Solar PV grid connection feasibility study

Report example

Contents

Object description

To connect a Photovoltaic system (PV system) to a low voltage (LV) grid a feasibility study was carried out following IEC standards. The study evaluates the connection of a 250 kW solar power plant to LV Section 2. The network's single line diagram can be found in Annex no. 1. All the calculations were performed using EA-PSM Electric software.

Distribution network short circuit currents

Short circuit currents calculations are based on IEC 60909 standard. Network data is in Table 1.

Table 1 Distribution network short circuit currents

Bus	K3 max	K3 min	K2 max	K2 min	K1 max	K1 min
Section 2	16,749 kA	13,322 kA	14,445 kA	11,453 kA	6,279 A	5,587 A
Section 1	18,134 kA	14,246 kA	15,704 kA	12,336 kA	1,804 A	1,606 A

Distribution network voltage is controlled with 110/10 kV autotransformers, they ensure that the voltage level is about 10.5 kV at the transformer terminals.

Equipment data

The main characteristics for transformers and low voltage cables is provided in Table 2 and Table 3.

Table 2 Transformer data

Title	U_k	P_k	U_n(W1)	U_n(W2)	S_N	Connection ...	Connection ...
TR2 110	6 %	120 kW	110 kV	10,5 kV	20 MVA	Grounded star	Star
TR1 110	6 %	120 kW	110 kV	10 kV	20 MVA	Grounded star	Star
TR2 10	6 %	8,8 kW	10 kV	400 V	1 MVA	Delta	Grounded star
TR1 10	6 %	8,8 kW	10 kV	400 V	1 MVA	Delta	Grounded star

Table 3 Cable data

Title	Resistance	Reactance	Capacitance	Conductor types
L-LV Section 2-Bus 15	10,309 mΩ	8,038 mΩ	400 pF	NYY-J Cu PVC 1.0kV 2...
L-LV Section 2-Bus 16	2,788 mΩ	747,32 μΩ	10 pF	NYY-J Cu PVC 1.0kV 3...
L-LV Section 2-Bus 17	9,55 mΩ	4,332 mΩ	60 pF	NYY-J Cu PVC 1.0kV 4...
L-LV Section 1-Bus 18	14,512 mΩ	11,1 mΩ	196,5 nF	Polycab Cu PVC 1.1kV ...
L-LV Section 1-Bus 19	2,788 mΩ	747,32 μΩ	10 pF	NYY-J Cu PVC 1.0kV 3...
L-LV Section 1-Bus 20	3,225 mΩ	2,467 mΩ	393 nF	Polycab Cu PVC 1.1kV ...
L-LV Section 2-Bus 21	16,109 mΩ	4,084 mΩ	56 nF	AXMK-PLUS Al PVC 1....

AC CABLE SELECTION

Cable ampacity

Firstly, in this study low voltage, AC cables for solar power plant inverters are selected. When connecting a PV system to the grid it is important to choose the cables according to the maximum output power of the inverter. The permitted currents for the cables are calculated as stated in IEC 60364-5-52 standard.

Maximum long term current from inverter: 250 kW ⟶ 360 A

For 250 kW inverter 2(4×120) AL cables line is selected. Cable ampacity calculation results are depicted in Figure 1.

Derated ampacity for AL 1(4×120) cable is 212 A. Therefore, 2 parallel cables must be used to ensure cable line capability in case of maximum long-term current. Two parallel cables will ensure 424 A line permitted current and about 17% safety margin. One step smaller cables line 2(4×95) would only allow 364 A maximum current, therefore, is not recommended due to the small safety margin.

Results

Calculations are based on IEC 60364-5-52 standard

Cable derating factors	
Ambient temperature derating factor (B.52-14)	**1**
Grouping derating factor (B.52-21)	**0,86**
Total derating factor	**0,86**
Cable ampacity rating	
Cable ampacity rating	**247 A**
Derated ampacity rating	**212 A**

Figure 1 Cable ampacity

Voltage drop calculations

Voltage drop calculation results in the selected cable line are depicted in Figure 2.

