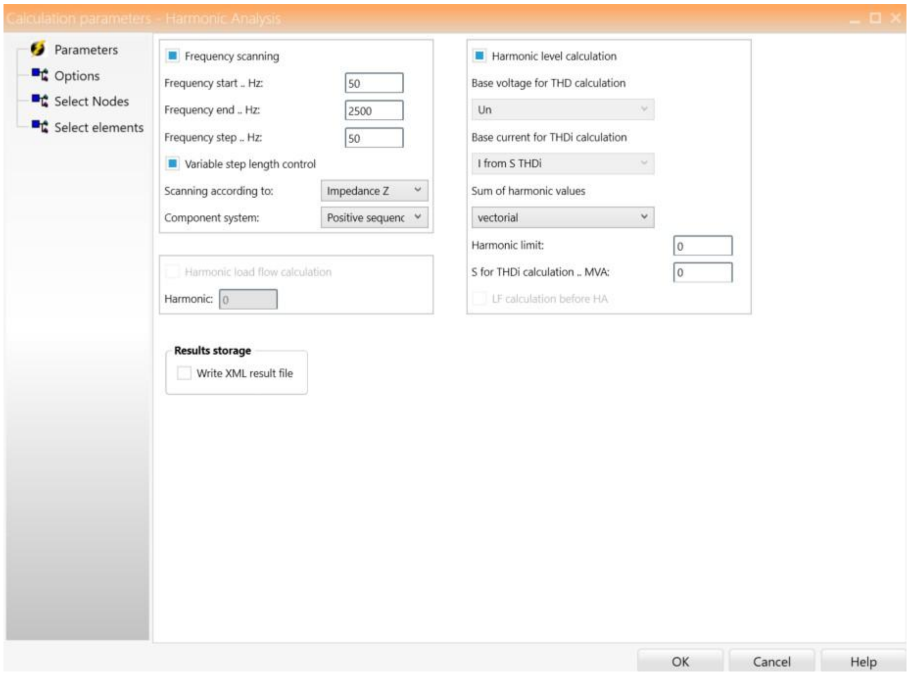
Ir .. kA: 0.123

Fig. 1 Defining the harmonic content for the DG source

Enter the values in percentages of the fundamental of the currents on each harmonic rank (for h5, h7 and h11) . The option "Is harmonic source" must also be checked.

Similarly, loads can be defined as sources of harmonics.

b. From the *Analysis* tab, select *Harmonic Analysis* and set the parameters required for the calculation. The figures below show the necessary settings.



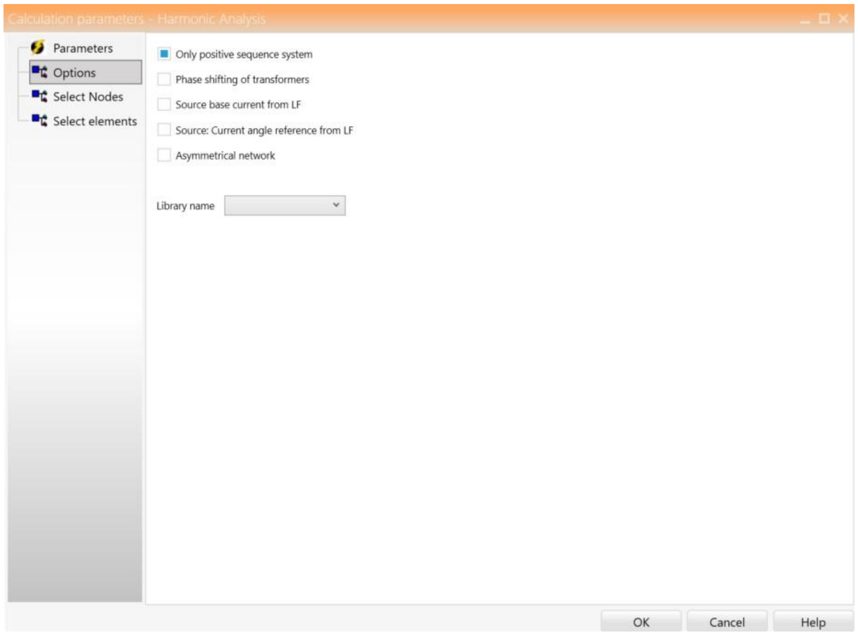
☑ Frequency scanning
Frequency start .. Hz: 50
Frequency end .. Hz: 2500
Frequency step .. Hz: 50
☑ Variable step length control
Scanning according to: Impedance Z
Component system: Positive sequenc

☐ Harmonic load flow calculation
Harmonic: 0

☑ Harmonic level calculation
Base voltage for THD calculation: Un
Base current for THDi calculation: I from S THDi
Sum of harmonic values: vectorial
Harmonic limit: 0
S for THDi calculation .. MVA: 0
☐ LF calculation before HA

