Load Management of an Electricity Distribution Network

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Introduction

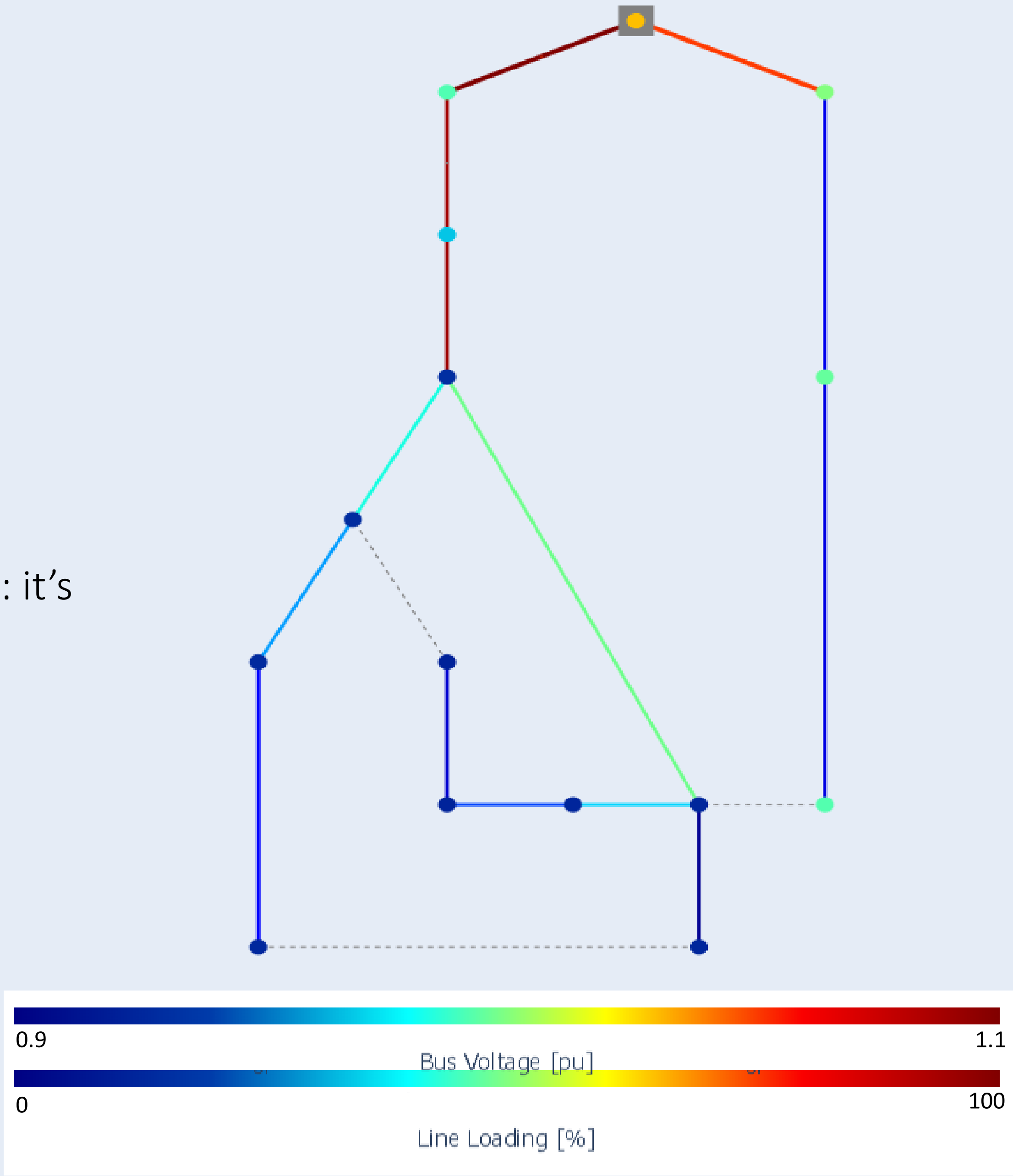
- Electrification of the transport sector is a key to reducing emissions and achieving climate goals
- Technical challenges for the electricity network: overloading the grid and voltage reductions
- Hypothetical electric grid has been examined, fitted with existing loads, and implemented with new loads in the form of EVs

Step 1.1: The network in its original state

- 0.9 [pu] ≤ Bus voltage ≤ 1.1 [pu]
- Loading rate ≤ 100%

Transformer 0 is the only unit that is outside our specifications: it's overloaded with 1.4 percentage units.

Transformer loading [%] (net.res_trafo.loading_percent)	
0	101.411473
1	84.698048

