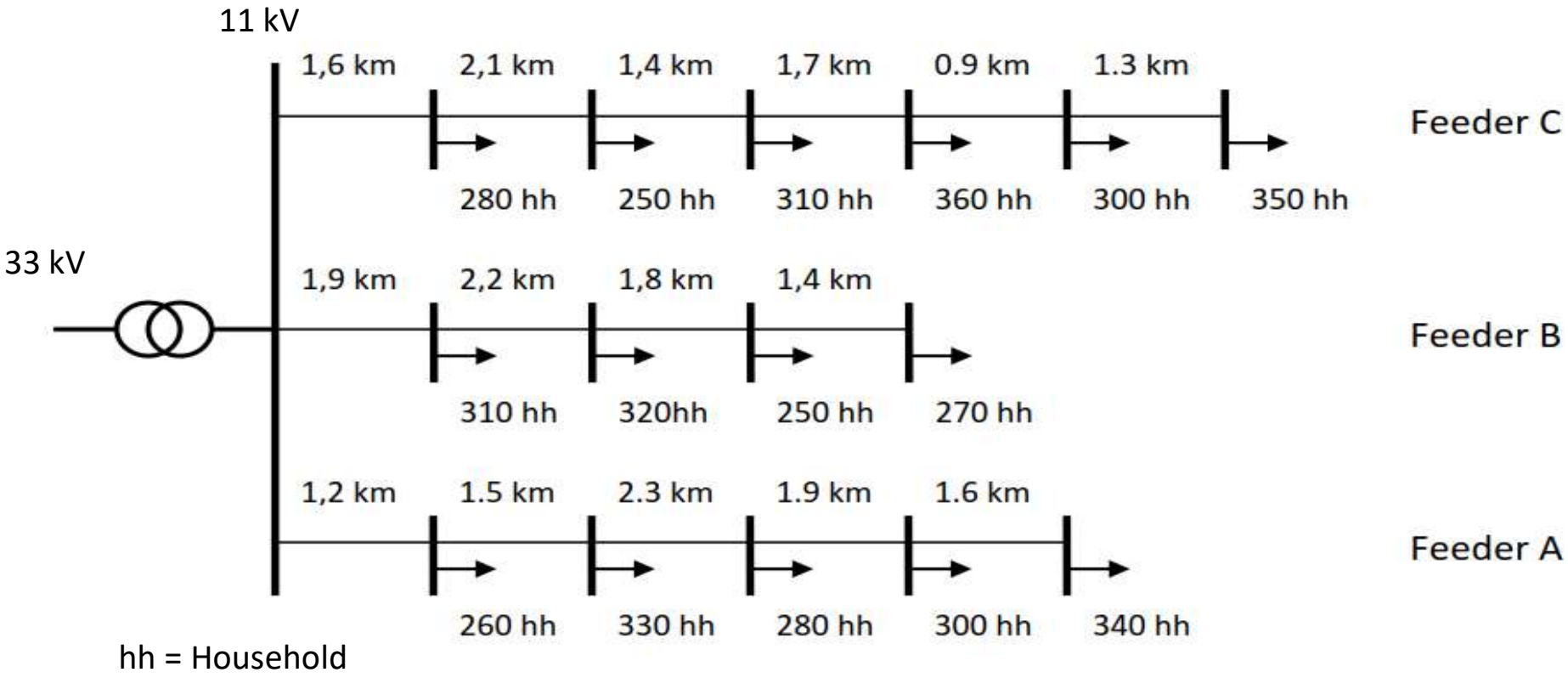
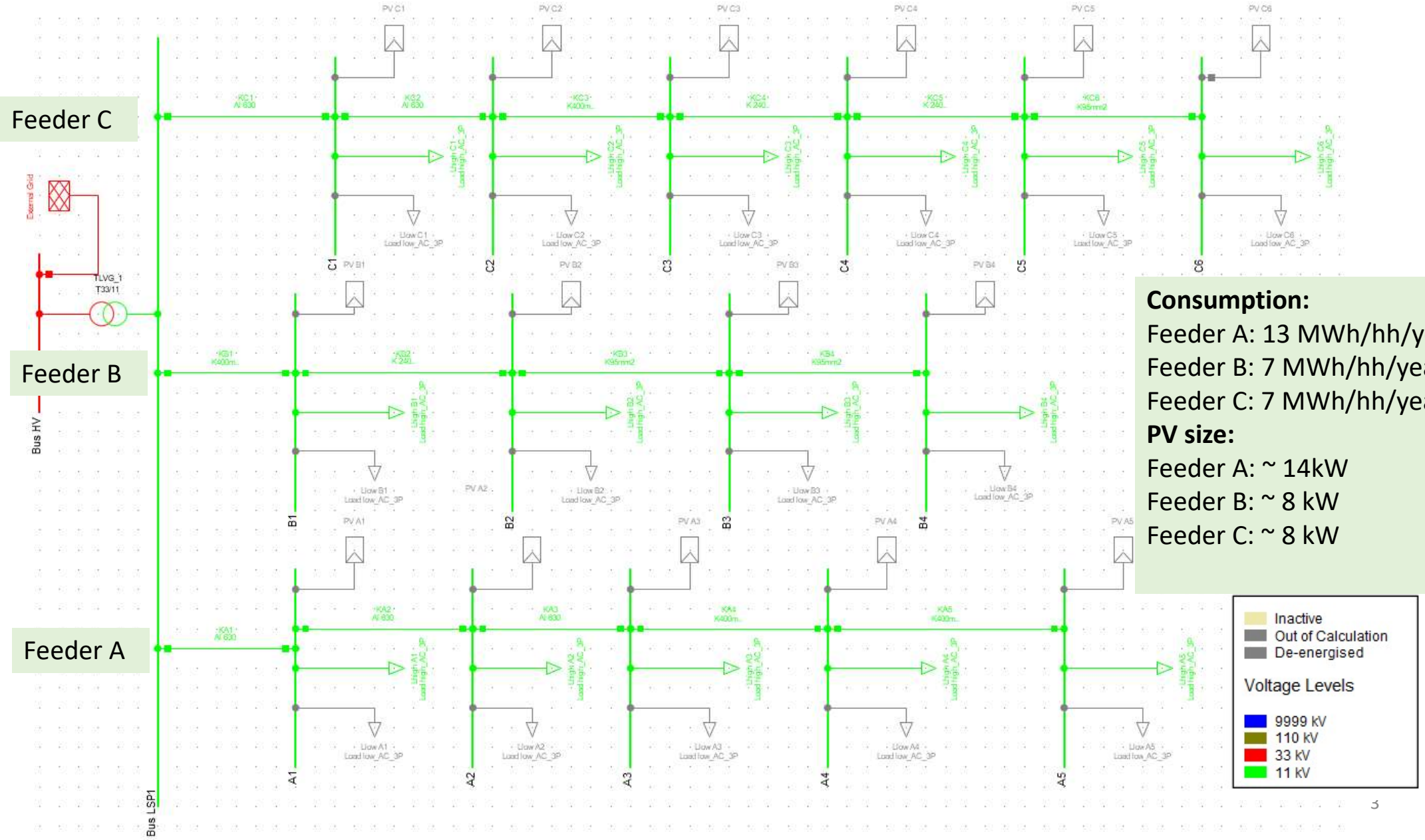
Session 3

Losses from increased level of RE - 11 kV PF case study

Homework



hh = Household


Feeder C
Feeder B
Feeder A
External Grid
TLVG_1
T33/11
Bus HV
Bus LSP1
PV C1
PV C2
PV C3
PV C4
PV C5
PV C6
PV B1
PV B2
PV B3
PV B4
PV A1
PV A2
PV A3
PV A4
PV A5
C1
C2
C3
C4
C5
C6
B1
B2
B3
B4
A1
A2
A3
A4
A5
Consumption:
Feeder A: 13 MWh/hh/year
Feeder B: 7 MWh/hh/year
Feeder C: 7 MWh/hh/year
PV size:
Feeder A: ~ 14kW
Feeder B: ~ 8 kW
Feeder C: ~ 8 kW
Inactive
Out of Calculation
De-energised
Voltage Levels
9999 kV
110 kV
33 kV
11 kV

Case Study- PF SSEG

- 11 kV grid with three feeders, A, B and C and 4510 attached households
- The 11 kV grid is connected to single feeding source, a 33 kV distribution grid. Here named “External Grid”(top-down) (slack)
- Let’s study some cases and see how the loss pattern changes with SSEG

Assumptions:
??
??

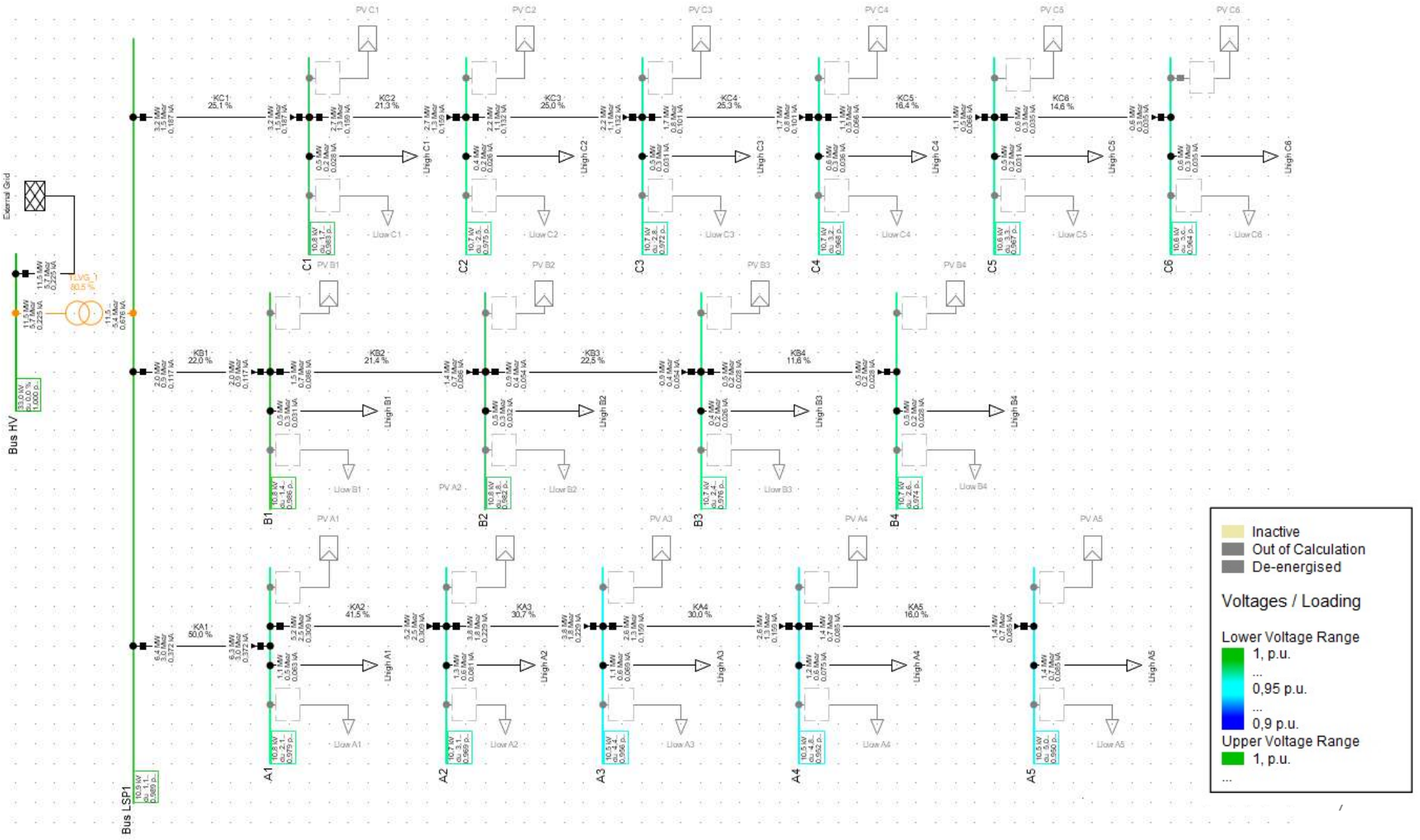
Case Study- PF SSEG

- 11 kV grid with three feeders, A, B and C and 4510 attached households
- The 11 kV grid is connected to single feeding source, a 33 kV distribution grid. Here named “External Grid”(top-down) (slack)
- Let’s study some cases and see how the loss pattern changes with SSEG
- Assumptions and questions:
- Voltage will increase locally
- Consumption close to the production – reduced distribution
- → Reduced system losses
- Increased share of SSEG – exceeding production compared to consumption
- More distribution throughout the grid
- → increased losses
- But where is the breaking point?
- What solutions can be used to enable more SSEG?

Case 1 – External Grid keeps active power balance

- External Grid keeps active power balance (slack)
- The house hold loads are at their highest
- No SSEG connected

- This case represents the base case, no SSEG and high load is the “worst” operating case for the power grid during these conditions.


External Grid
Bus HV
TLVG_1
80,5 %
Bus LSP1
PV C1
PV C2
PV C3
PV C4
PV C5
PV C6
KC1
25,1 %
KC2
21,3 %
KC3
25,0 %
KC4
25,3 %
KC5
16,4 %
KC6
14,6 %
C1
C2
C3
C4
C5
C6
PV B1
PV B2
PV B3
PV B4
KB1
22,0 %
KB2
21,4 %
KB3
22,5 %
KB4
11,6 %
B1
B2
B3
B4
PV A1
PV A2
PV A3
PV A4
PV A5
KA1
50,0 %
KA2
41,5 %
KA3
30,7 %
KA4
30,0 %
KA5
16,0 %
A1
A2
A3
A4
A5
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 1 – External Grid keeps active power balance

- External Grid keeps active power balance (slack)
- The house hold loads are at their highest
- No SSEG connected

- This case represents the base case, no SSEG and high load is the "worst" operating case for the power grid during these conditions.

- Grid losses: 0.32MW
- Voltages decreasing due to high consumption from hh

Case 1 – External Grid keeps active power balance

Load Flow Calculation					Grid Summary
AC Load Flow, balanced, positive sequence			Automatic Model Adaptation for Convergence		No
Automatic tap adjustment of transformers		No	Max. Acceptable Load Flow Error for		
Consider reactive power limits		No	Nodes		1,00 kVA
			Model Equations		0,10 %

Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 1

Grid: LV-Grid Summary

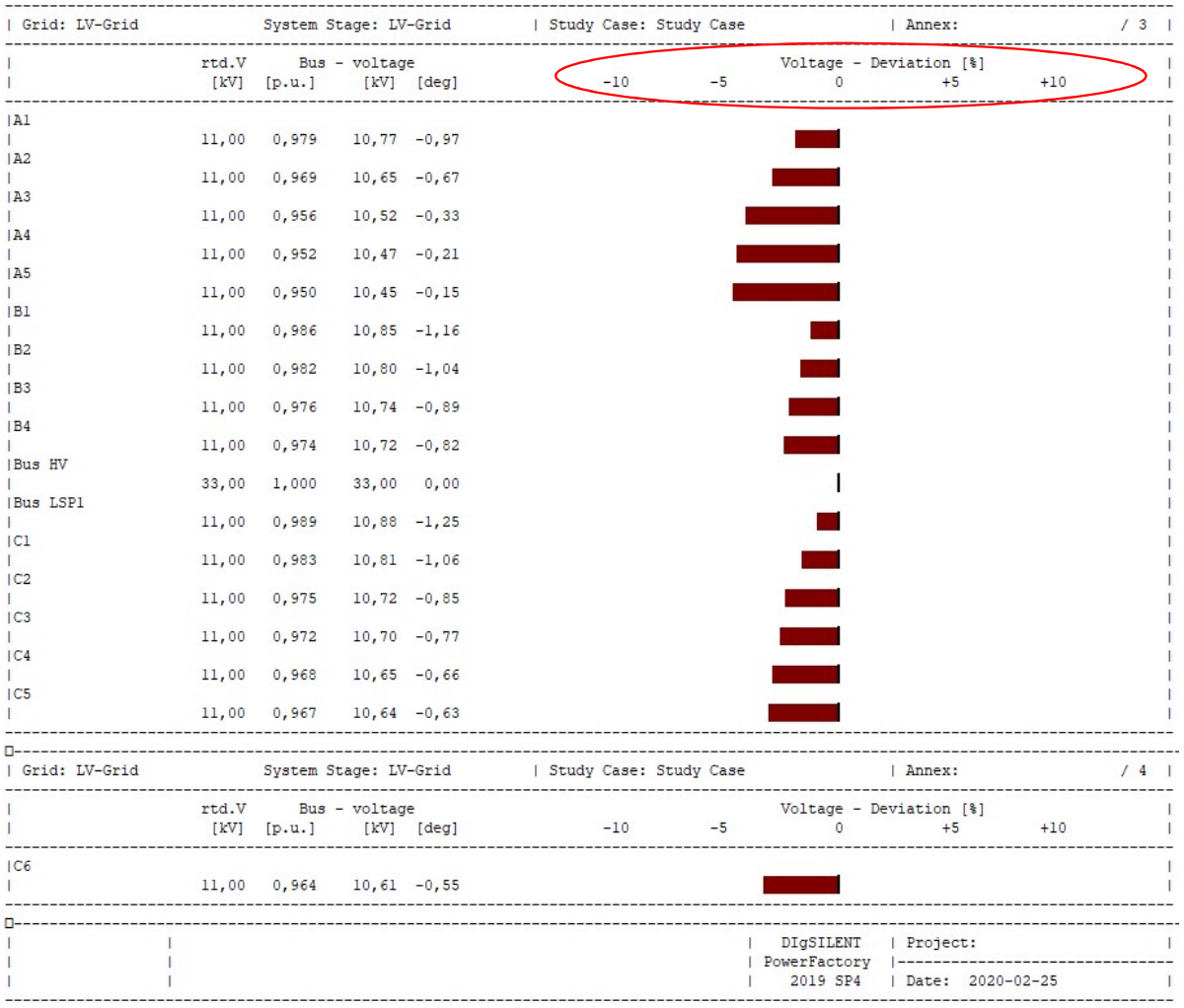
No. of Substations	0	No. of Busbars	17	No. of Terminals	0	No. of Lines	15
No. of 2-w Trfs.	1	No. of 3-w Trfs.	0	No. of syn. Machines	0	No. of asyn.Machines	0
No. of Loads	15	No. of Shunts/Filters	0	No. of SVS	0		