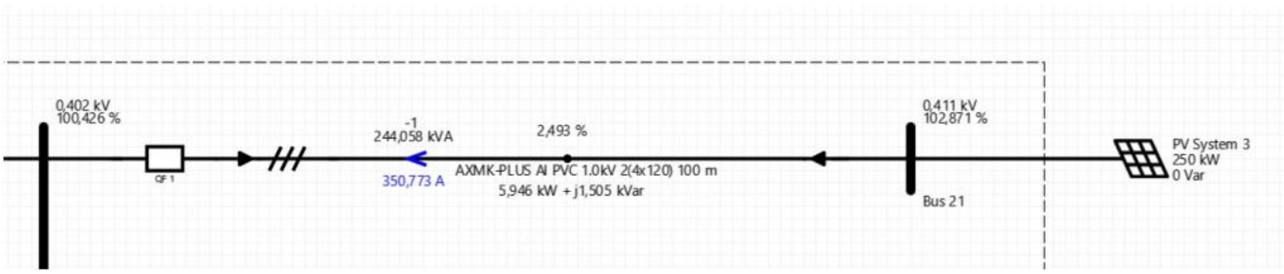


Figure 2 Voltage drop results

The maximum voltage drop is equal to 2,493%. When the voltage in LV Section 2 bus is less than 107%, the voltage at solar inverter terminals will not exceed the permitted 10% overvoltage limit. Voltage calculation results with different transformer tap positions:
TAP = -1

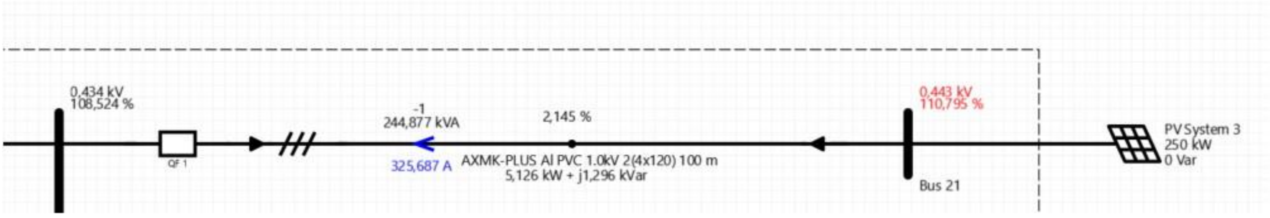


Figure 3 Voltage drop results at tap position -1

TAP = 0

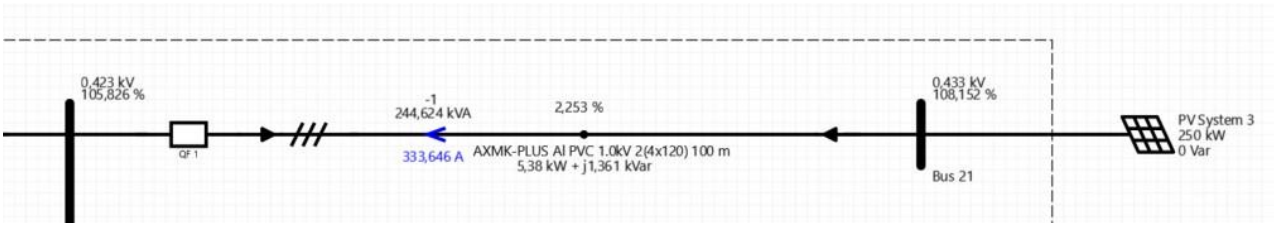


Figure 4 Voltage drop results at tap position 0

Calculation results show, that setting transformer tap changer position TAP = -1 or TAP = -2 should not be allowed.

Economic cable sizing

We will use the energy yield coefficient for inverter power derating to calculate annual power losses in the selected cable line. According to historical solar irradiation data, the energy yield coefficient is equal to 30%. Power losses calculation results with this energy yield coefficient are depicted in Figure 5.