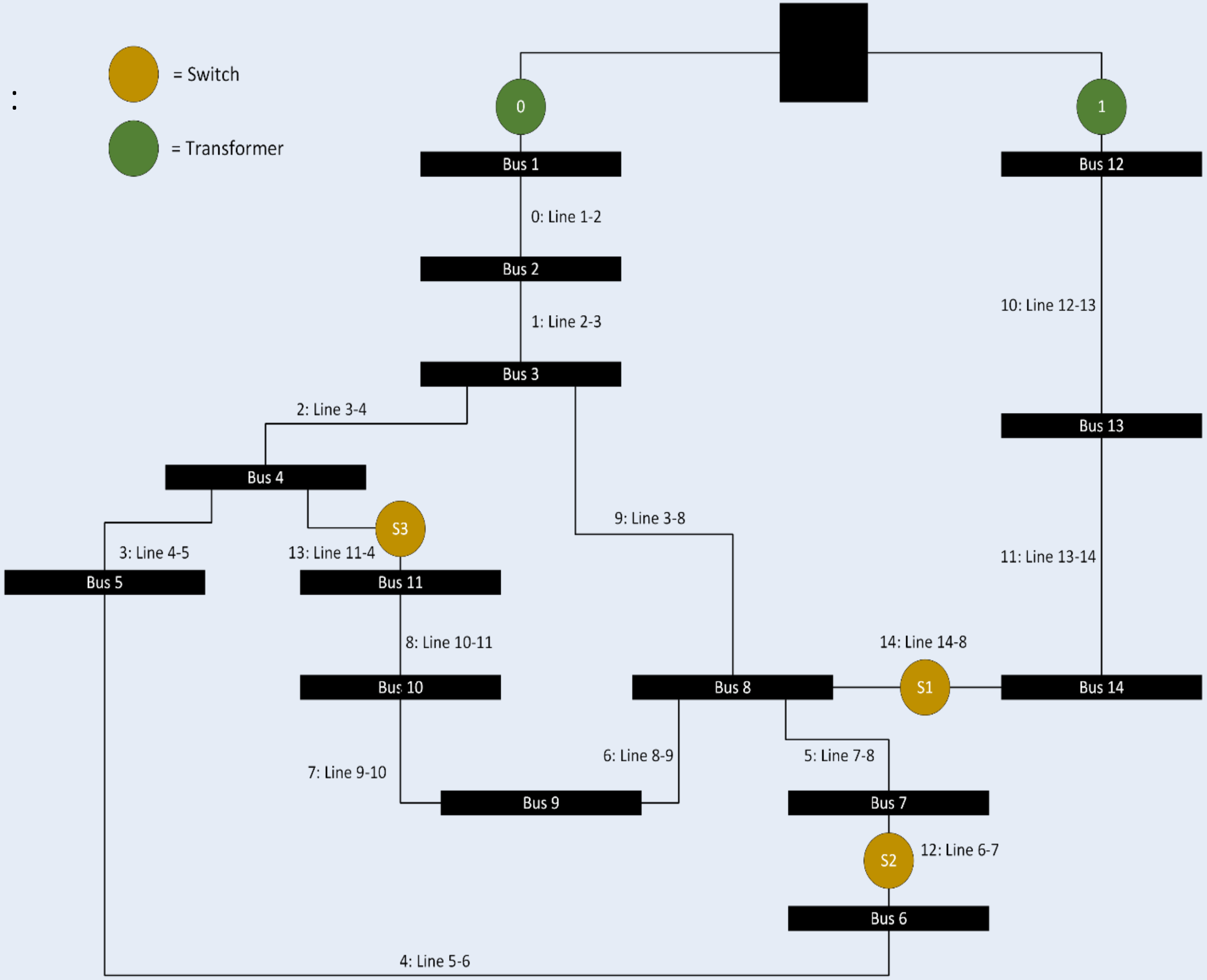


Step 1.2 & 1.3: Contingency (N-1) analysis

- These are the switches that needed to be closed for the whole system to get electricity :

Line dropped	Switch closed
Line 0 dropped	S1
Line 1 dropped	S1
Line 2 dropped	S2 or S3
Line 3 dropped	S2
Line 4 dropped	S2
Line 5 dropped	S2
Line 6 dropped	S3
Line 7 dropped	S3
Line 8 dropped	S3
Line 9 dropped	S1, S2 or S3
Line 10 dropped	S1
Line 11 dropped	S1

- If two switches could be closed, we analyzed the best-case scenario because we have the choice.