Generation	=	0,00	MW	0,00	Mvar	0,00 MVA
External Infeed	=	11,53	MW	5,74	Mvar	12,88 MVA
Inter Grid Flow	=	0,00	MW	0,00	Mvar	
Load P(U)	=	11,21	MW	5,43	Mvar	12,46 MVA
Load P(Un)	=	11,21	MW	5,43	Mvar	12,46 MVA
Load P(Un-U)	=	-0,00	MW	-0,00	Mvar	
Motor Load	=	0,00	MW	0,00	Mvar	0,00 MVA
Grid Losses	=	0,32	MW	0,31	Mvar	
Line Charging	=			0,00	Mvar	
Compensation ind.	=			0,00	Mvar	
Compensation cap.	=			0,00	Mvar	
Installed Capacity	=	0,00	MW			
Spinning Reserve	=	0,00	MW			

Total Power Factor:

Generation	=	0,00	[-]
Load/Motor	=	0,90 / 0,00	[-]

Case 1 – External Grid keeps active power balance



Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 3

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
A1					
	11,00	0,979	10,77	-0,97	
A2					
	11,00	0,969	10,65	-0,67	
A3					
	11,00	0,956	10,52	-0,33	
A4					
	11,00	0,952	10,47	-0,21	
A5					
	11,00	0,950	10,45	-0,15	
B1					
	11,00	0,986	10,85	-1,16	
B2					
	11,00	0,982	10,80	-1,04	
B3					
	11,00	0,976	10,74	-0,89	
B4					
	11,00	0,974	10,72	-0,82	
Bus HV					
	33,00	1,000	33,00	0,00	
Bus LSP1					
	11,00	0,989	10,88	-1,25	
C1					
	11,00	0,983	10,81	-1,06	
C2					
	11,00	0,975	10,72	-0,85	
C3					
	11,00	0,972	10,70	-0,77	
C4					
	11,00	0,968	10,65	-0,66	
C5					
	11,00	0,967	10,64	-0,63	

Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 4

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
C6					
	11,00	0,964	10,61	-0,55	

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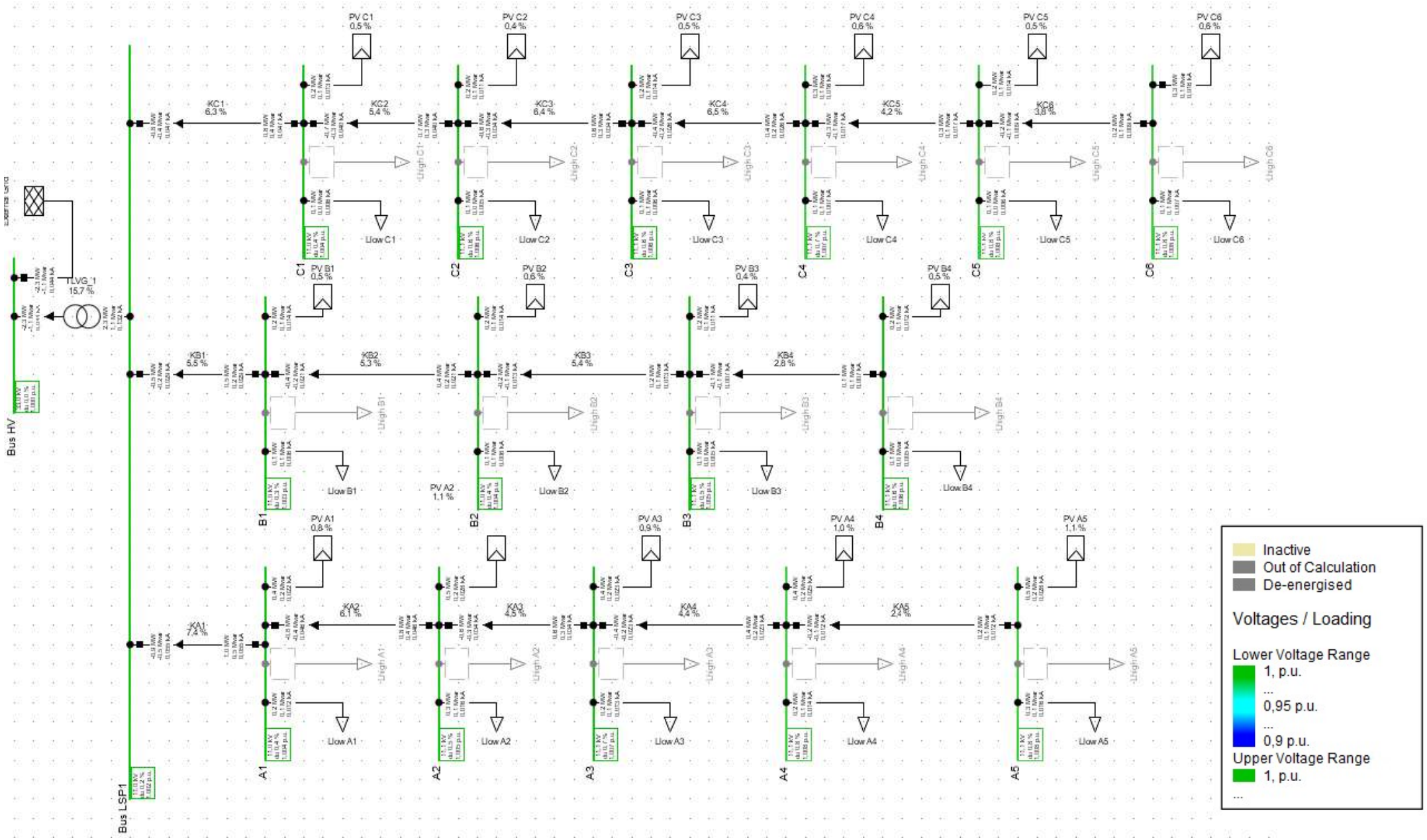
Different share of SSEG connected to the grid

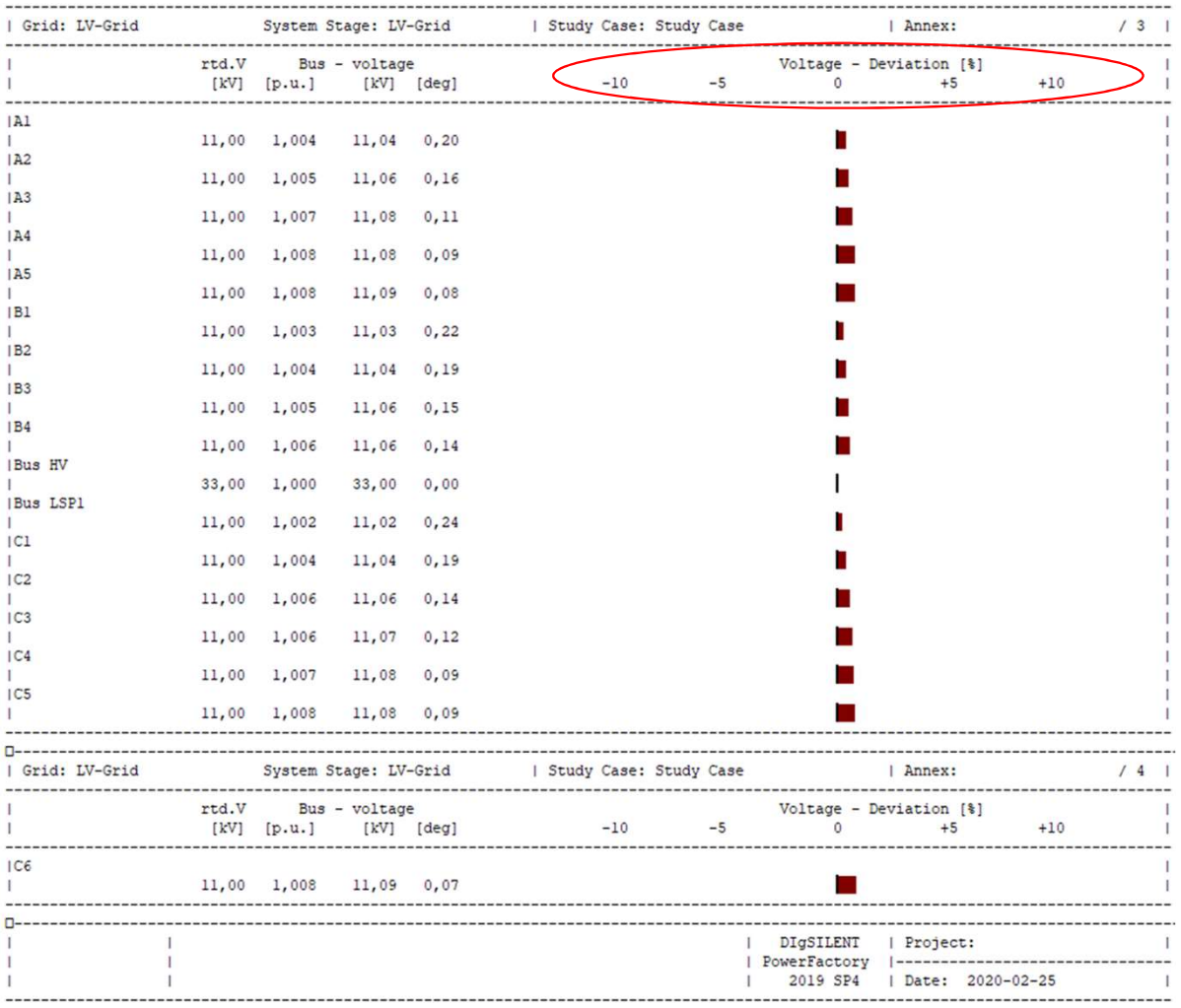
- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- X% SSEG connected
- This case represents the “worst” operating case when SSEG is connected. Sunny day with low load in the grid → maximum feed in to the power grid.
- All SSEG sources are contributing to the production of reactive power (inductive, pf=0.9)

Case 2 – 10% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 10% SSEG connected


Bus HV
Bus LSP1
LVG 1
15,7 %
PV C1
0,5 %
PV C2
0,4 %
PV C3
0,5 %
PV C4
0,6 %
PV C5
0,5 %
PV C6
0,6 %
KC1
6,3 %
KC2
5,4 %
KC3
6,4 %
KC4
6,5 %
KC5
4,2 %
KC6
3,8 %
Uhigh C1
Uhigh C2
Uhigh C3
Uhigh C4
Uhigh C5
Uhigh C6
Ulow C1
Ulow C2
Ulow C3
Ulow C4
Ulow C5
Ulow C6
C1
C2
C3
C4
C5
C6
PV B1
0,5 %
PV B2
0,6 %
PV B3
0,4 %
PV B4
0,5 %
KB1
5,5 %
KB2
5,3 %
KB3
5,4 %
KB4
2,8 %
Uhigh B1
Uhigh B2
Uhigh B3
Uhigh B4
Ulow B1
Ulow B2
Ulow B3
Ulow B4
B1
B2
B3
B4
PV A2
1,1 %
PV A1
0,8 %
PV A3
0,9 %
PV A4
1,0 %
PV A5
1,1 %
KA1
7,2 %
KA2
6,1 %
KA3
5,3 %
KA4
4,4 %
KA5
2,2 %
Uhigh A1
Uhigh A2
Uhigh A3
Uhigh A4
Uhigh A5
Ulow A1
Ulow A2
Ulow A3
Ulow A4
Ulow A5
A1
A2
A3
A4
A5
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 2 – 10% of the hh install SSEG



Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 3

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
A1	11,00	1,004	11,04	0,20	
A2	11,00	1,005	11,06	0,16	
A3	11,00	1,007	11,08	0,11	
A4	11,00	1,008	11,08	0,09	
A5	11,00	1,008	11,09	0,08	
B1	11,00	1,003	11,03	0,22	
B2	11,00	1,004	11,04	0,19	
B3	11,00	1,005	11,06	0,15	
B4	11,00	1,006	11,06	0,14	
Bus HV	33,00	1,000	33,00	0,00	
Bus LSP1	11,00	1,002	11,02	0,24	
C1	11,00	1,004	11,04	0,19	
C2	11,00	1,006	11,06	0,14	
C3	11,00	1,006	11,07	0,12	
C4	11,00	1,007	11,08	0,09	
C5	11,00	1,008	11,08	0,09	

Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 4

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
C6	11,00	1,008	11,09	0,07	

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Case 2 – 10% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 10% SSEG connected

- Grid losses: 0.01MW
- Voltages slightly increasing due to production and consumption locally, less power distributed throughout the grid
- Changed power flow – bottom up

Case 2 – 10% of the hh install SSEG

		DIgSILENT PowerFactory 2019 SP4	Project:
			Date: 2020-02-25

Load Flow Calculation — Grid Summary

AC Load Flow, balanced, positive sequence		Automatic Model Adaptation for Convergence	No
Automatic tap adjustment of transformers	No	Max. Acceptable Load Flow Error for	
Consider reactive power limits	No	Nodes	1,00 kVA
		Model Equations	0,10 %

Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 1

Grid: LV-Grid Summary

No. of Substations	0	No. of Busbars	17	No. of Terminals	0	No. of Lines	15
No. of 2-w Trfs.	1	No. of 3-w Trfs.	0	No. of syn. Machines	0	No. of asyn.Machines	0
No. of Loads	15	No. of Shunts/Filters	0	No. of SVS	0		