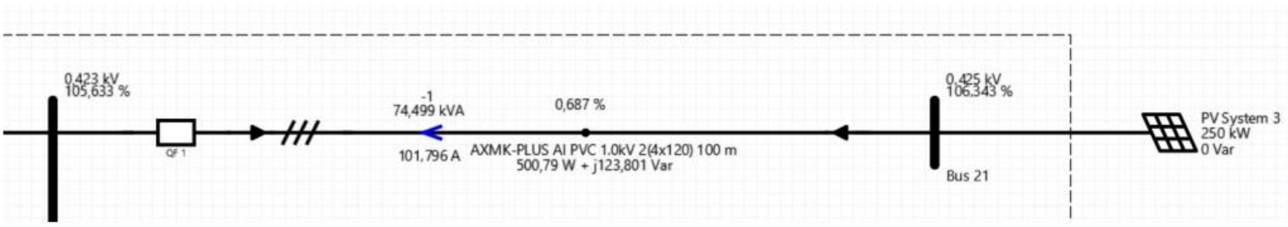


Figure 5 Power losses calculation results

Calculated average energy losses are equal to 500 W. Annual energy losses in cable lines are equal to 4380 kWh. The average electricity price is assumed to be 0.07 Eur/kWh. Annual financial losses due to power losses in the cable are equal to 306 Eur.

One step bigger cable line AL 2(4×150) would allow saving 876 kWh (61 Eur) per year, therefore, it is not economically beneficial to increase the cross-section area of the cable.

GRID CONNECTION FEASIBILITY STUDY

After selecting proper cables the grid connection feasibility study can be performed. In this study such calculations will be carried out:

- Network Short Circuit Power
- Voltage Calculation
- Voltage Fluctuation
- Harmonic Calculation
- Load Flows Calculation
- Short Circuit Current Calculation

Network Short Circuit Power

To begin the feasibility study network short circuit power will be evaluated. The power of the solar plant is 250 kW=0.25 MW. Medium voltage Section 2 calculated the maximum short circuit current is 16.676 kA. Network short circuit power is as follows:

$$Sgrid = 1.73UI = 1.73*10500*16676=302.9 \text{ MVA}$$

The ratio between network short circuit power and solar plant power:

$$r = (Spv/Sgrid)*100\% = 0.25/302.9 = 0.08\%$$

Because r < 0.1% power plant impact to voltage level and power quality in the distribution network is minimal and IEC 61000-3-7 standard does not limit the number of voltage changes.

Voltage calculation

After determining short circuit power the voltage is evaluated. Let us estimate minimum loading conditions (all distribution network loads will consume 0% of their nominal power). When the solar power plant is working at full power, the voltage level at medium voltage Section 2 bus is equal to 10.503 kV (105.033%). Due to generation loss from the solar power plant, the voltage would go down to 10.502 kV (105.023%). As a result, the voltage difference is only 0.01%, therefore, the autotransformer will not change tap position.

Not only does the no-load operation mode must be determined but also the maximum loading conditions have to be evaluated (all distribution network loads will consume 100% from their nominal power). When the solar power plant is working at full power, the voltage at medium voltage Section 2 bus is equal to 10.548 kV (105.478%). Due to generation loss from the solar power plant, the voltage would go down to 10.547 kV (105.466%). As a result, the voltage difference is only 0.012%, therefore, the autotransformer will not change tap position.

In conclusion, power losses from the solar power plant's effect on voltage levels in the distribution network are negligible.

Voltage fluctuation

Next voltage fluctuation will be analyzed. Voltage fluctuation coefficient is calculated according to IEC 61000-3-7 standard using the following formula:

$$Pst = 0.5 * d * Pst2$$

The maximum value of P_{st2} (equal to 5.6) will be assumed in this calculation. Voltage difference d is calculated in the previous section (voltage level). The maximum voltage fluctuation coefficient is equal to:

$$Pst = 0.5 * 0.012\% * 5.6 = 0.0336$$

According to IEC 61000-3-7 standard allowable P_{st} value is < 1. Therefore, the solar power plant will not cause voltage fluctuations.

Harmonics calculation

Let's evaluate harmonic distortions next. Calculated current harmonics in TR2 10 are depicted in Figure 6.