Results storage
☐ Write XML result file

Fig. 2. Setting parameters for harmonic calculation

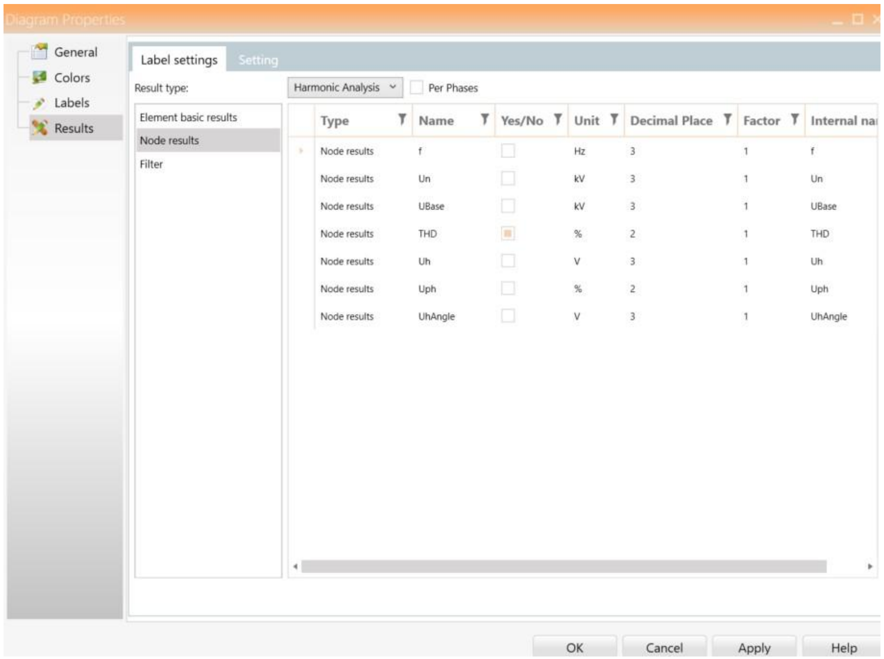


☑ Only positive sequence system
☐ Phase shifting of transformers
☐ Source base current from LF
☐ Source: Current angle reference from LF
☐ Asymmetrical network

Library name

Fig. 3 Setting parameters for harmonic calculation (b)

To view the results, in the *Diagram Properties* box – *Results* – *Node results* you will select the THD option.



Result type: Harmonic Analysis ☐ Per Phases

Element basic results
Node results
Filter

Type	Name	Yes/No	Unit	Decimal Place	Factor	Internal na
Node results	f	☐	Hz	3	1	f
Node results	Un	☐	kV	3	1	Un
Node results	UBase	☐	kV	3	1	UBase
Node results	THD	☑	%	2	1	THD
Node results	Uh	☐	V	3	1	Uh
Node results	Uph	☐	%	2	1	Uph
Node results	UhAngle	☐	V	3	1	UhAngle

Fig. 4 Show THD results on the diagram

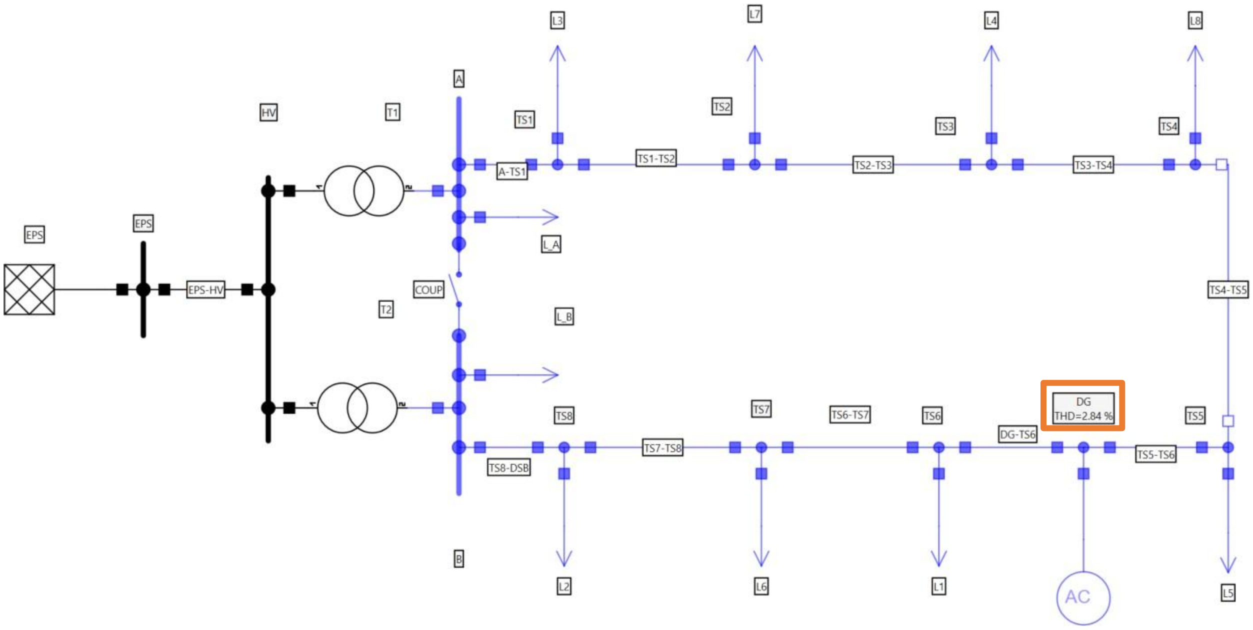


Fig. 5 Results of harmonic calculation

The maximum allowable limits for current harmonics of a distributed generator in Romanian medium voltage networks (6-35 kV) are regulated by ANRE norms and IEC 61000-3-6 standards, with current THD <5-10%.

8.2. Analysis of the operating conditions of the distribution power network for topologies with *N* – 1 elements in operation (power line/power transformer loading, voltage level, slow and rapid voltage variations), for Solution 1

Disconnect one of the power lines near the DG connection point, ensuring that all loads remain powered (it may be necessary to connect the disconnected section considered optimal for unlooping in the reconfiguration process).

Run the power flow analysis and interpret the results.

9. Conclusions

Several network studies were perform to find solutions of flexibility, resilience and minimize power losses for this MV network in radial configuration. For each case, optimal solutions were found.