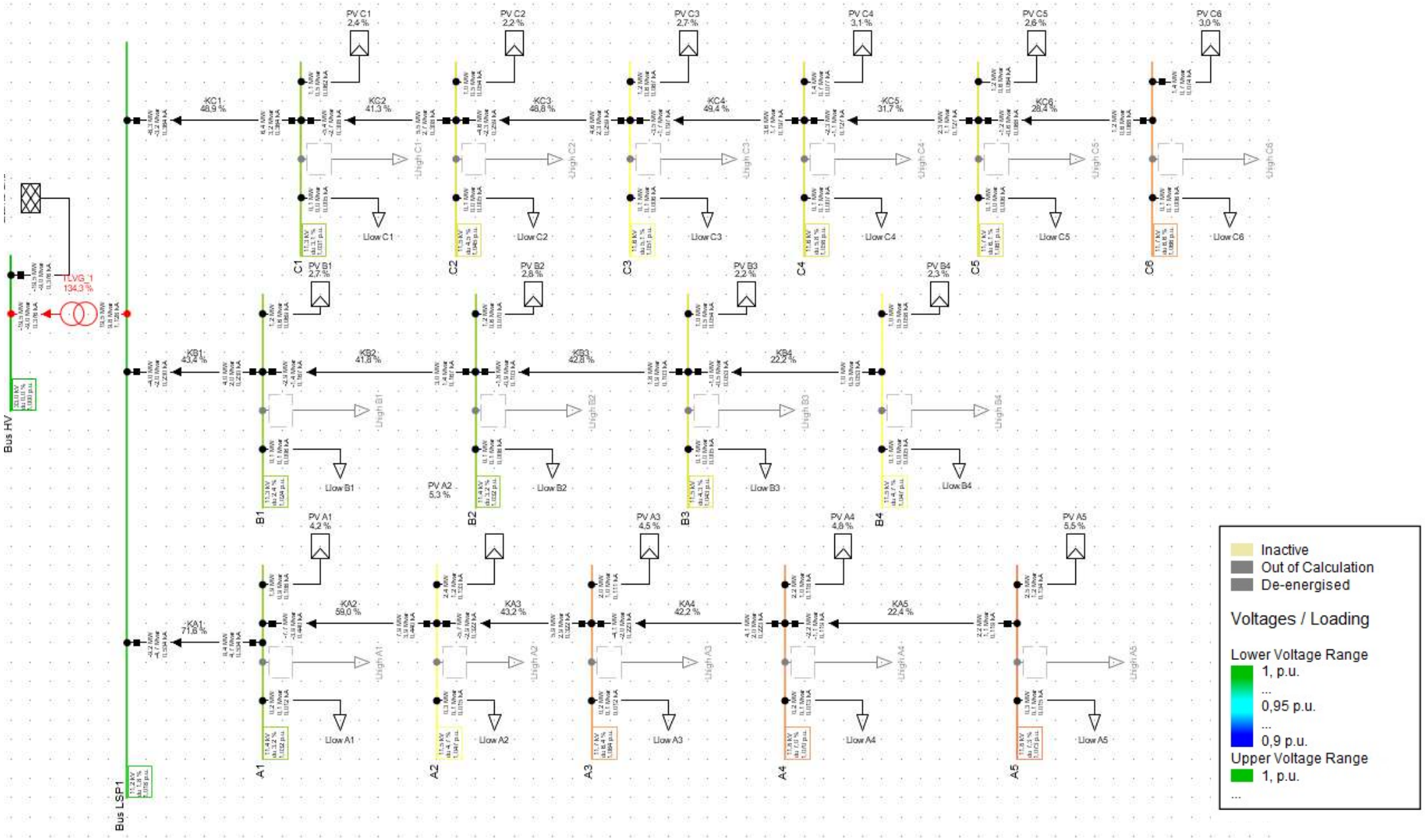
Generation	=	4,51 MW	2,19 Mvar	5,02 MVA	
External Infeed	=	-2,26 MW	-1,09 Mvar	2,51 MVA	
Inter Grid Flow	=	0,00 MW	0,00 Mvar		
Load P(U)	=	2,24 MW	1,09 Mvar	2,49 MVA	
Load P(Un)	=	2,24 MW	1,09 Mvar	2,49 MVA	
Load P(Un-U)	=	-0,00 MW	-0,00 Mvar		
Motor Load	=	0,00 MW	0,00 Mvar	0,00 MVA	
Grid Losses	=	0,01 MW	0,01 Mvar		
Line Charging	=		0,00 Mvar		
Compensation ind.	=		0,00 Mvar		
Compensation cap.	=		0,00 Mvar		
Installed Capacity	=	675,00 MW			
Spinning Reserve	=	0,00 MW			

Total Power Factor:

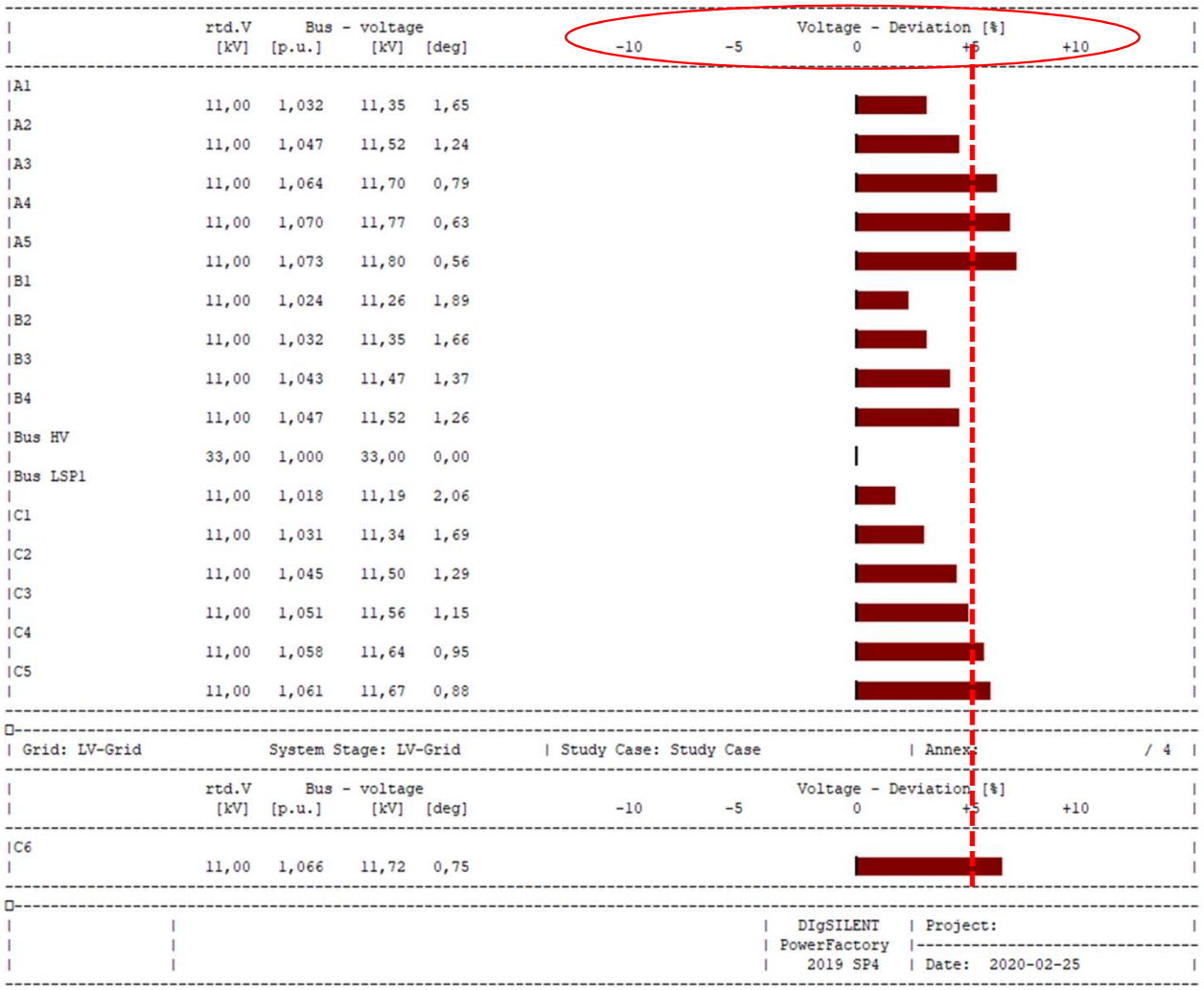
Generation	=	0,90 [-]
Load/Motor	=	0,90 / 0,00 [-]

Case 3 – 50% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 50% SSEG connected


Bus HV
Bus LSP1
TLVG_1
134,3 %
PV C1
2,4 %
PV C2
2,2 %
PV C3
2,7 %
PV C4
3,1 %
PV C5
2,6 %
PV C6
3,0 %
KC1
48,9 %
KC2
41,3 %
KC3
46,8 %
KC4
49,4 %
KC5
31,7 %
KC6
28,4 %
C1
C2
C3
C4
C5
C6
Uhigh C1
Uhigh C2
Uhigh C3
Uhigh C4
Uhigh C5
Uhigh C6
Ulow C1
Ulow C2
Ulow C3
Ulow C4
Ulow C5
Ulow C6
PV B1
2,7 %
PV B2
2,8 %
PV B3
2,2 %
PV B4
2,3 %
KB1
43,4 %
KB2
41,8 %
KB3
42,8 %
KB4
22,2 %
B1
B2
B3
B4
Uhigh B1
Uhigh B2
Uhigh B3
Uhigh B4
Ulow B1
Ulow B2
Ulow B3
Ulow B4
PV A2
5,3 %
PV A1
4,2 %
PV A3
4,5 %
PV A4
4,8 %
PV A5
5,5 %
KA1
71,6 %
KA2
59,0 %
KA3
43,2 %
KA4
42,2 %
KA5
22,4 %
A1
A2
A3
A4
A5
Uhigh A1
Uhigh A2
Uhigh A3
Uhigh A4
Uhigh A5
Ulow A1
Ulow A2
Ulow A3
Ulow A4
Ulow A5
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 3 – 50% of the hh install SSEG



	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
A1	11,00	1,032	11,35	1,65
A2	11,00	1,047	11,52	1,24
A3	11,00	1,064	11,70	0,79
A4	11,00	1,070	11,77	0,63
A5	11,00	1,073	11,80	0,56
B1	11,00	1,024	11,26	1,89
B2	11,00	1,032	11,35	1,66
B3	11,00	1,043	11,47	1,37
B4	11,00	1,047	11,52	1,26
Bus HV	33,00	1,000	33,00	0,00
Bus LSP1	11,00	1,018	11,19	2,06
C1	11,00	1,031	11,34	1,69
C2	11,00	1,045	11,50	1,29
C3	11,00	1,051	11,56	1,15
C4	11,00	1,058	11,64	0,95
C5	11,00	1,061	11,67	0,88

Voltage - Deviation [%]: -10, -5, 0, +5, +10

Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 4

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
C6	11,00	1,066	11,72	0,75

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Case 3 – 50% of the hh install SSEG

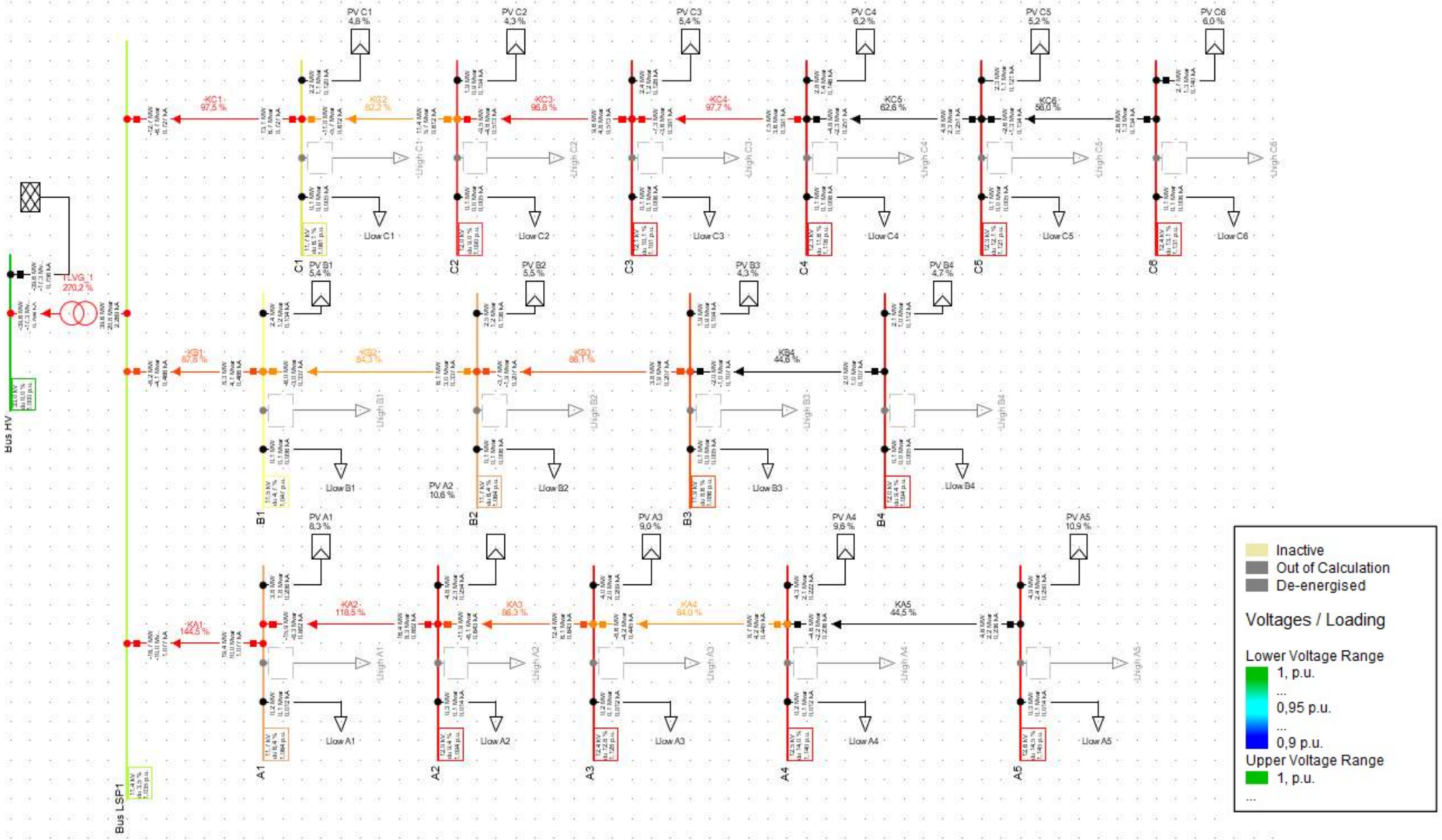
- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 50% SSEG connected

- Grid losses: 0.82MW
- Voltages increasing and in some cases exceeding the limits of +5% due to production exceeding consumption
- Changed power flow – bottom up

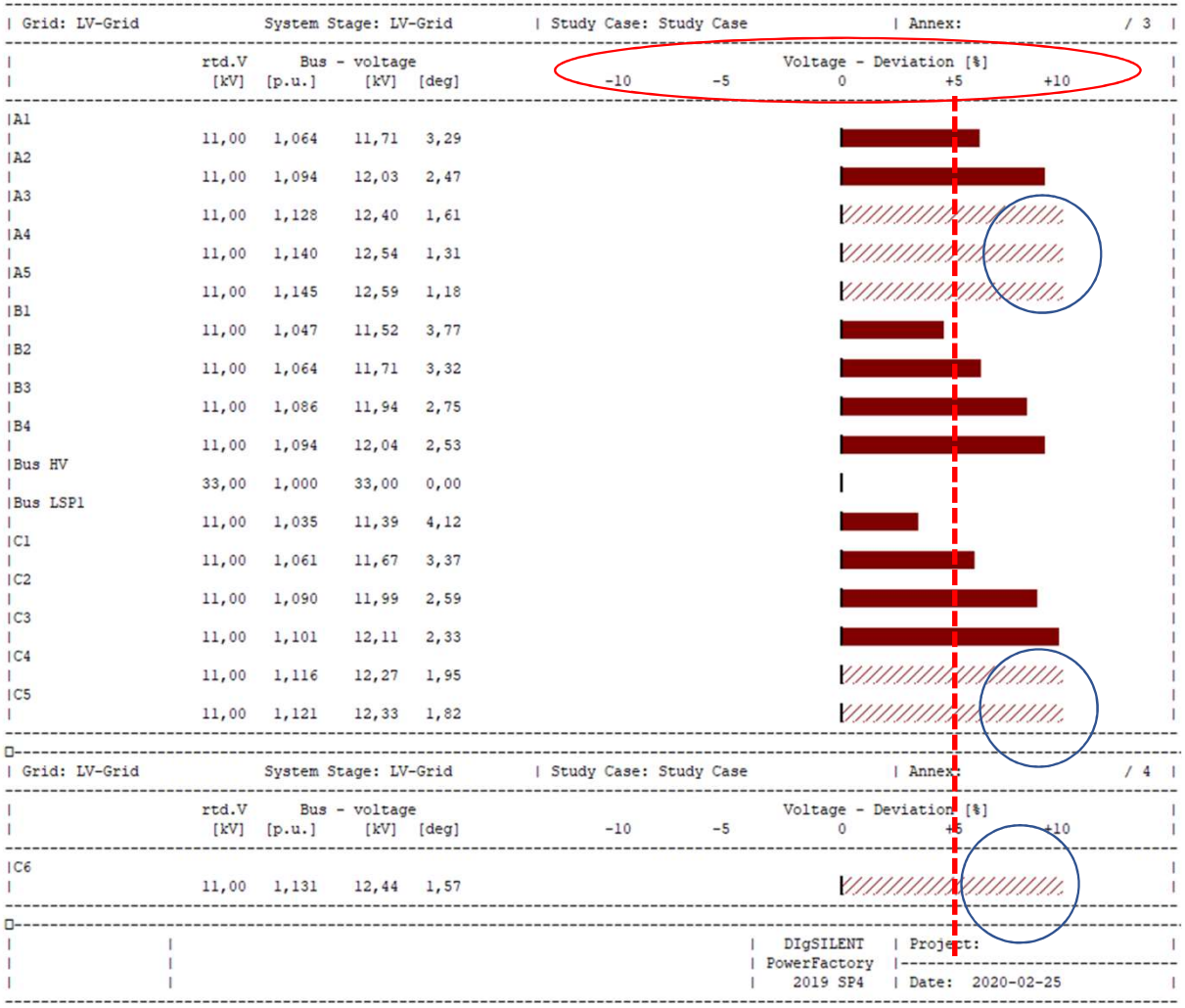
Case 4 – 100% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 100% SSEG connected
- This case **is** the worst operating case when all hh has SSEG and is at low load

➢50% share of SEEG showed that the voltages increased above limits and de losses increased as well, what will happened now?