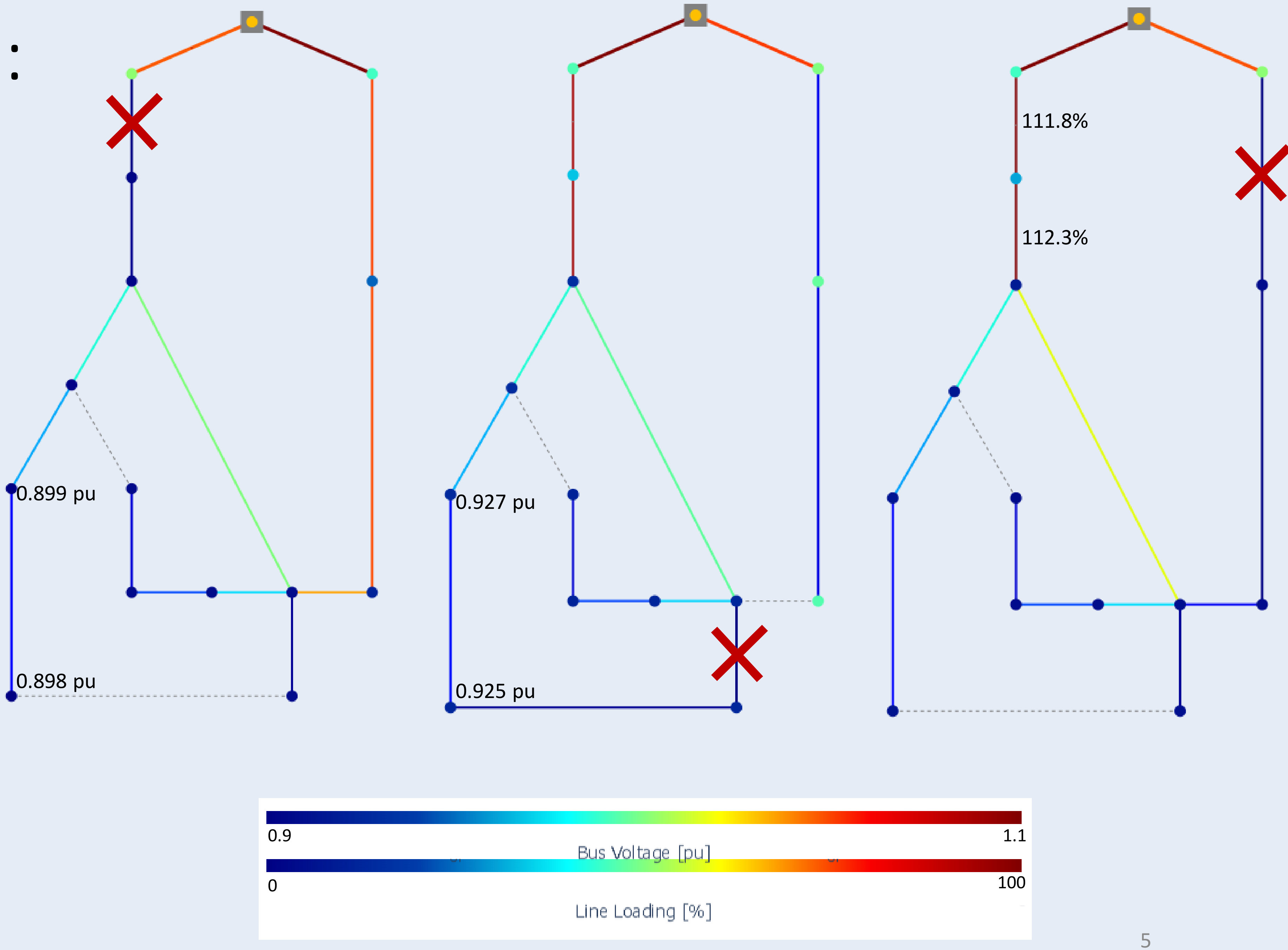


Step 1.2 & 1.3: (N-1) analysis

- **0.9 [pu] ≤ Bus voltage ≤ 1.1 [pu]**
- **Loading rate ≤ 100%**

- Examples when line 0, line 5 and line 10 is dropped

- Critical situations occur when line 0 and line 10 is dropped



Step 2: Implementation of Charging Stations

Scenario 1: Charging stations no EV

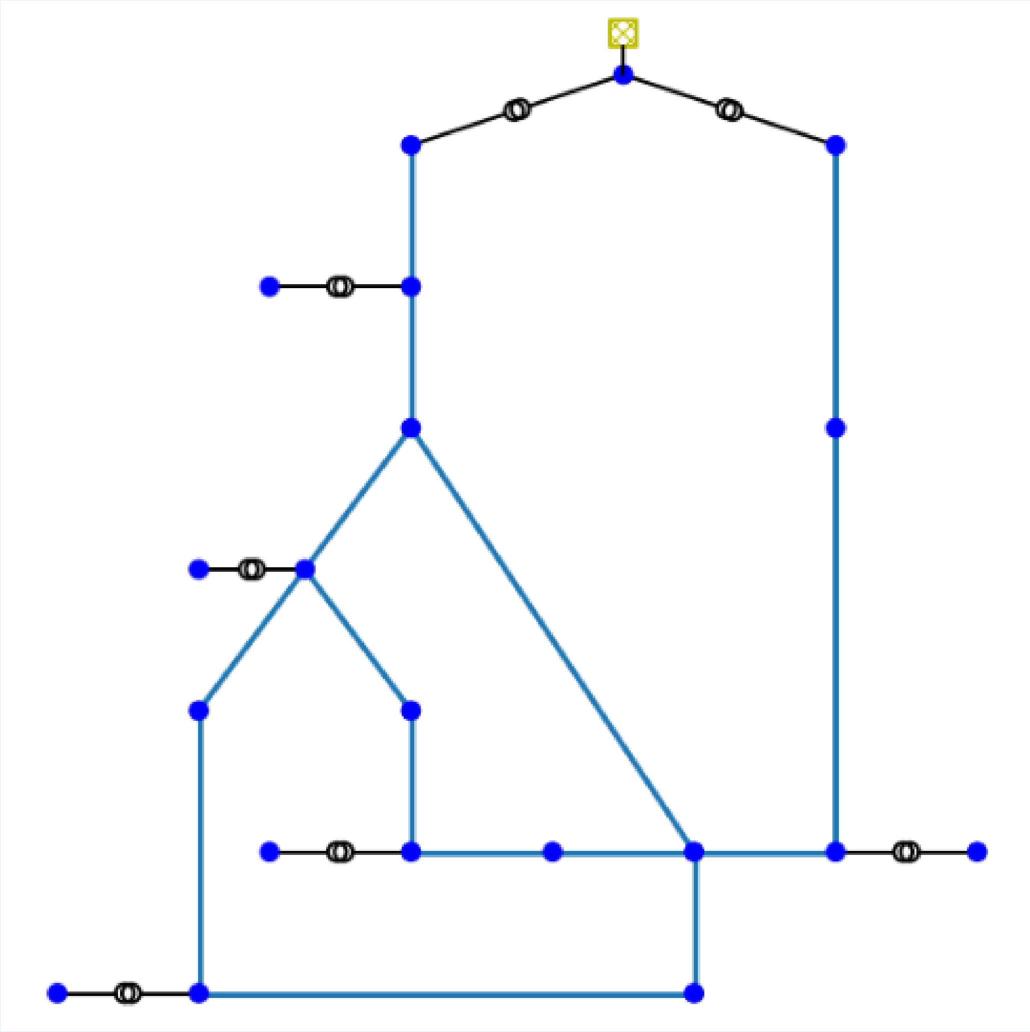
In this step, we first added 5 **new charging stations** to the existent network.

It consisted of creating :

- 5 new low voltage buses (0.4 kV)

- 5 transformers 20/0.4 kV on buses 2, 4, 6, 12, 14

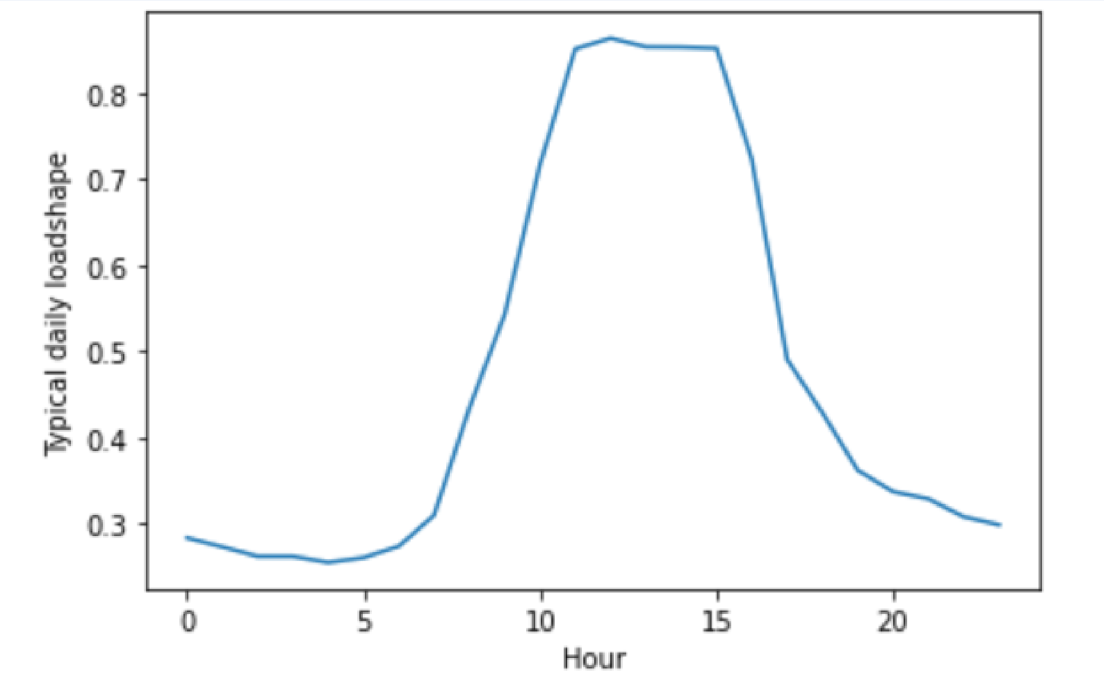
We decided to put the biggest transformer, with a rated power of 0.63 MVA, to put the maximum number of EV in the next step.