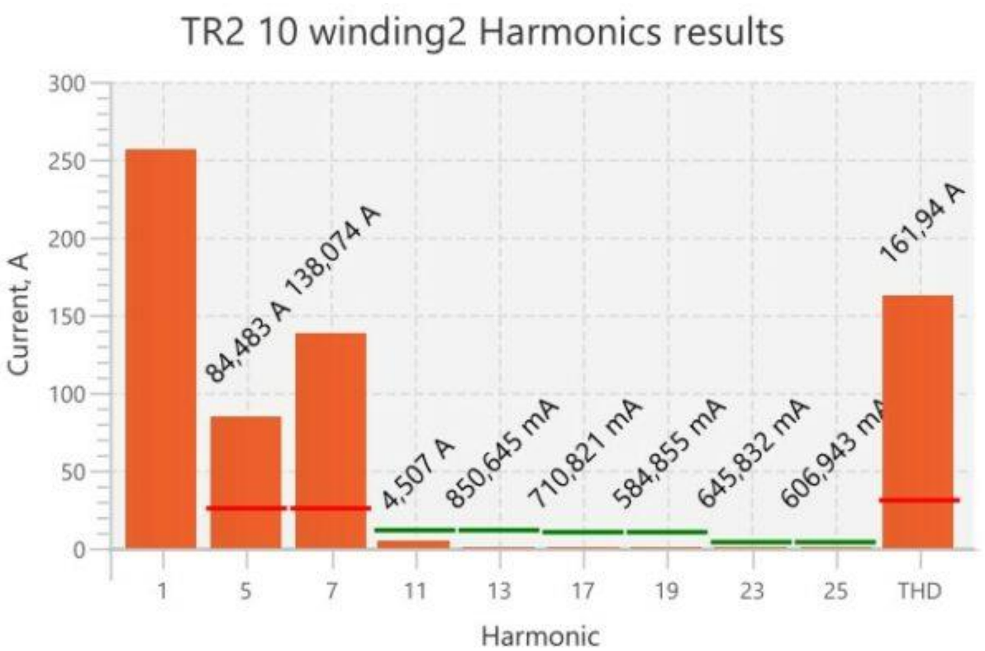


Figure 6 Current harmonics

According to calculation results, we can see that the 5th and the 7th harmonics exceed IEEE 519 standard allowable limit. For this reason, we select the detuned passive harmonics filter. Reactor parameters for the filter are depicted in Table 4.

Table 4 Reactor parameters for the filter

R	X	U_k	P_k	U_n	S_N
100 nΩ	100 nΩ	4 %	1 kW	400 V	200 kVA

Harmonic results with the detuned reactor are depicted in .