Bus HV
LVG_1
270,2 %
Bus LSP1
PV C1
4,8 %
PV C2
4,3 %
PV C3
5,4 %
PV C4
6,2 %
PV C5
5,2 %
PV C6
6,0 %
KC1:
97,5 %
KC2:
82,2 %
KC3:
95,8 %
KC4:
97,7 %
KC5:
82,6 %
KC6:
58,0 %
C1
C2
C3
C4
C5
C6
Ulow C1
Ulow C2
Ulow C3
Ulow C4
Ulow C5
Ulow C6
Uhigh C1
Uhigh C2
Uhigh C3
Uhigh C4
Uhigh C5
Uhigh C6
PV B1
5,4 %
PV B2
5,5 %
PV B3
4,3 %
PV B4
4,7 %
KB1:
87,8 %
KB2:
84,3 %
KB3:
88,1 %
KB4
44,8 %
B1
B2
B3
B4
Ulow B1
Ulow B2
Ulow B3
Ulow B4
Uhigh B1
Uhigh B2
Uhigh B3
Uhigh B4
PV A2
10,6 %
PV A1
8,3 %
PV A3
9,0 %
PV A4
9,6 %
PV A5
10,9 %
KA1:
144,5 %
KA2:
116,5 %
KA3
86,3 %
KA4
84,0 %
KA5
44,5 %
A1
A2
A3
A4
A5
Ulow A1
Ulow A2
Ulow A3
Ulow A4
Ulow A5
Uhigh A1
Uhigh A2
Uhigh A3
Uhigh A4
Uhigh A5
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 4 – 100% of the hh install SSEG



Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 3

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
A1	11,00	1,064	11,71	3,29	
A2	11,00	1,094	12,03	2,47	
A3	11,00	1,128	12,40	1,61	
A4	11,00	1,140	12,54	1,31	
A5	11,00	1,145	12,59	1,18	
B1	11,00	1,047	11,52	3,77	
B2	11,00	1,064	11,71	3,32	
B3	11,00	1,086	11,94	2,75	
B4	11,00	1,094	12,04	2,53	
Bus HV	33,00	1,000	33,00	0,00	
Bus LSP1	11,00	1,035	11,39	4,12	
C1	11,00	1,061	11,67	3,37	
C2	11,00	1,090	11,99	2,59	
C3	11,00	1,101	12,11	2,33	
C4	11,00	1,116	12,27	1,95	
C5	11,00	1,121	12,33	1,82	

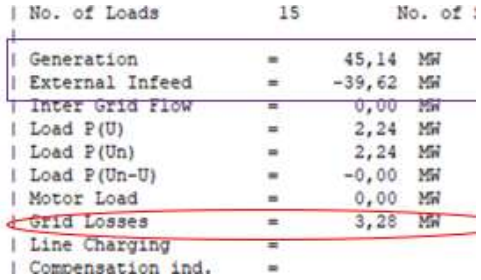
Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 4

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
C6	11,00	1,131	12,44	1,57	

DIgSILENT PowerFactory 2019 SP4 | Project: | Date: 2020-02-25

Case 4 – 100% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 100% SSEG connected



No. of Loads		15	No. of
Generation	=	45,14	MW
External Infeed	=	-39,62	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	-0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	3,28	MW
Line Charging	=		
Compensation ind.	=		

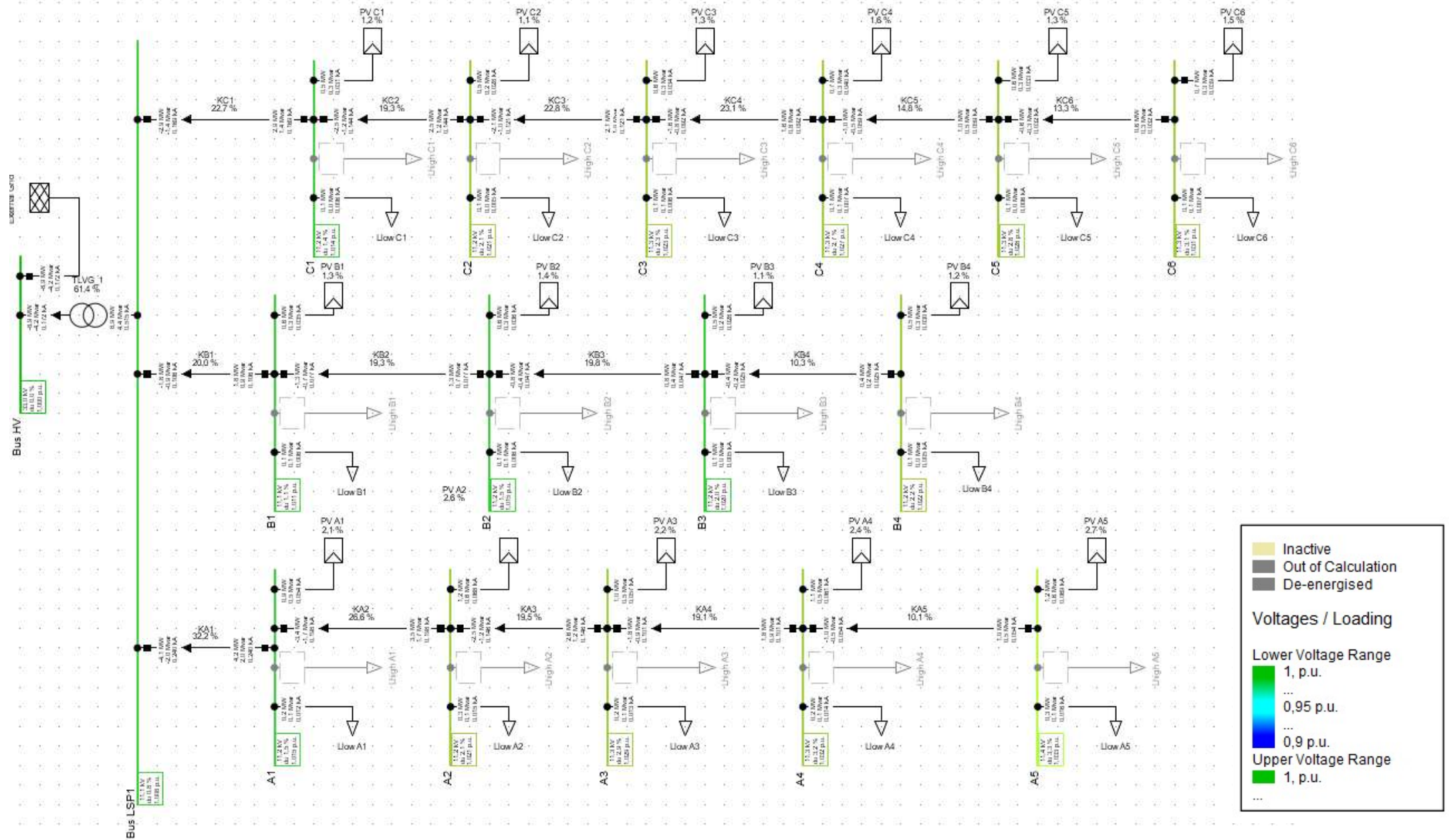
- Grid losses: 3.28MW
- Voltages increasing and at all busses exceeding the limits of +5% due to production exceeding consumption
- Changed power flow – bottom up

Break even

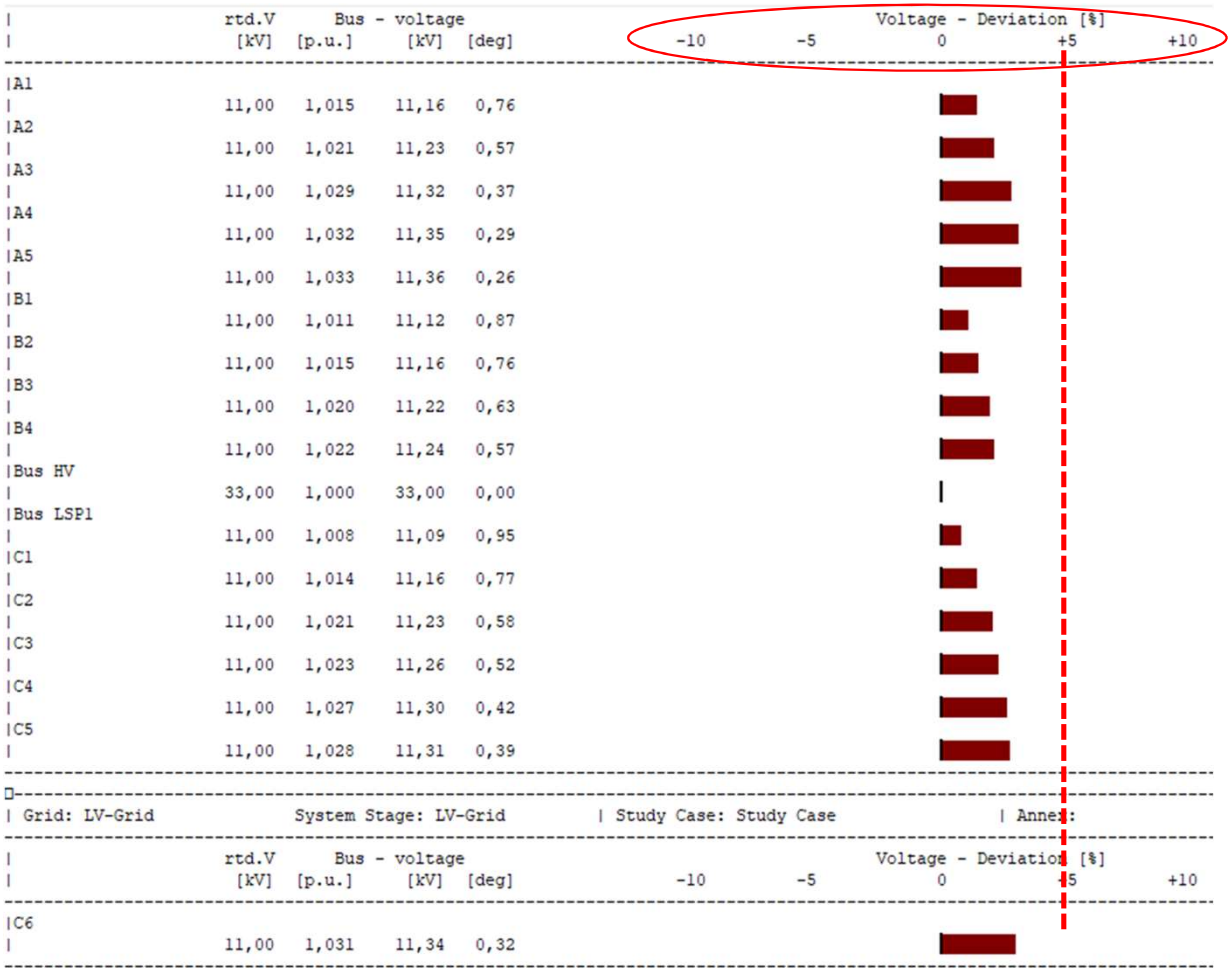
- How do we find the tipping point?
- 10% SSEG was ok, 50 % SSEG lead to exceeding the voltage increase limits and higher grid losses.

Case 5 – 25% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 25% SSEG connected


Bus HV
TLVG 1
61,4 %
Bus LSP1
KC1
22,7 %
KC2
19,3 %
KC3
22,8 %
KC4
23,1 %
KC5
14,8 %
KC6
13,3 %
KB1
20,0 %
KB2
19,3 %
KB3
19,8 %
KB4
10,3 %
KA1
32,2 %
KA2
26,6 %
KA3
19,5 %
KA4
19,1 %
KA5
10,1 %
PV C1
1,2 %
PV C2
1,1 %
PV C3
1,3 %
PV C4
1,6 %
PV C5
1,3 %
PV C6
1,5 %
PV B1
1,3 %
PV B2
1,4 %
PV B3
1,1 %
PV B4
1,2 %
PV A1
2,1 %
PV A2
2,6 %
PV A3
2,2 %
PV A4
2,4 %
PV A5
2,7 %
Uhigh C1
Uhigh C2
Uhigh C3
Uhigh C4
Uhigh C5
Uhigh C6
Uhigh B1
Uhigh B2
Uhigh B3
Uhigh B4
Uhigh A1
Uhigh A2
Uhigh A3
Uhigh A4
Uhigh A5
Ulow C1
Ulow C2
Ulow C3
Ulow C4
Ulow C5
Ulow C6
Ulow B1
Ulow B2
Ulow B3
Ulow B4
Ulow A1
Ulow A2
Ulow A3
Ulow A4
Ulow A5
C1
C2
C3
C4
C5
C6
B1
B2
B3
B4
A1
A2
A3
A4
A5
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 5 – 25% of the hh install SSEG



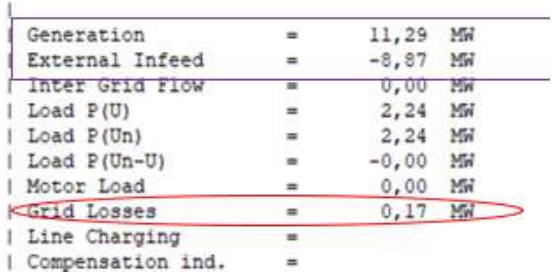
	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
A1	11,00	1,015	11,16	0,76	
A2	11,00	1,021	11,23	0,57	
A3	11,00	1,029	11,32	0,37	
A4	11,00	1,032	11,35	0,29	
A5	11,00	1,033	11,36	0,26	
B1	11,00	1,011	11,12	0,87	
B2	11,00	1,015	11,16	0,76	
B3	11,00	1,020	11,22	0,63	
B4	11,00	1,022	11,24	0,57	
Bus HV	33,00	1,000	33,00	0,00	
Bus LSP1	11,00	1,008	11,09	0,95	
C1	11,00	1,014	11,16	0,77	
C2	11,00	1,021	11,23	0,58	
C3	11,00	1,023	11,26	0,52	
C4	11,00	1,027	11,30	0,42	
C5	11,00	1,028	11,31	0,39	

Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex:

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
C6	11,00	1,031	11,34	0,32	

Case 5 – 25% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 25% SSEG connected



Generation	=	11,29	MW
External Infeed	=	-8,87	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	-0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	0,17	MW
Line Charging	=		
Compensation ind.	=		

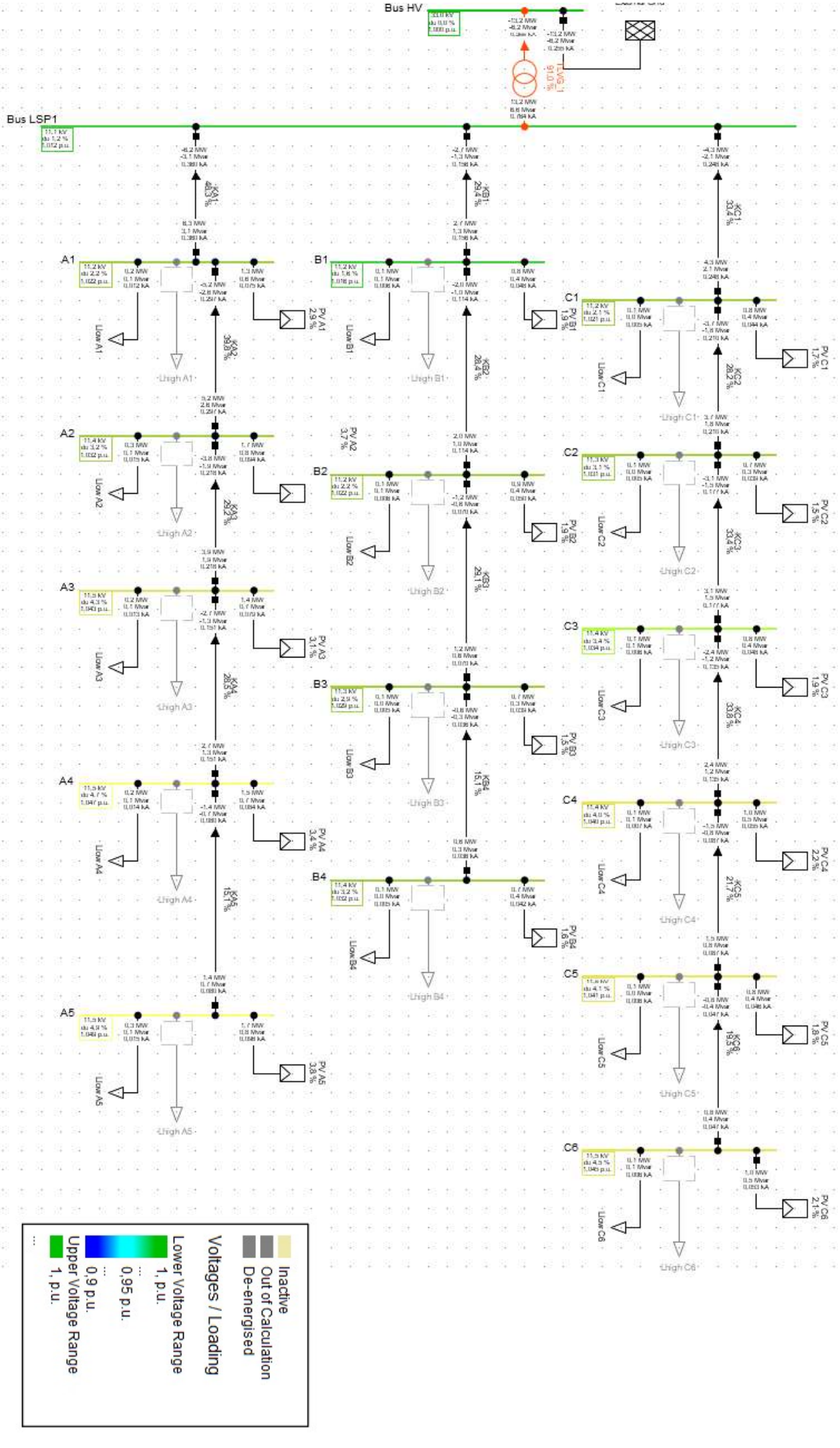
- Grid losses: 0.17MW
- Voltages increasing at all busses but within limits
- Changed power flow – bottom up

Break even

- Can we go even further?