New network, using the geodata information

Step 2: Implementation of a time series

Then we implemented the time series with changing loads on all buses.
We added a loadshape to the existent 18 customers, so that they don't have a constant load.



--> After that we ran the time series :

- Maximum line load= 82,21% (line 0 at 12h)

Step 1 : lines L0 and L1 were respectively loaded at **96,48%** and **96,96%**.

- 0,94 < vm_pu bus <1,03

Step 1 : vm_pu could drop to 0,92 (bus 11)

Discussion about Step 2

--> Compared with step 1, the lines are less loaded (>82%) and bus voltages stay higher than 0.94 pu. The state of the network is better.

Why ?

- In step 1 : we used a static load
- In step 2 : we only apply a fraction (<100%) of this load with the loadshape given. Therefore, the **power in the lines is lower**.

- We did not add the EV, so there is **no new load** in the network.

Step 3.1: EVs allocation – Choosen number of EVs

Model:

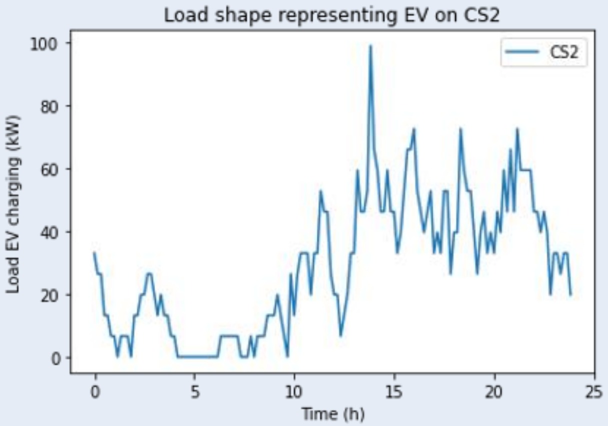
- We choose to put 100 EVs on each charging station
- Each EV follow a different charging profile from the recharging profiles data
- For each CS, we sum 100 different profiles and apply it as the CS load

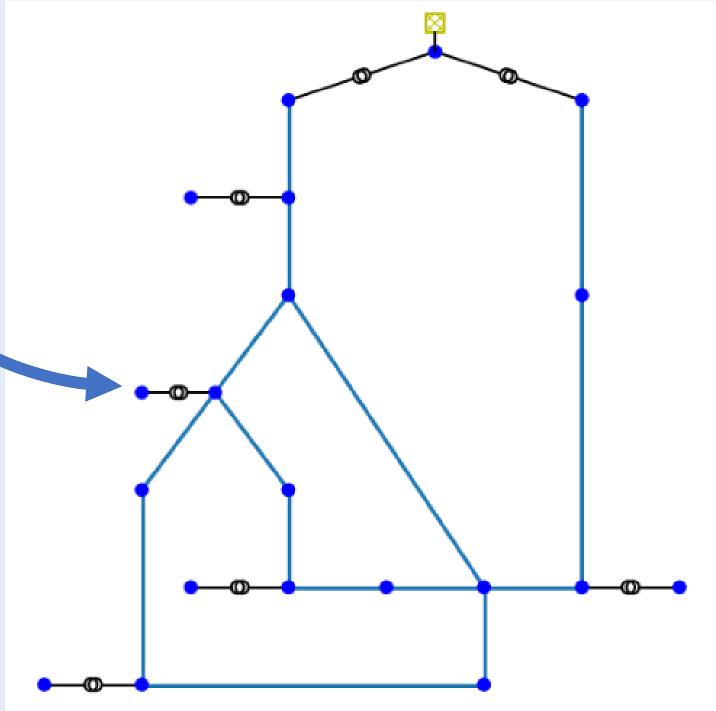
Step 3.1: EVs allocation – Choosen number of EVs

Model:

Time	Vehicle 1	Vehicle 2	Vehicle 3	...	Vehicle 100
0:00	0	0	0	...	0
0:10	6600	0	0	...	0
0:20	6600	0	0	...	0
0:30	6600	6600	0	...	0
0:40	6600	6600	6600	...	0
0:50	0	0	6600	...	0
1:00	0	0	0	...	6600

CS2
0
6600
6600
13200
19800
6600
6600





- EVs are mostly recharged during the day between 10 AM and 12 PM
- less than 15% of the fleet is charging at the same time