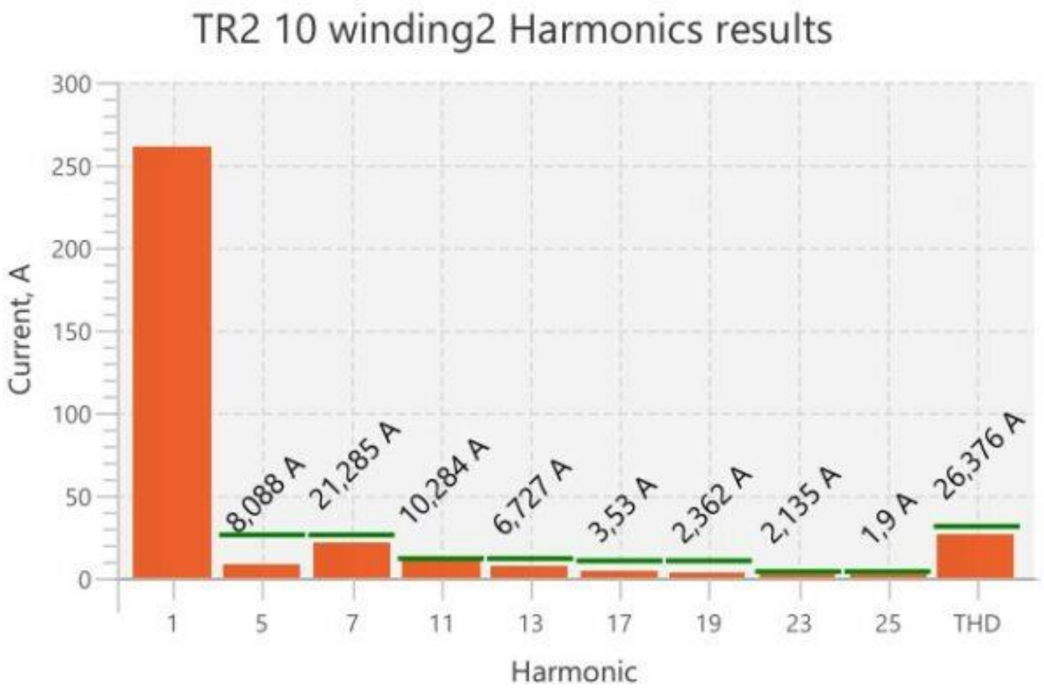


Figure 7 Current harmonics with detuned reactor

After adding the filter, all harmonics are within permissible limits. The detuned filter is the cheapest option to reduce higher harmonics. Other possible alternatives are active filters and tuned passive filters.

Load flows calculation results (maximum load and generation conditions)

In addition to previously carried out, calculations load flows have to also be assessed. Results for the maximum load and generation conditions can be found in Table 5and Table 6.

Table 5 Load flow results

Title	Voltage level	Ux	Ux, %	δ
Sekcija II	110 kV	110 kV	100 %	0
Bus 1	110 kV	110 kV	100 %	0
Section 2	10 kV	10,547 kV	105,474 %	-1,351
Bus 3	10 kV	10,124 kV	101,242 %	-1,829
Bus 4	10 kV	10,483 kV	104,831 %	-1,396
Bus 5	10 kV	10,545 kV	105,45 %	-1,367
Bus 6	10 kV	10,426 kV	104,262 %	-1,437
LV Section 2	400 V	412,507 V	103,127 %	28,049
LV Section 1	400 V	397,377 V	99,344 %	27,686
Bus 9	10 kV	10,477 kV	104,766 %	-1,257
Bus 9	10 kV	10,43 kV	104,298 %	-1,318
Bus 9	10 kV	10,495 kV	104,948 %	-1,247
Bus 9	10 kV	10,465 kV	104,65 %	-1,265
Bus 9	110 kV	110 kV	100 %	0
Section 1	10 kV	10,497 kV	104,967 %	-1,242
Bus 15	400 V	399,513 V	99,878 %	27,403
Bus 16	400 V	412,897 V	103,224 %	27,841
Bus 17	400 V	412,507 V	103,127 %	28,049
Bus 18	400 V	404,514 V	101,129 %	28,477
Bus 19	400 V	397,819 V	99,455 %	27,446
Bus 20	400 V	391,734 V	97,934 %	27,519
Bus 21	400 V	422,042 V	105,511 %	28,385
Bus 22	400 V	429,952 V	107,488 %	27,54

Table 6 Load flow results

Title	I	ΔU	ΔU, %	cosφ	Sij	ΔP
TR2 110 windin...	46,256 A	1,433 kV	1,302 %	0,948	8,813 MVA	11,65 kW
TR2 110 windin...	475,869 A	134,293 V	1,26 %	0,951	8,738 MVA	11,235 kW
L-Bus 2	120,042 A	431,912 V	4,053 %	0,947	2,193 MVA	77,815 kW
L-Bus 9	116,537 A	68,343 V	0,645 %	0,95	2,119 MVA	11,953 kW
TR1 110 windin...	46,535 A	1,38 kV	1,255 %	0,947	8,866 MVA	11,791 kW
TR1 110 windin...	481,353 A	117,98 V	1,113 %	0,95	8,791 MVA	10,427 kW
TR2 10 winding1	10,315 A	54,973 V	0,516 %	0,911	188,4 kVA	140,45 W
TR2 10 winding2	261,946 A	2,234 V	0,537 %	0,907	186,861 kVA	144,916 W
TR1 10 winding1	17,296 A	94,604 V	0,892 %	0,998	314,402 kVA	394,89 W
TR1 10 winding2	452,267 A	3,958 V	0,983 %	0,999	311,857 kVA	432 W
L-LV Section 2-...	608,477 A	13,778 V	3,315 %	0,946	434,747 kVA	11,451 kW
L-LV Section 2-...	310,292 A	1,551 V	0,373 %	0,01	221,698 kVA	805,294 W
L-LV Section 2-...	4,489 μA	0 V	0 %	0	3,207 mVA	0 W
L-LV Section 1-...	285,454 A	9,033 V	2,243 %	-1	196,471 kVA	3,548 kW
L-LV Section 1-...	344,522 A	1,722 V	0,428 %	0,004	237,126 kVA	992,768 W
L-LV Section 1-...	818,783 A	5,758 V	1,429 %	0,899	563,55 kVA	6,486 kW
L-LV Section 2-...	341,998 A	9,844 V	2,368 %	-1	244,352 kVA	5,653 kW
[R] Bus 16	310,292 A	17,198 V	4,138 %	0,006	221,908 kVA	1,155 kW