Case 6 – 35% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 35% SSEG connected


Bus HV
TLVS 1
91.0 %
Bus LSP1
A1
A2
A3
A4
A5
B1
B2
B3
B4
C1
C2
C3
C4
C5
C6
KA1
KA2
KA3
KA4
KA5
KB1
KB2
KB3
KB4
KC1
KC2
KC3
KC4
KC5
KC6
PV A1
PV A2
PV A3
PV A4
PV A5
PV B1
PV B2
PV B3
PV B4
PV C1
PV C2
PV C3
PV C4
PV C5
PV C6
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
0,95 p.u.
0,9 p.u.
Upper Voltage Range
1, p.u.

Case 6 – 35% of the hh install SSEG

Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 3

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
A1	11,00	1,022	11,24	1,12	
A2	11,00	1,032	11,35	0,85	
A3	11,00	1,043	11,48	0,54	
A4	11,00	1,047	11,52	0,43	
A5	11,00	1,049	11,54	0,38	
B1	11,00	1,016	11,18	1,28	
B2	11,00	1,022	11,24	1,13	
B3	11,00	1,029	11,32	0,93	
B4	11,00	1,032	11,35	0,85	
Bus HV	33,00	1,000	33,00	0,00	
Bus LSP1	11,00	1,012	11,13	1,40	
C1	11,00	1,021	11,23	1,15	
C2	11,00	1,031	11,34	0,87	
C3	11,00	1,034	11,38	0,78	
C4	11,00	1,040	11,44	0,64	
C5	11,00	1,041	11,46	0,59	

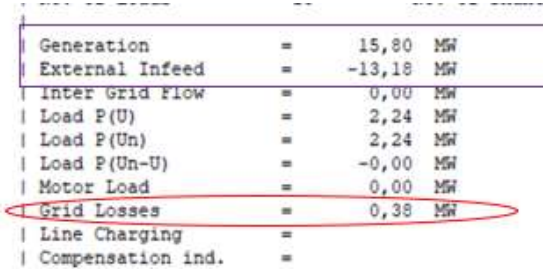
Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 4

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
C6	11,00	1,045	11,49	0,49	

DIgSILENT PowerFactory 2019 SP4	Project:	Date: 2020-02-25

Case 6 – 35% of the hh install SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 35% SSEG connected



Generation	=	15,80	MW
External Infeed	=	-13,18	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	-0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	0,38	MW
Line Charging	=		
Compensation ind.	=		

- Grid losses: 0.38MW
- Voltages increasing at all busses but within limits
- Changed power flow – bottom up

Conclusion

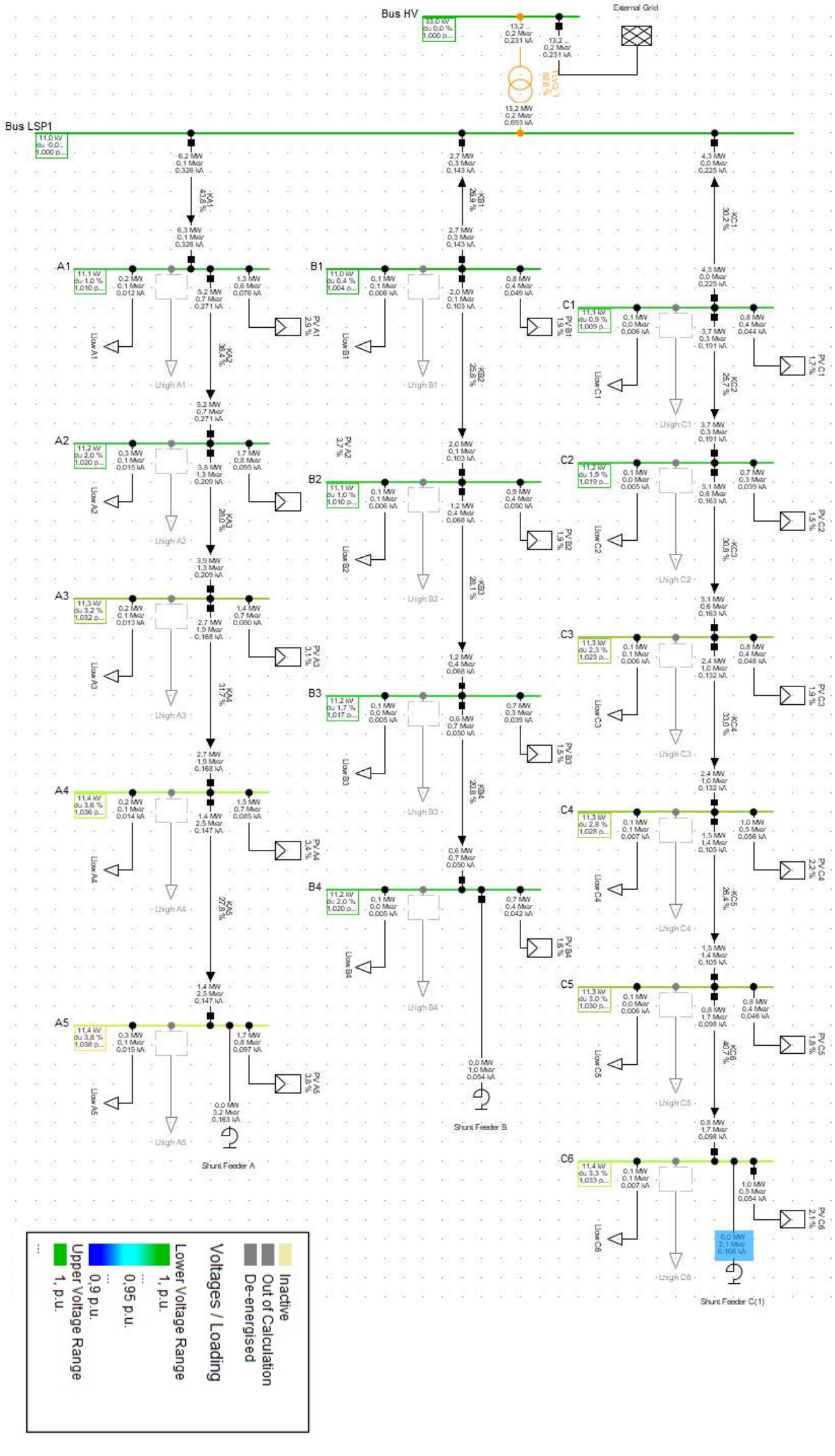
	Grid losses [MW]	Exceeding voltage limits?
Case 1 - 0 % SSEG	0.32	no
Case 2 - 10 % SSEG	0.01	no
Case 3 - 50 % SSEG	0.82	some busses
Case 4 - 100 % SSEG	3.28	all busses
Case 5 - 25 % SSEG	0.17	no
Case 6 - 35 % SSEG	0.38	no

More SSEG?

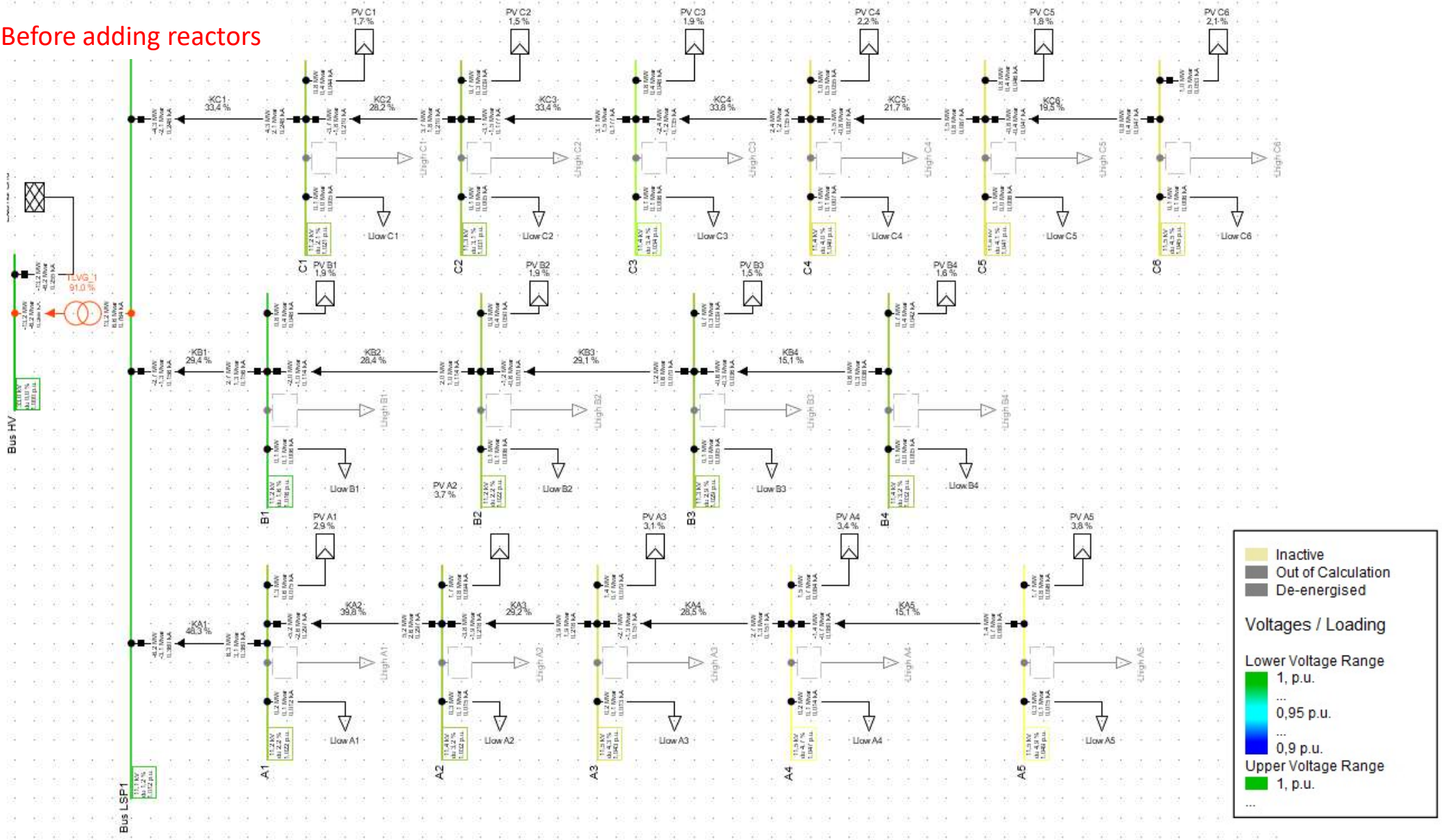
- What can be done to accommodate 35 % SSEG?
- How will different solutions affect the grid losses?

Case 7 – 35% of the hh install SSEG, reactors

- The power grid company installs Shunt reactors at the end of Feeder A, B and C
- The reactors should reduce the voltage at the end busses in Feeder A, B and C
- Can these reactors push the tipping point for allowed share of SSEG in this grid to extend to 35%?
- What will happen to the grid losses?


Bus HV
External Grid
Bus LSP1
Shunt Feeder A
Shunt Feeder B
Shunt Feeder C(1)
Voltages / Loading
Inactive
Out of Calculation
De-energised
Lower Voltage Range
1, p.u.
0,95 p.u.
0,9 p.u.
Upper Voltage Range
1, p.u.

Before adding reactors



Case 7 – 35% of the hh install SSEG, reactors

| Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 3 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
A1	11,00	1,012	11,13	1,43	
A2	11,00	1,022	11,24	1,50	
A3	11,00	1,034	11,37	1,73	
A4	11,00	1,038	11,41	1,89	
A5	11,00	1,040	11,43	2,07	
B1	11,00	1,006	11,07	1,39	
B2	11,00	1,012	11,13	1,41	
B3	11,00	1,019	11,21	1,56	
B4	11,00	1,022	11,24	1,75	
Bus HV	33,00	1,000	33,00	0,00	
Bus LSP1	11,00	1,002	11,02	1,42	
C1	11,00	1,011	11,12	1,29	
C2	11,00	1,021	11,23	1,17	
C3	11,00	1,025	11,27	1,15	
C4	11,00	1,030	11,33	1,13	
C5	11,00	1,032	11,35	1,15	

| Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 4 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
C6	11,00	1,035	11,39	1,31	

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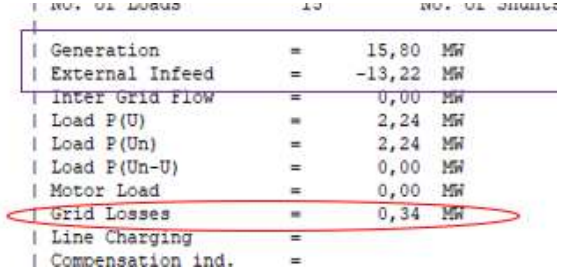
Case 7 – 35% of the hh install SSEG, reactors

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 35% SSEG connected
- Reactors are added at the end of Feeder A, B and C

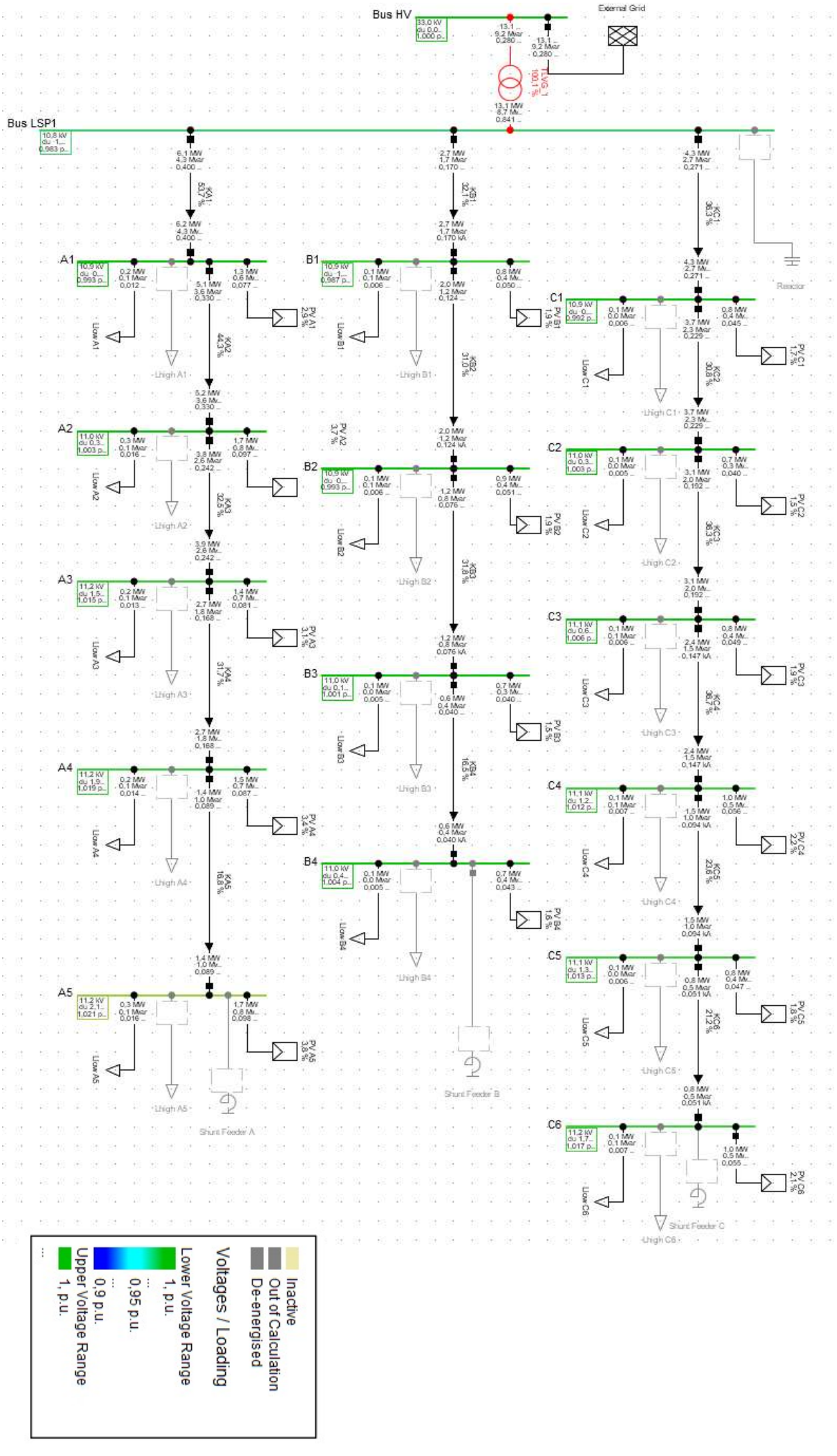


Generation	=	15,80	MW
External Infeed	=	-13,22	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	0,34	MW
Line Charging	=		
Compensation ind.	=		

- Grid losses: 0.34MW
- Voltages decreasing thanks to reactors
- Changed power flow – bottom up

Case 8 – 35% of the hh install SSEG, cap. SSEG

- The Shunt reactors are set out of service for all the feeders
- Instead the power factor of the PV inverters are changed to **0.9 capacitive**
- This gives that the PV-sources now are consuming reactive power
- What will happen to the grid losses?