Step 3.1: EVs allocation – Choosen number of EVs

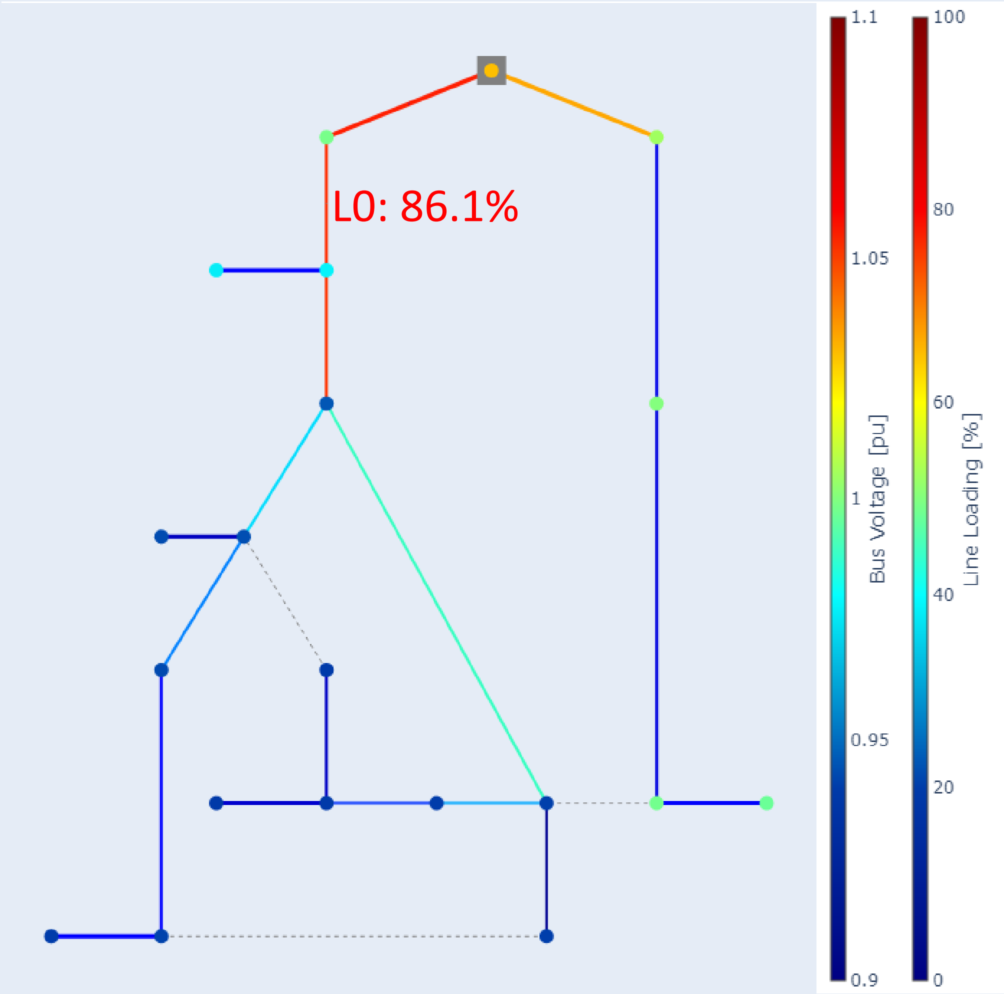
Scenario 2 : 100 EV on each charging stations

Evaluate:

State of the network at 12:50 :