The blue color indicates that the current exceeds recommended economical limit (1 mm² = 1 A). Orange and yellow indicate a higher than recommended voltage drop in the cable.

Short circuit results

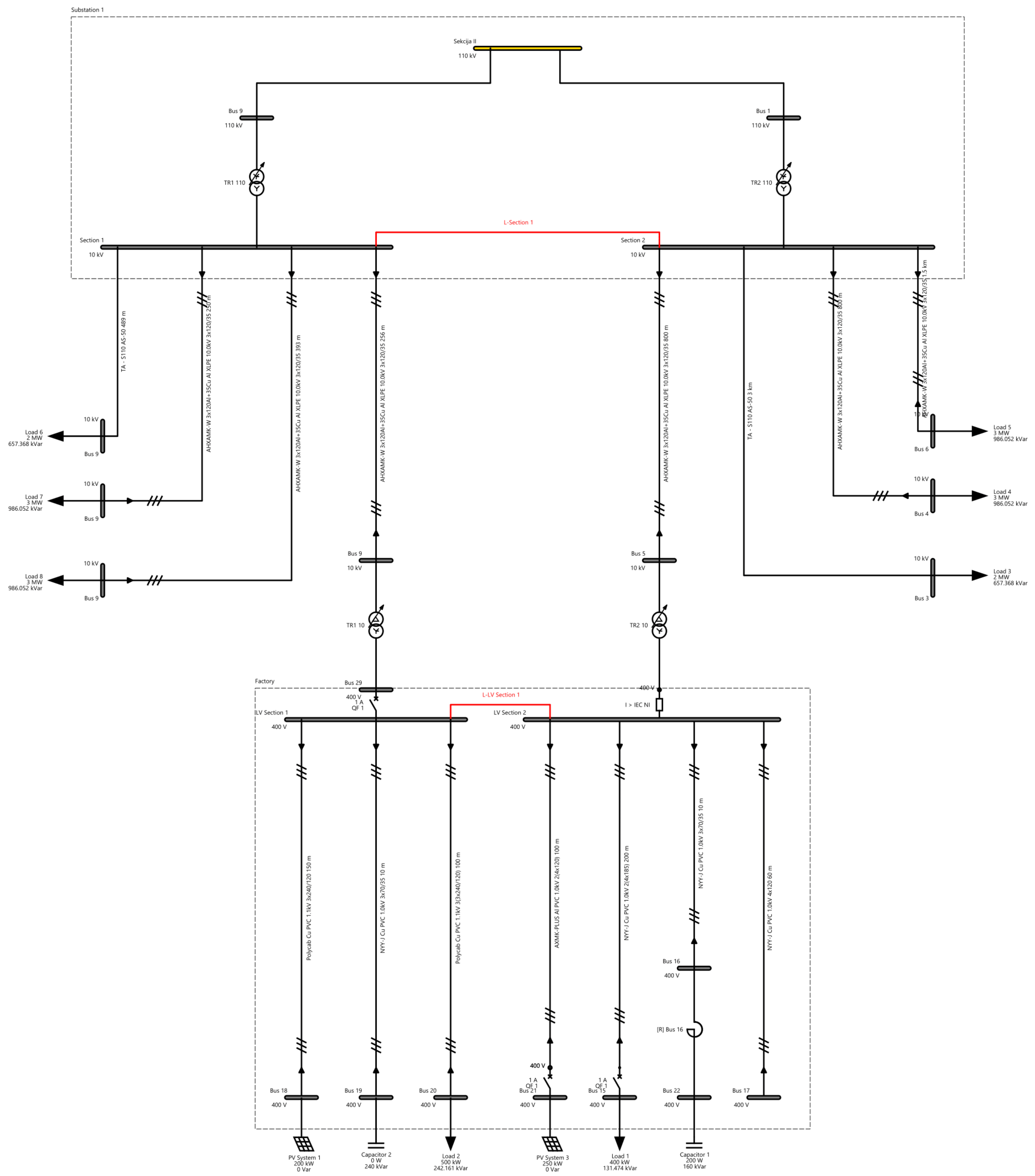
Finally, short circuit analysis is conducted. The result can be found in Table 7. Types of short circuits:

- K3 – three-phase short circuit;
- K2 – phase-to-phase short circuit;
- K1 – phase-to-earth short circuit;
- K1,1 – two-phase-to-earth short circuit.

Table 7 Short circuit analysis results

Bus	K3 max	K3 min	K2 max	K2 min	K1 max	K1 min	K11 max	K11 min
Sekcija II	13,82 kA	5,859 kA	11,969 kA	5,074 kA	14,334 kA	6,946 kA	13,82 kA	5,859 kA
Bus 1	13,82 kA	5,859 kA	11,969 kA	5,074 kA	14,334 kA	6,946 kA	13,82 kA	5,859 kA
Section 2	16,749 kA	13,322 kA	14,445 kA	11,453 kA	6,279 A	5,587 A	16,679 kA	13,225 kA
Bus 3	2,734 kA	2,399 kA	2,367 kA	2,075 kA	6,292 A	5,368 A	2,733 kA	2,396 kA
Bus 4	12,055 kA	9,879 kA	10,406 kA	8,507 kA	6,28 A	5,551 A	12,016 kA	9,824 kA
Bus 5	12,066 kA	9,849 kA	10,415 kA	8,482 kA	6,281 A	5,585 A	12,027 kA	9,795 kA
Bus 6	9,258 kA	7,754 kA	7,997 kA	6,686 kA	6,281 A	5,52 A	9,235 kA	7,72 kA
LV Section 2	24,435 kA	21,605 kA	21,066 kA	18,612 kA	25,114 kA	22,15 kA	24,328 kA	21,495 kA
LV Section 1	24,855 kA	22,004 kA	21,525 kA	19,054 kA	25,077 kA	22,1 kA	24,856 kA	22,003 kA
Bus 9	16,254 kA	12,907 kA	14,076 kA	11,176 kA	1,804 A	1,603 A	16,254 kA	12,906 kA
Section 1	18,134 kA	14,246 kA	15,704 kA	12,336 kA	1,804 A	1,606 A	18,134 kA	14,245 kA
Bus 15	11,631 kA	10,318 kA	10,044 kA	8,906 kA	3,033 kA	2,601 kA	11,599 kA	10,285 kA
Bus 16	21,267 kA	18,695 kA	18,33 kA	16,103 kA	17,257 kA	15,169 kA	21,168 kA	18,597 kA
Bus 17	13,775 kA	12,058 kA	11,888 kA	10,401 kA	7,08 kA	6,216 kA	13,728 kA	12,011 kA
Bus 18	9,839 kA	8,582 kA	8,521 kA	7,431 kA	3,563 kA	3,112 kA	9,84 kA	8,581 kA
Bus 19	21,709 kA	19,066 kA	18,801 kA	16,509 kA	17,303 kA	15,167 kA	21,71 kA	19,065 kA
Bus 20	18,938 kA	16,789 kA	16,401 kA	14,538 kA	5,646 kA	4,893 kA	18,939 kA	16,788 kA
Bus 21	11,639 kA	10,175 kA	10,05 kA	8,783 kA	5,221 kA	4,586 kA	12,818 kA	11,204 kA
Bus 22	5,828 kA	5,126 kA	5,042 kA	4,432 kA	5,566 kA	4,89 kA	5,822 kA	5,119 kA

ANNEX NO. 1



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Rev.	Date of issue	Reason of change			
Certificate No.	EA-PSM	UAB Energy Advice K. Barsauskas str. 59, LT-51423 Kaunas			
			2021-07-27	Single line diagram example with EA-PSM	Rev.
			2021-07-27		
			2021-07-27		
Stage				EXAMPLE	Sheet: 1 / Pages: 1