Bus HV
External Grid
Bus LSP1
A1
A2
A3
A4
A5
B1
B2
B3
B4
C1
C2
C3
C4
C5
C6
Shunt Feeder A
Shunt Feeder B
Shunt Feeder C
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
0,95 p.u.
0,9 p.u.
Upper Voltage Range
1, p.u.

Case 8 – 35% of the hh install SSEG, cap. SSEG

| Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 3 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
A1	11,00	0,993	10,92	1,84	
A2	11,00	1,003	11,04	2,24	
A3	11,00	1,015	11,17	2,69	
A4	11,00	1,019	11,21	2,85	
A5	11,00	1,021	11,23	2,92	
B1	11,00	0,987	10,86	1,59	
B2	11,00	0,993	10,92	1,80	
B3	11,00	1,001	11,01	2,07	
B4	11,00	1,004	11,04	2,18	
Bus HV	33,00	1,000	33,00	0,00	
Bus LSP1	11,00	0,983	10,81	1,43	
C1	11,00	0,992	10,92	1,78	
C2	11,00	1,003	11,03	2,15	
C3	11,00	1,006	11,07	2,28	
C4	11,00	1,012	11,13	2,47	
C5	11,00	1,013	11,15	2,53	

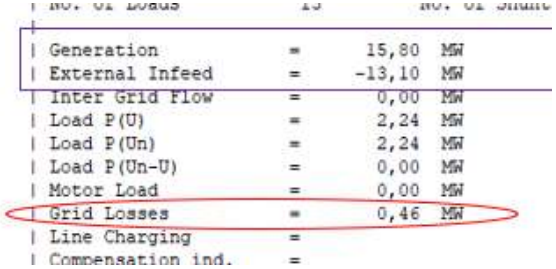
| Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 4 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
C6	11,00	1,017	11,19	2,66	

DIgSILENT PowerFactory 2019 SP4 | Project: | Date: 2020-04-03

Case 8 – 35% of the hh install SSEG, cap. SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 35% SSEG connected
- PV-sources 0.9 capacitive

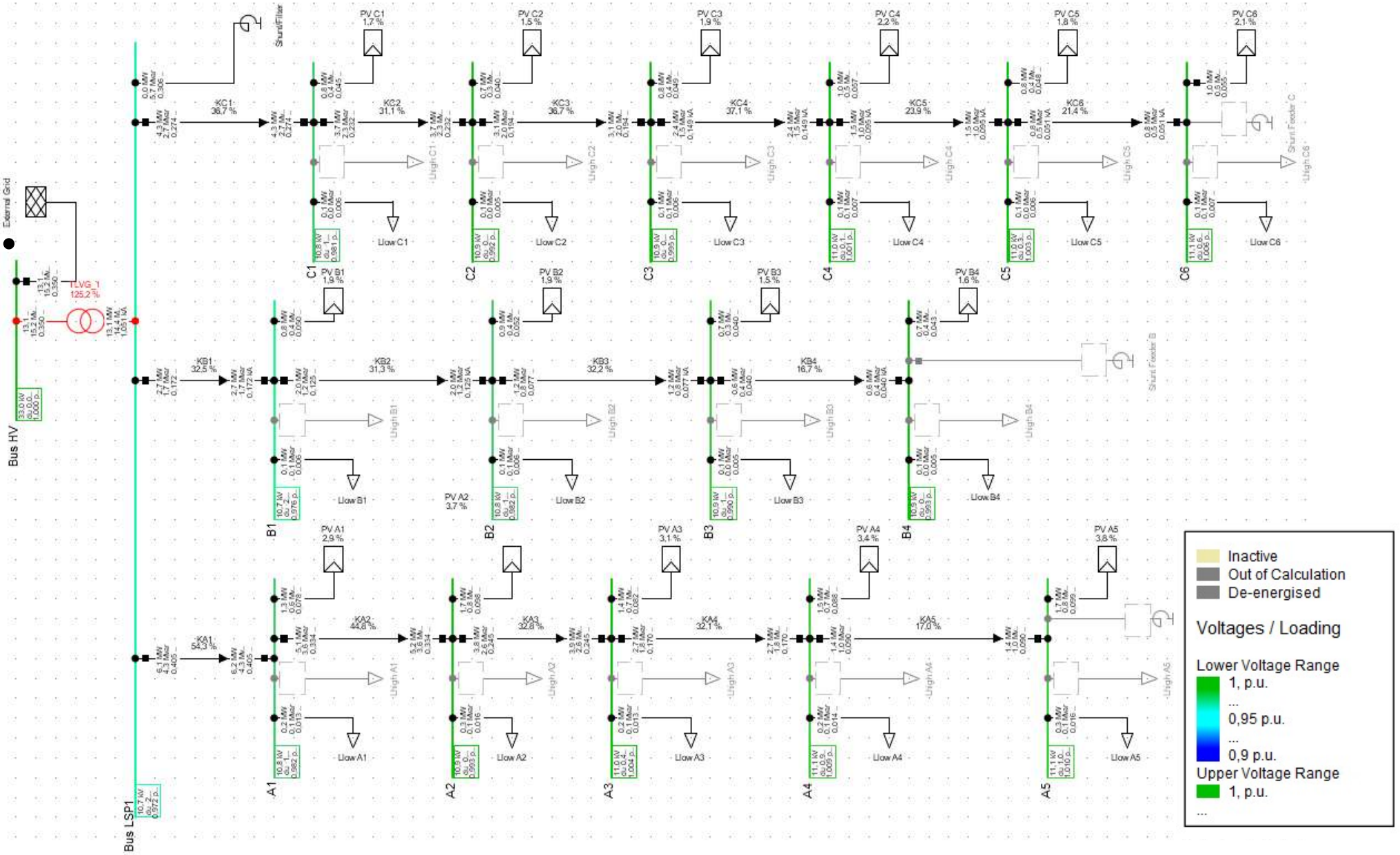


Generation	=	15,80	MW
External Infeed	=	-13,10	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	0,46	MW
Line Charging	=		

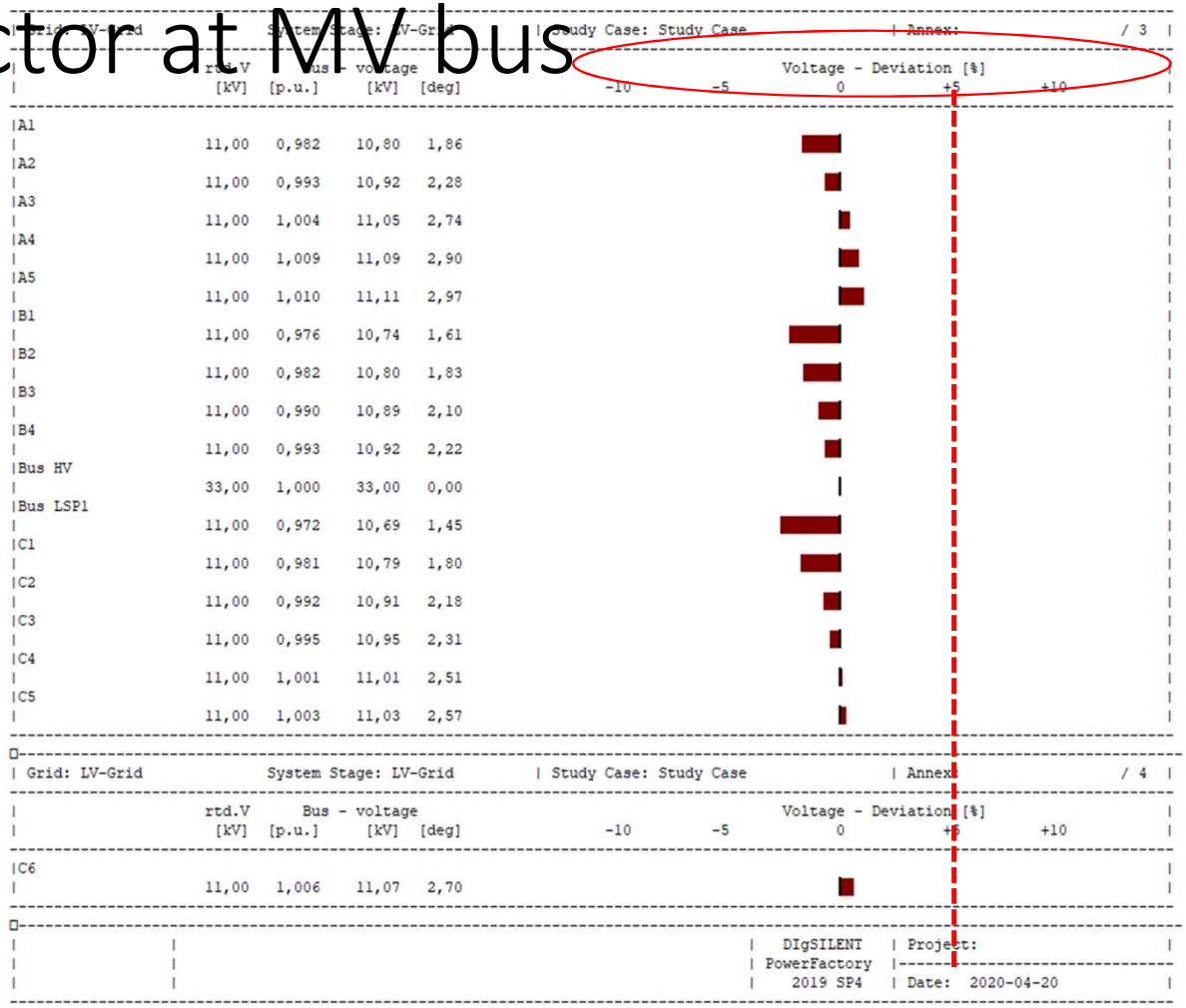
- Grid losses: 0.46MW
- Voltages increasing at all busses but within limits
- Changed power flow – bottom up

Case 9 – 35% of the hh install SSEG, cap. SSEG and reactor at MV bus

- The SSEG systems are still capacitive
- A shunt reactor at the MV bus is added


External Grid
Bus HV
LVG_1
125,2 %
Bus LSP1
Shunt/Filter
KC1
36,7 %
KC2
31,1 %
KC3
36,7 %
KC4
37,1 %
KC5
23,9 %
KC6
21,4 %
KB1
32,5 %
KB2
31,3 %
KB3
32,2 %
KB4
16,7 %
KA1
54,3 %
KA2
44,8 %
KA3
32,8 %
KA4
32,1 %
KA5
17,0 %
PV C1
1,7 %
PV C2
1,5 %
PV C3
1,9 %
PV C4
2,2 %
PV C5
1,8 %
PV C6
2,1 %
PV B1
1,9 %
PV B2
1,9 %
PV B3
1,5 %
PV B4
1,6 %
PV A1
2,9 %
PV A2
3,7 %
PV A3
3,1 %
PV A4
3,4 %
PV A5
3,8 %
C1
C2
C3
C4
C5
C6
B1
B2
B3
B4
A1
A2
A3
A4
A5
Shunt Feeder C
Shunt Feeder B
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 9 – 35% of the hh install SSEG, cap. SSEG and reactor at MV bus



Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 3

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
A1	11,00	0,982	10,80	1,86	
A2	11,00	0,993	10,92	2,28	
A3	11,00	1,004	11,05	2,74	
A4	11,00	1,009	11,09	2,90	
A5	11,00	1,010	11,11	2,97	
B1	11,00	0,976	10,74	1,61	
B2	11,00	0,982	10,80	1,83	
B3	11,00	0,990	10,89	2,10	
B4	11,00	0,993	10,92	2,22	
Bus HV	33,00	1,000	33,00	0,00	
Bus LSP1	11,00	0,972	10,69	1,45	
C1	11,00	0,981	10,79	1,80	
C2	11,00	0,992	10,91	2,18	
C3	11,00	0,995	10,95	2,31	
C4	11,00	1,001	11,01	2,51	
C5	11,00	1,003	11,03	2,57	

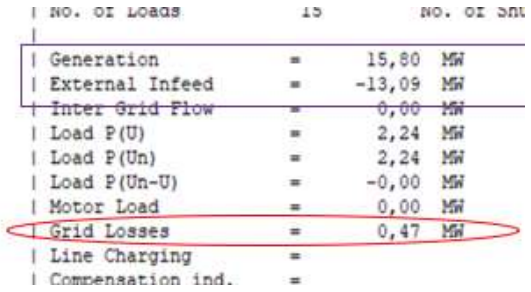
Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 4

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
C6	11,00	1,006	11,07	2,70	

DIgSILENT PowerFactory 2019 SP4	Project:	Date: 2020-04-20

Case 9 – 35% of the hh install SSEG, cap. SSEG and reactor at MV bus

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 35% SSEG connected

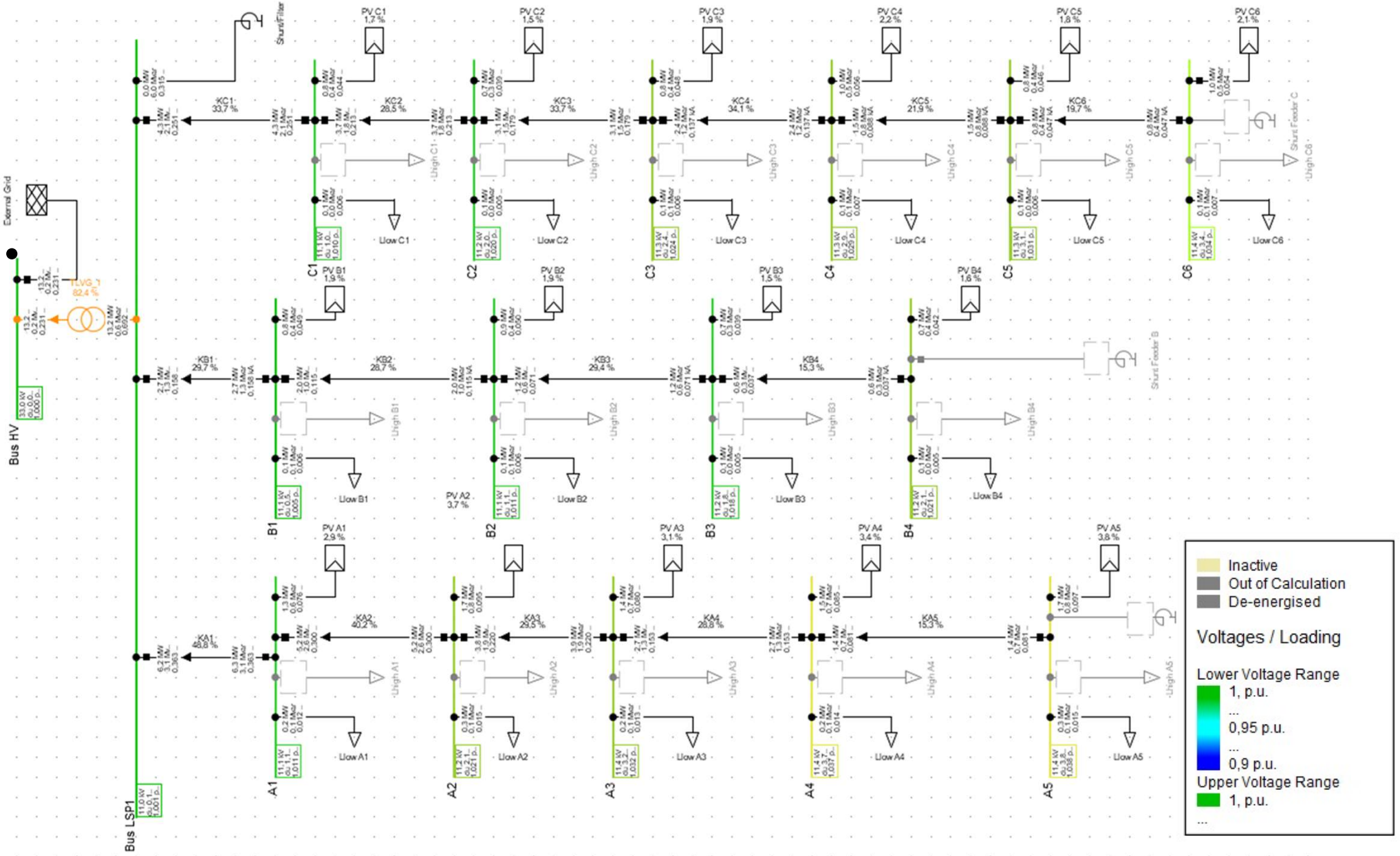


Generation	=	15,80	MW
External Infeed	=	-13,09	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	-0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	0,47	MW
Line Charging	=		