-Max load on L0 : 86.1 % (**Sc1: 82% with no EVs)**

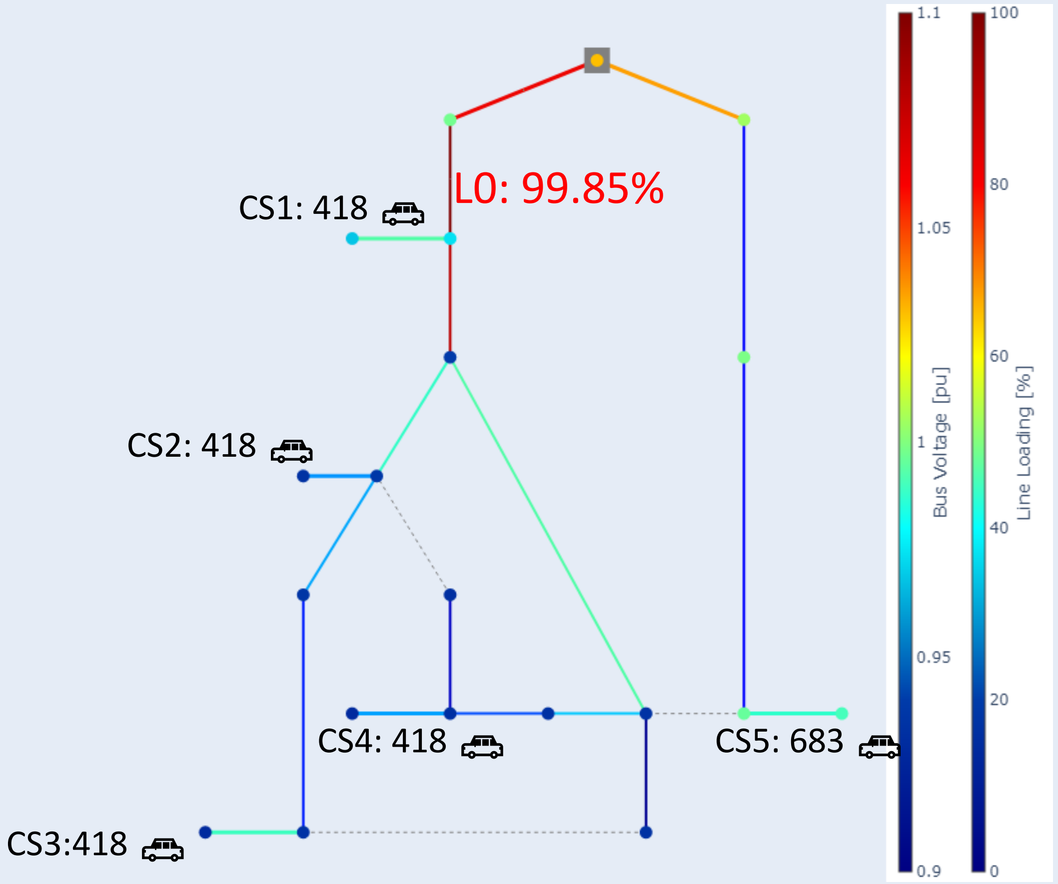
--> Nothing is overloaded

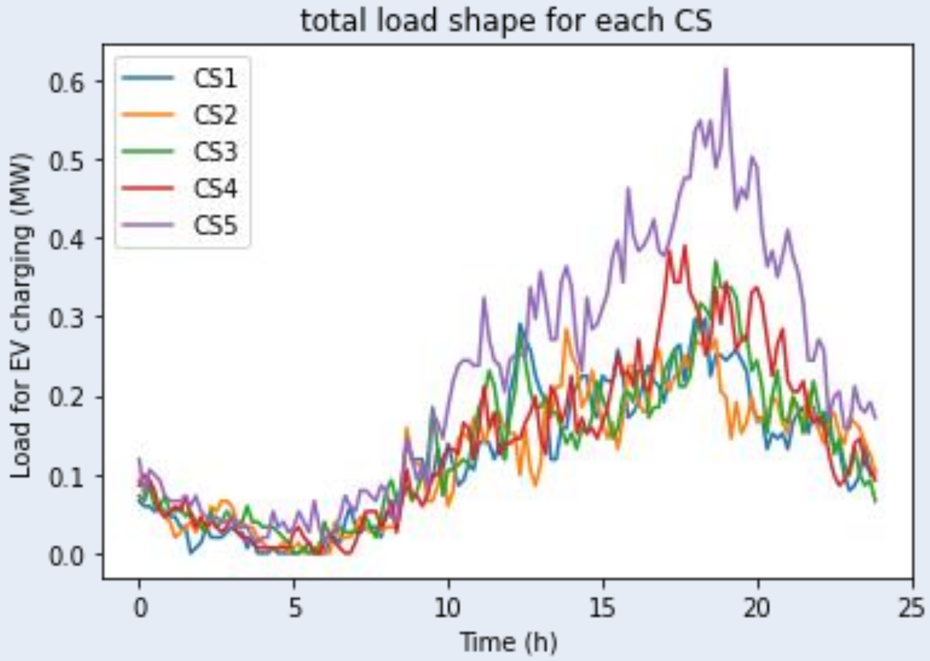


Step 3.2: EVs allocation - Maximum number of EVs

Scenario 3 : Max number of EV : 418 EV on each charging stations CS1-4 and 683 on CS5

- Increase the number of vehicles on each CS until the network is overloaded
- Total fleet of 2355 vehicles (This result can change a bit depending on the profiles chosen from the data)

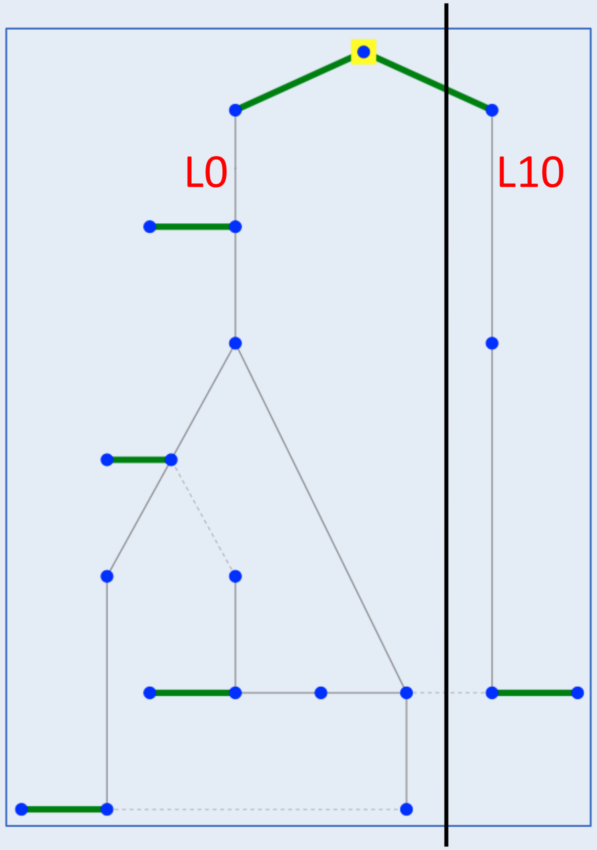




Step 3.2: EVs allocation - Maximum number of EVs

Analyze:

- The left and right sides are independent as S1 is opened
- Either the heading line or the trafos limit the number of vehicles charging :



Line's limit :

- Calculated based on the heading line for each side (depending on the additional load it can sustain)

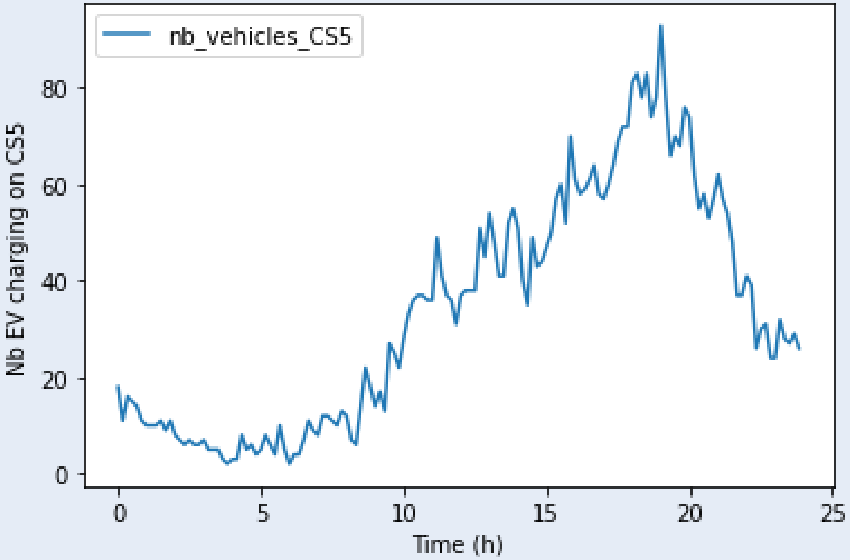
CS Trafo's limit :

- P-trafo = 0.63 MVA

Step 3.2: EVs allocation - Maximum number of EVs

Analyze: right side

- On the right side, the trafo of the CS5 limits the number of vehicles charging at the same time (the line is not very loaded without the EV)



Trafo's limit :

- P-trafo = 0.63 MVA
- Max EV charging at the same time to not overload the trafo : 95
- Corresponding Nb of vehicles in the fleet on each CS : 633 (as <15% are charging at any time)