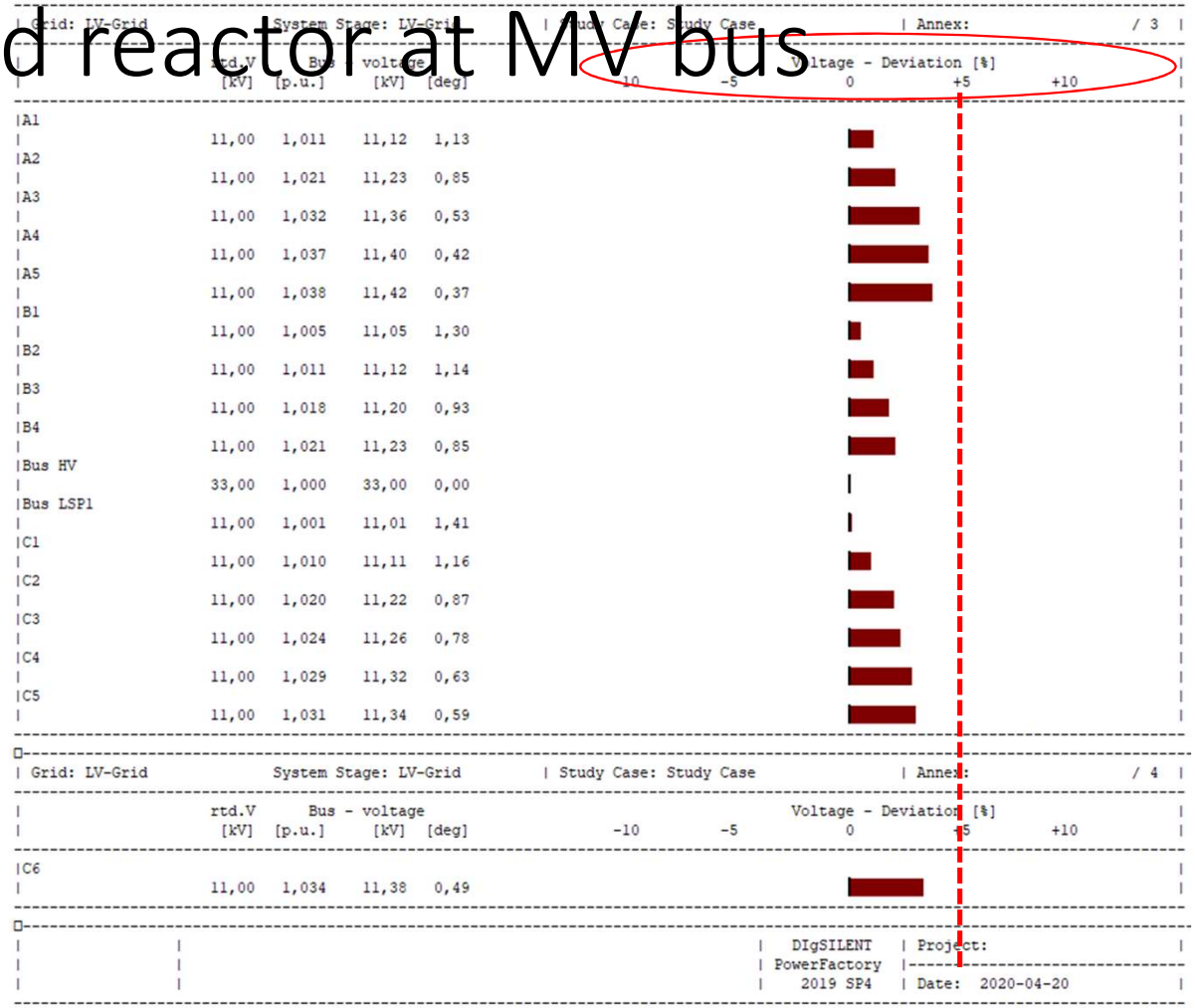
- Grid losses: 0.47MW
- Voltages decreasing, within limits
- Changed power flow – bottom up

Case 10 – 35% of the hh install SSEG, ind. SSEG and reactor at MV bus

- The SSEG systems are inductive (default)
- A shunt reactor at the MV bus is added


External Grid
Bus HV
Bus LSP1
T LVG_1
82,4 %
ShuntFilter
Shunt Feeder C
Shunt Feeder B
PV C1
1,7 %
PV C2
1,5 %
PV C3
1,9 %
PV C4
2,2 %
PV C5
1,8 %
PV C6
2,1 %
KC1
33,7 %
KC2
28,5 %
KC3
33,7 %
KC4
34,1 %
KC5
21,9 %
KC6
19,7 %
C1
C2
C3
C4
C5
C6
Load C1
Load C2
Load C3
Load C4
Load C5
Load C6
PV B1
1,9 %
PV B2
1,9 %
PV B3
1,5 %
PV B4
1,6 %
KB1
29,7 %
KB2
28,7 %
KB3
29,4 %
KB4
15,3 %
B1
B2
B3
B4
Load B1
Load B2
Load B3
Load B4
PV A1
2,9 %
PV A2
3,7 %
PV A3
3,1 %
PV A4
3,4 %
PV A5
3,8 %
KA1
46,8 %
KA2
40,2 %
KA3
29,5 %
KA4
28,8 %
KA5
15,3 %
A1
A2
A3
A4
A5
Load A1
Load A2
Load A3
Load A4
Load A5
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 10 – 35% of the hh install SSEG, ind. SSEG and reactor at MV bus



| Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 3 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10	-5	0	+5	+10
A1	11,00	1,011	11,12	1,13					
A2	11,00	1,021	11,23	0,85					
A3	11,00	1,032	11,36	0,53					
A4	11,00	1,037	11,40	0,42					
A5	11,00	1,038	11,42	0,37					
B1	11,00	1,005	11,05	1,30					
B2	11,00	1,011	11,12	1,14					
B3	11,00	1,018	11,20	0,93					
B4	11,00	1,021	11,23	0,85					
Bus HV	33,00	1,000	33,00	0,00					
Bus LSP1	11,00	1,001	11,01	1,41					
C1	11,00	1,010	11,11	1,16					
C2	11,00	1,020	11,22	0,87					
C3	11,00	1,024	11,26	0,78					
C4	11,00	1,029	11,32	0,63					
C5	11,00	1,031	11,34	0,59					

| Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 4 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10	-5	0	+5	+10
C6	11,00	1,034	11,38	0,49					

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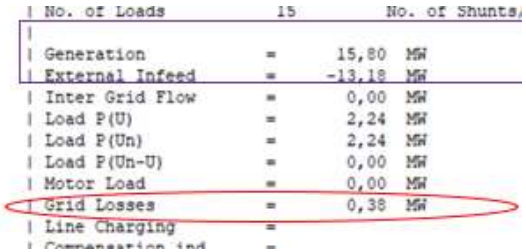
Case 10 – 35% of the hh install SSEG, ind. SSEG and reactor at MV bus

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 35% SSEG connected

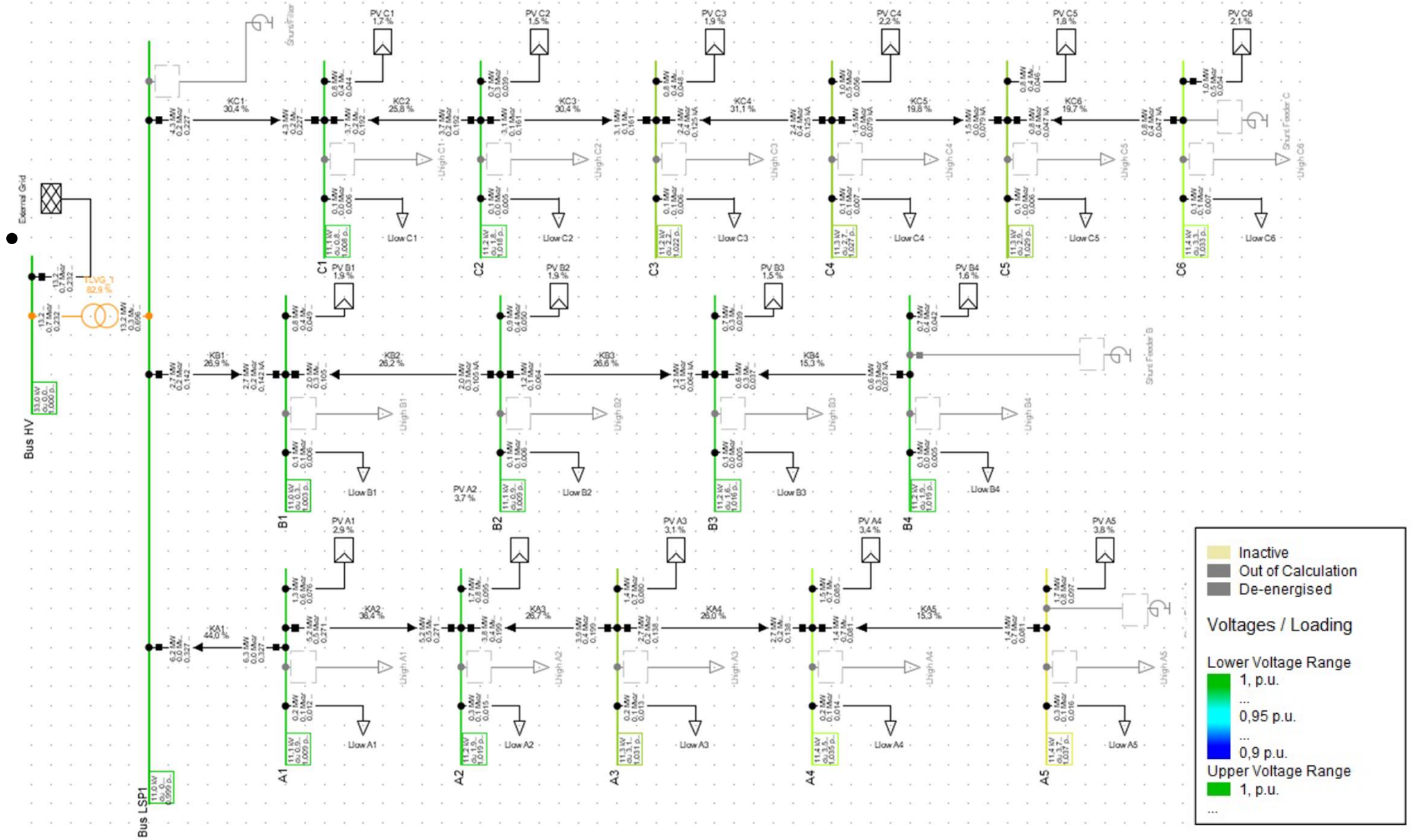


No. of Loads	15	No. of Shunts	
Generation	=	15,80	MW
External Infeed	=	-13,18	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	0,38	MW
Line Charging	=		

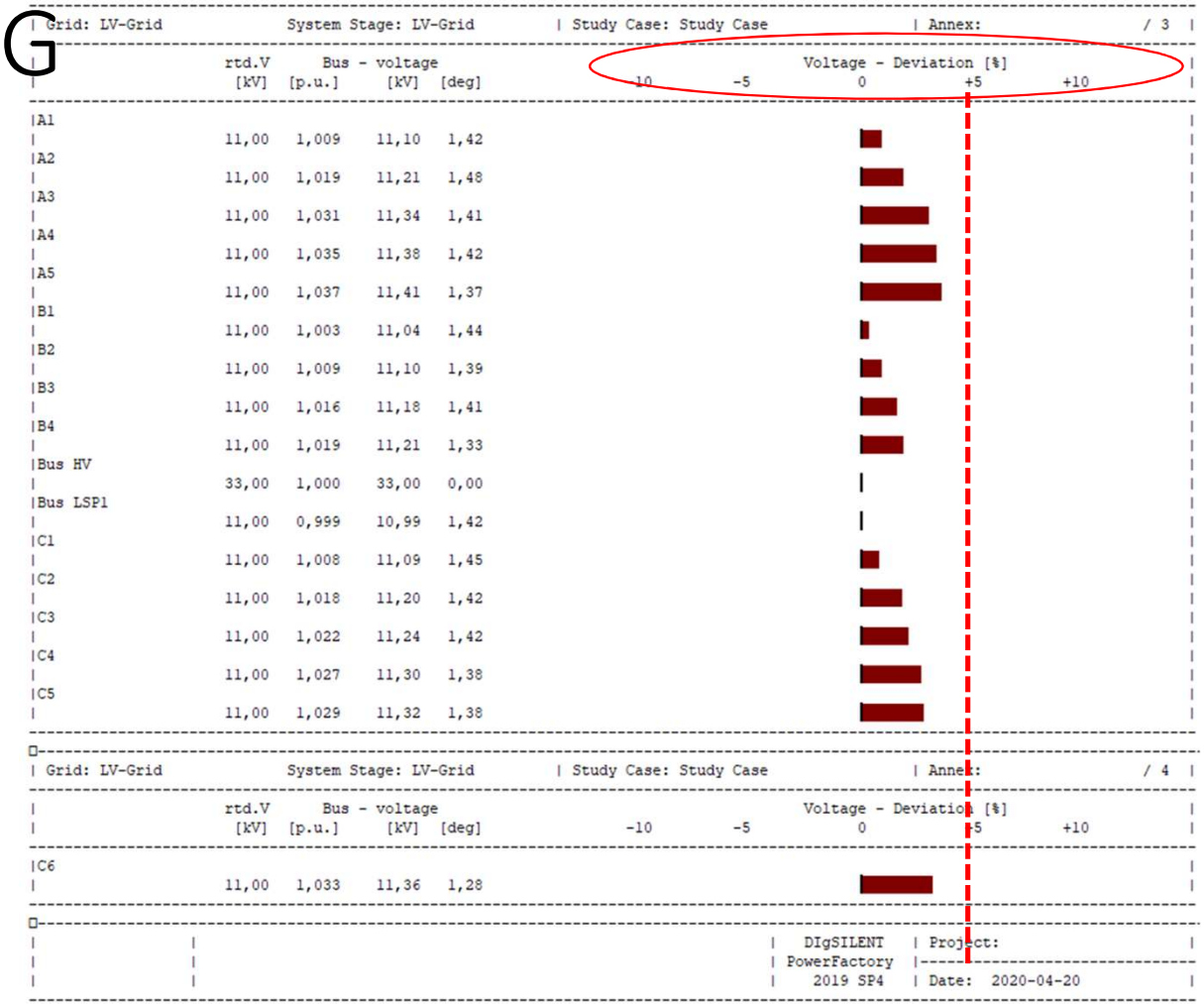
- Grid losses: 0.38MW
- Reduced voltage at some busses

Case 11 – 35% of the hh install SSEG, cap. and ind. SSEG

- Every second SSEG systems is capacitive


External Grid
Bus HV
Bus LSP1
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 11 – 35% of the hh install SSEG, cap. and ind. SSEG



Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 3

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
A1					
	11,00	1,009	11,10	1,42	
A2					
	11,00	1,019	11,21	1,48	
A3					
	11,00	1,031	11,34	1,41	
A4					
	11,00	1,035	11,38	1,42	
A5					
	11,00	1,037	11,41	1,37	
B1					
	11,00	1,003	11,04	1,44	
B2					
	11,00	1,009	11,10	1,39	
B3					
	11,00	1,016	11,18	1,41	
B4					
	11,00	1,019	11,21	1,33	
Bus HV					
	33,00	1,000	33,00	0,00	
Bus LSP1					
	11,00	0,999	10,99	1,42	
C1					
	11,00	1,008	11,09	1,45	
C2					
	11,00	1,018	11,20	1,42	
C3					
	11,00	1,022	11,24	1,42	
C4					
	11,00	1,027	11,30	1,38	
C5					
	11,00	1,029	11,32	1,38	