Max EV charging on CS5 : 91 at 6 PM

Step 3.2: EVs allocation - Maximum number of EVs

Analyze: left side

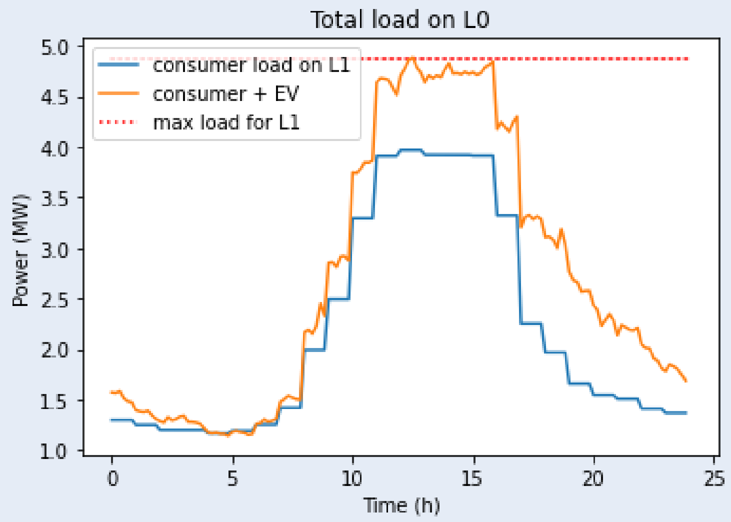
- On the left side, the line 0 is limiting the number of EV charging (very loaded without EV: max loading found at 12 PM : 81.8%)
- The maximum load that the line 0 can sustain :
  - Maximum load acceptable for L0 :

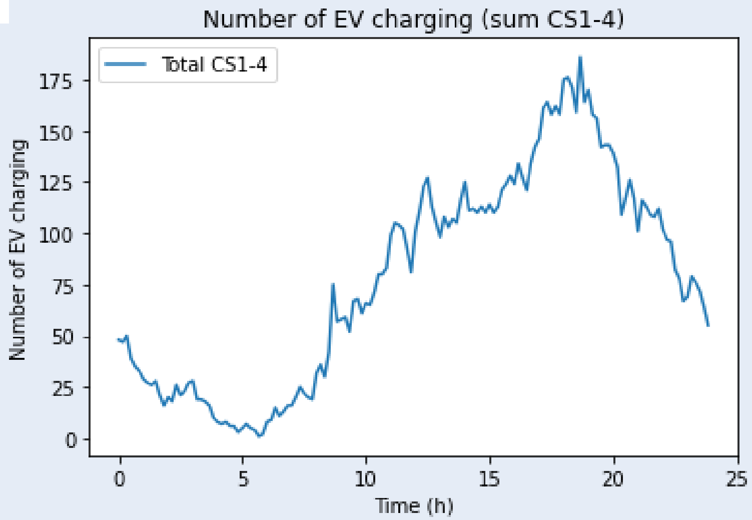
$$Max\_load\_L0 = \frac{S_{toL0,Step1}}{L0\_load, step1} = \frac{4.6919}{0.9648} = 4.8631\ MW$$

- Max additional load from EV (on CS1-4) depends on the time:

$$Max\_charging\_vehicle(\mathrm{t}) = Max\_load\_L0.(1 - loading(\mathrm{t}))/P\_vehicle$$