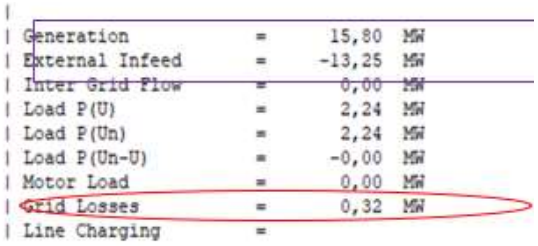
Grid: LV-Grid	System Stage: LV-Grid	Study Case: Study Case	Annex: / 4

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] -10 -5 0 +5 +10
C6					
	11,00	1,033	11,36	1,28	

DIgSILENT PowerFactory 2019 SP4	Project:	Date: 2020-04-20

Case 11 – 35% of the hh install SSEG, cap. and ind. SSEG

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 35% SSEG connected

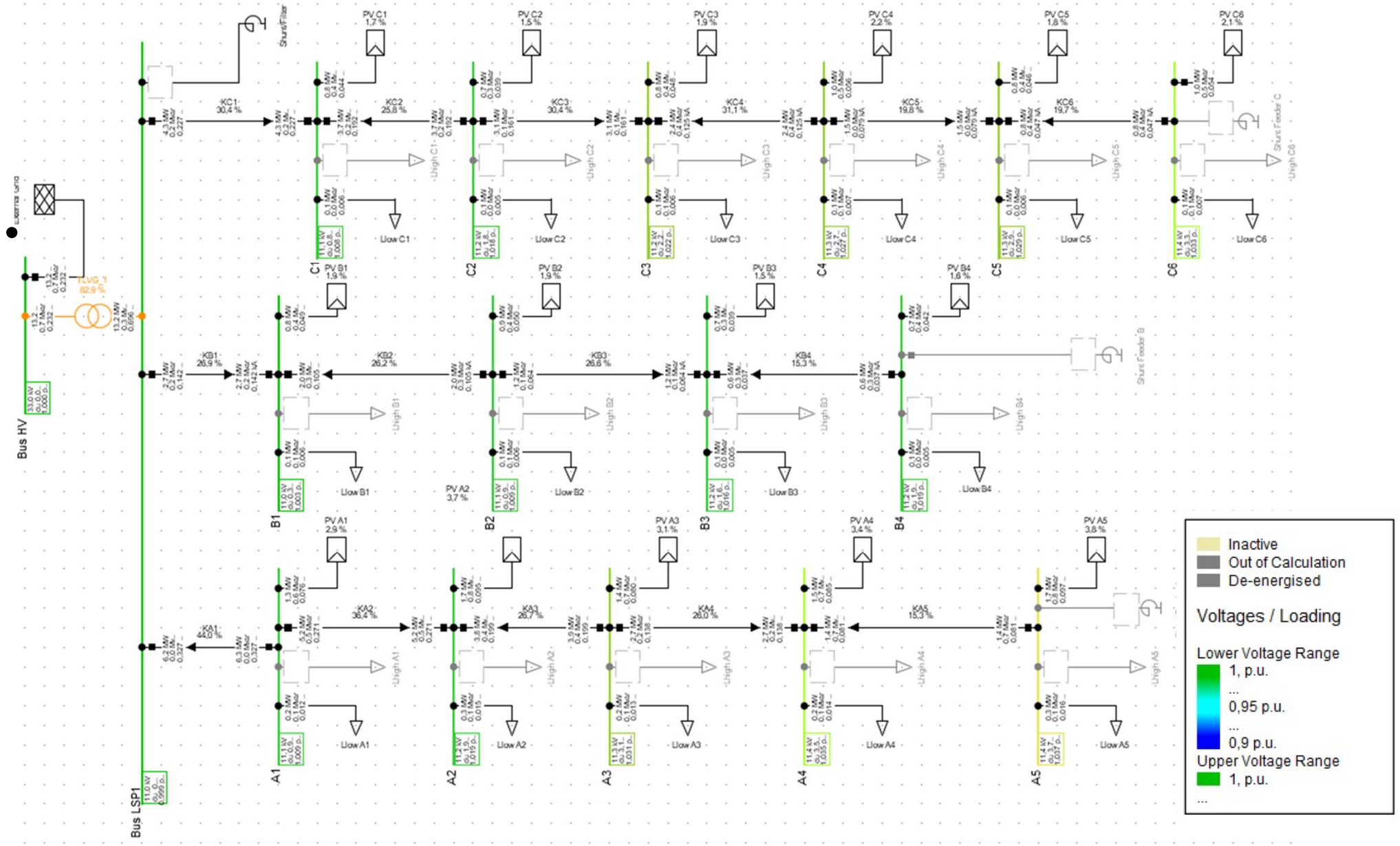


Generation	=	15,80	MW
External Infeed	=	-13,25	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	-0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	0,32	MW
Line Charging	=		

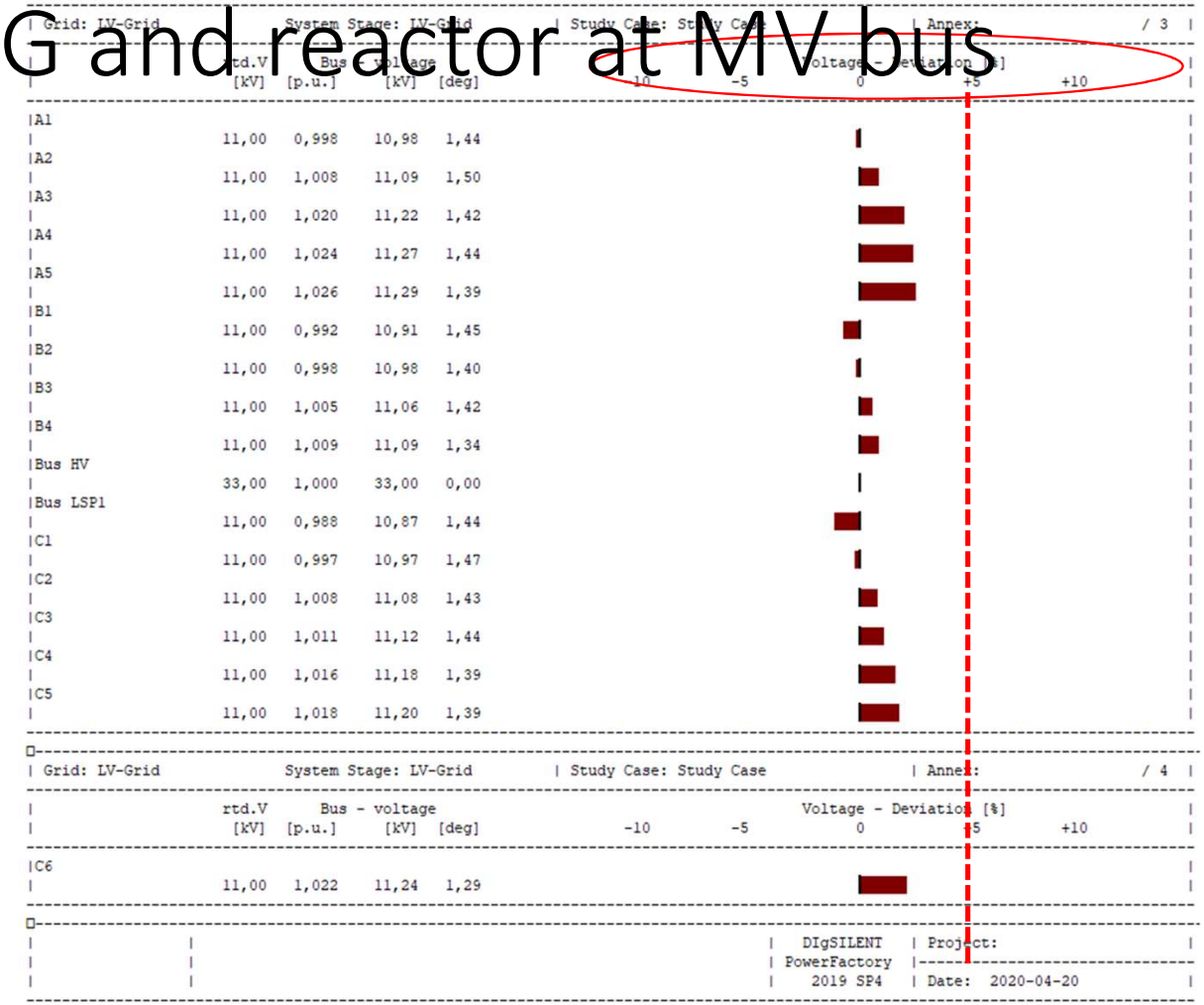
- Grid losses: 0.32MW
- Voltages within limits
- Changed power flow – bottom up

Case 12 – 35% of the hh install SSEG, cap. and ind. SSEG and reactor at MV bus

- Every second SSEG systems is capacitive
- A shunt reactor at the MV bus is added


Bus HV
Bus LSP1
TLVG_1
82,9 %
ShuntFilter
KC1
30,4 %
KC2
25,8 %
KC3
30,4 %
KC4
31,1 %
KC5
19,8 %
KC6
19,7 %
KB1
26,9 %
KB2
26,2 %
KB3
26,6 %
KB4
15,3 %
KA1
44,0 %
KA2
36,4 %
KA3
26,7 %
KA4
26,0 %
KA5
15,3 %
PV C1
1,7 %
PV C2
1,5 %
PV C3
1,9 %
PV C4
2,2 %
PV C5
1,8 %
PV C6
2,1 %
PV B1
1,9 %
PV B2
1,9 %
PV B3
1,5 %
PV B4
1,6 %
PV A1
2,9 %
PV A2
3,7 %
PV A3
3,1 %
PV A4
3,4 %
PV A5
3,8 %
Shunt Feeder C
Shunt Feeder B
Uhigh C1
Uhigh C2
Uhigh C3
Uhigh C4
Uhigh C5
Uhigh C6
Uhigh B1
Uhigh B2
Uhigh B3
Uhigh B4
Uhigh A1
Uhigh A2
Uhigh A3
Uhigh A4
Uhigh A5
Ulow C1
Ulow C2
Ulow C3
Ulow C4
Ulow C5
Ulow C6
Ulow B1
Ulow B2
Ulow B3
Ulow B4
Ulow A1
Ulow A2
Ulow A3
Ulow A4
Ulow A5
C1
C2
C3
C4
C5
C6
B1
B2
B3
B4
A1
A2
A3
A4
A5
Inactive
Out of Calculation
De-energised
Voltages / Loading
Lower Voltage Range
1, p.u.
...
0,95 p.u.
...
0,9 p.u.
Upper Voltage Range
1, p.u.
...

Case 12 – 35% of the hh install SSEG, cap. and ind. SSEG and reactor at MV bus



| Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 3 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
A1	11,00	0,998	10,98	1,44	
A2	11,00	1,008	11,09	1,50	
A3	11,00	1,020	11,22	1,42	
A4	11,00	1,024	11,27	1,44	
A5	11,00	1,026	11,29	1,39	
B1	11,00	0,992	10,91	1,45	
B2	11,00	0,998	10,98	1,40	
B3	11,00	1,005	11,06	1,42	
B4	11,00	1,009	11,09	1,34	
Bus HV	33,00	1,000	33,00	0,00	
Bus LSP1	11,00	0,988	10,87	1,44	
C1	11,00	0,997	10,97	1,47	
C2	11,00	1,008	11,08	1,43	
C3	11,00	1,011	11,12	1,44	
C4	11,00	1,016	11,18	1,39	
C5	11,00	1,018	11,20	1,39	

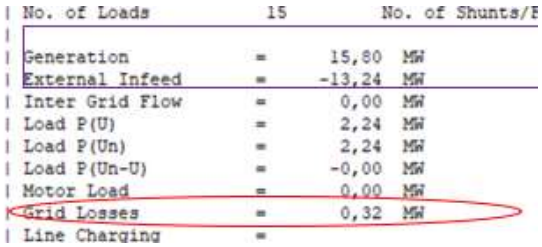
| Grid: LV-Grid | System Stage: LV-Grid | Study Case: Study Case | Annex: / 4 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]	Voltage - Deviation [%] −10 −5 0 +5 +10
C6	11,00	1,022	11,24	1,29	

DIgSILENT PowerFactory 2019 SP4	Project:	Date: 2020-04-20

Case 12 – 35% of the hh install SSEG, cap. and ind. SSEG and reactor at MV bus

- External Grid keeps active power balance (slack)
- The house hold loads are at their lowest
- 35% SSEG connected



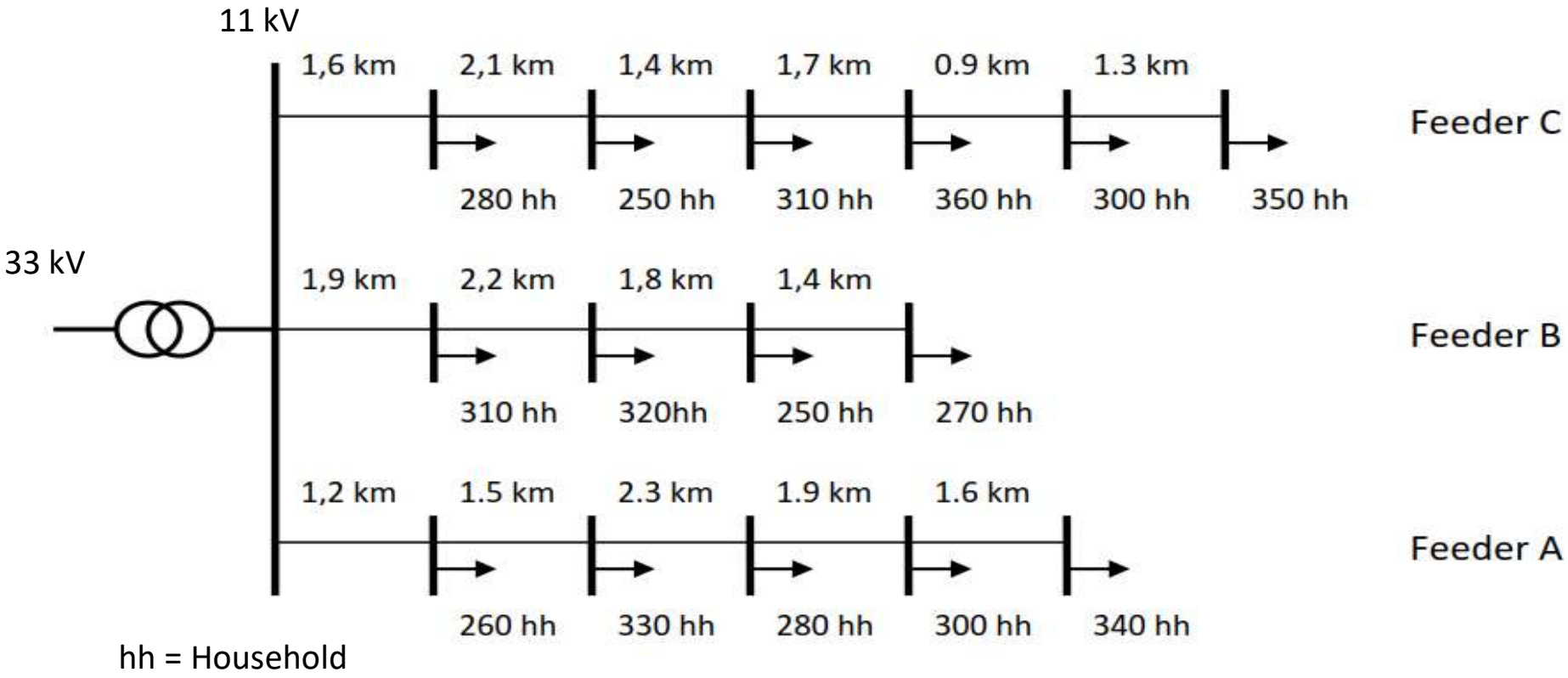
No. of Loads	15	No. of Shunts/F	
Generation	=	15,80	MW
External Infeed	=	-13,24	MW
Inter Grid Flow	=	0,00	MW
Load P(U)	=	2,24	MW
Load P(Un)	=	2,24	MW
Load P(Un-U)	=	-0,00	MW
Motor Load	=	0,00	MW
Grid Losses	=	0,32	MW
Line Charging	=		

- Grid losses: 0.32MW
- Voltages are decreased – more slack
- Changed power flow – bottom up

Conclusion

	Grid losses [MW]	Exceeding voltage limits?
Case 1 - 0 % SSEG	0.32	no
Case 7 - 35 % SSEG, reactors at end of feeders	0.34	no
Case 8 - 35 % SSEG, cap. SSEG	0.46	no
Case 9 - 35 % SSEG, cap SSEG & Reactor at main bus	0.47	no
Case 10 - 35 % SSEG, reactor at main bus	0.38	no
Case 11 - 35 % SSEG, cap. and ind. SSEG	0.32	no
Case 12 - 35 % SSEG, cap. and ind. SSEG & Reactor at main bus	0.32	no

Homework



hh = Household