  - It is around : 130 at 12:00 and over 500 at 5 AM

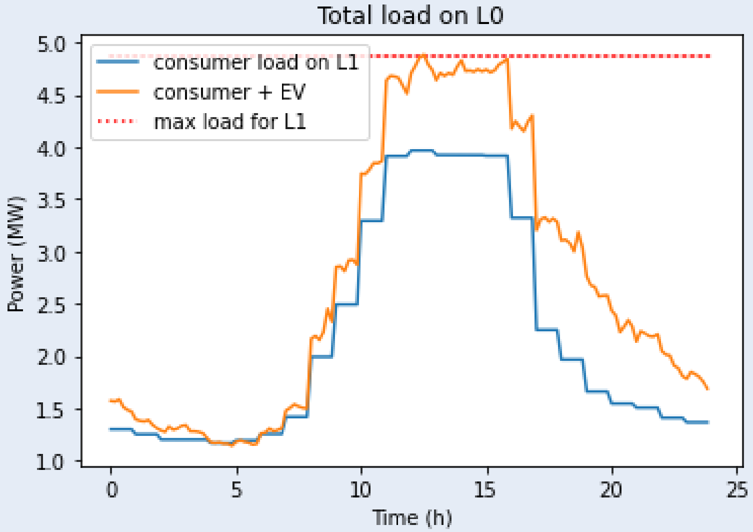




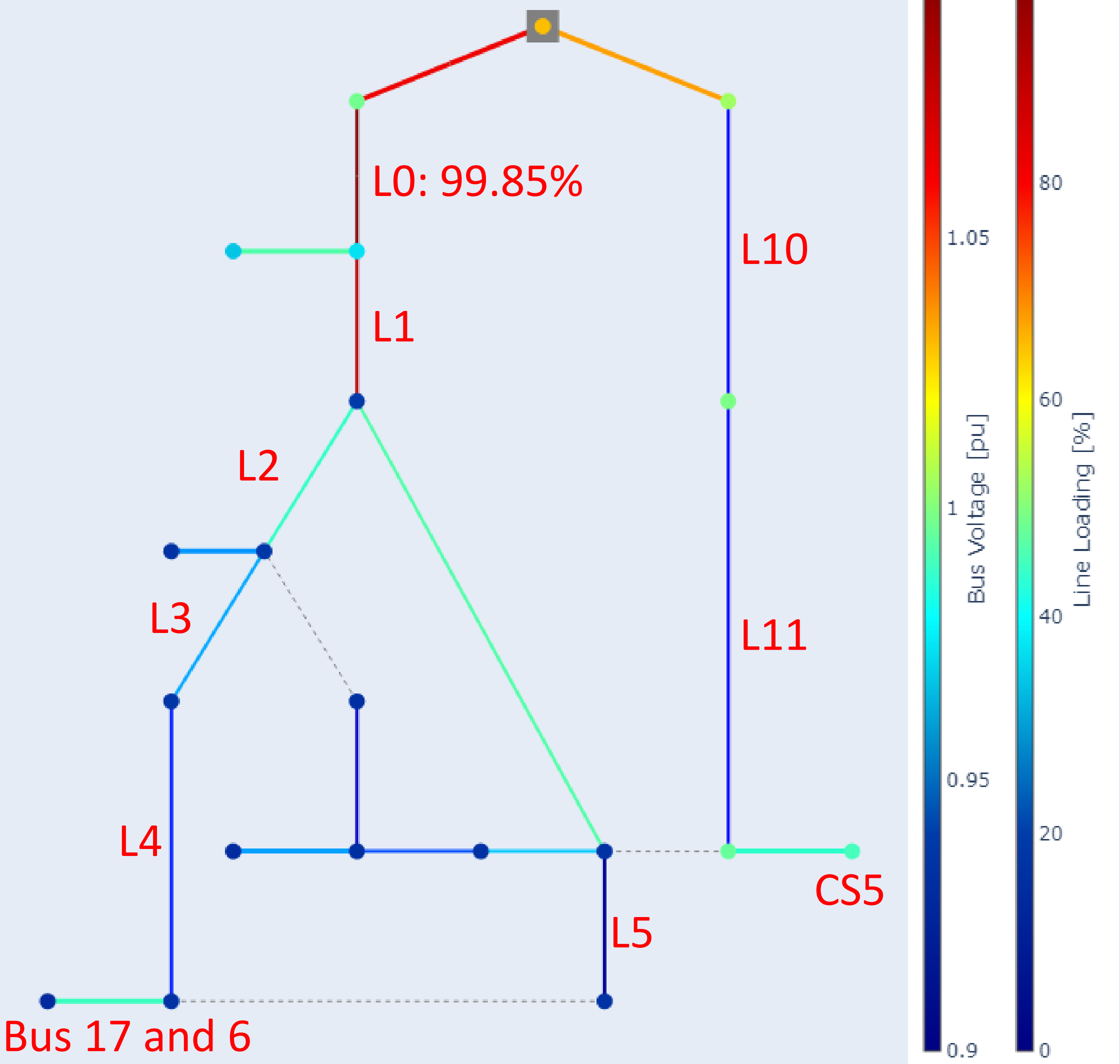
Step 3.3: EVs allocation – N-1 case

Scenario 3 : Max number N-1 case

- N-1 case considering the maximum EVs in the system
- We consider only the worst time of the day 12:50 PM (when the load under L0 is maximum) and run the N-1 case the same way as step 1 (same rules to close the switches)



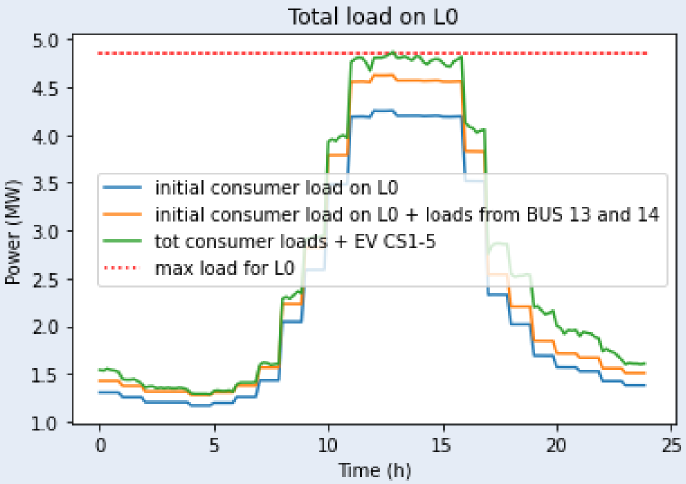
Critical line	Explanation
Line 0; Line 1	Voltage drop on bus 6 and 17
Line 2; Line 3; Line 4; Line 5	L0 slightly overloaded because of additional losses
Line 10; Line 11	L0 and L1 overloaded because of CS5 and consumer loads on the right side (0.37MW at 12:50 PM)



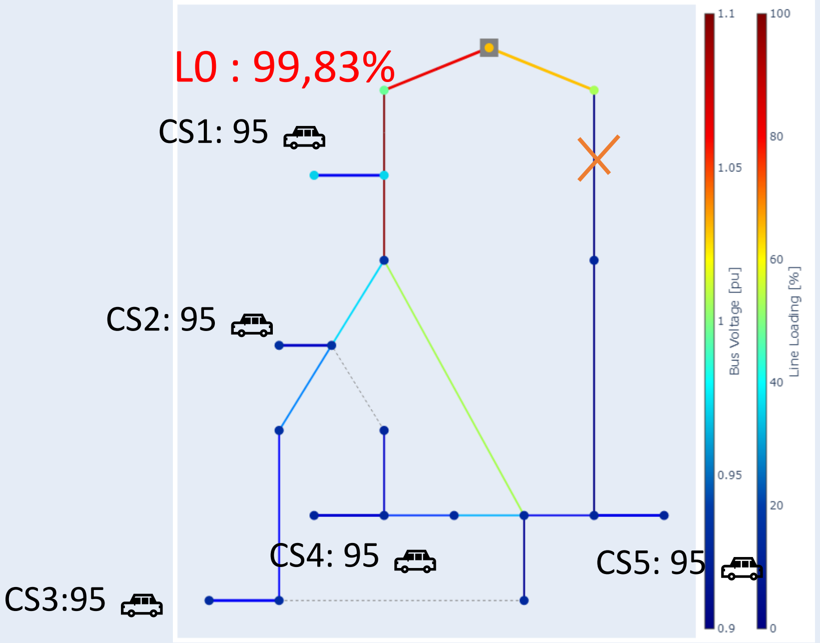
Step 3.4: EVs allocation – Reducing number of EVs for no violation in N-1 case

Scenario 4 : No violation in N-1 case : 95 EV on each charging stations (CS1-5)

- Lines L0 and L1 can't power loads on buses 13 and 14 and CS5 if L10 or L11 are dropped
- Reduce the number of EVs until line L0 can power the whole network
- Result: **95 vehicles on each CS** => 475 vehicles in total (20% of max number of EVs without N-1)
- 0 critical line



New max number of charging vehicle (CS1-5)



V_M Bus CS4: 0.924

S1 closed

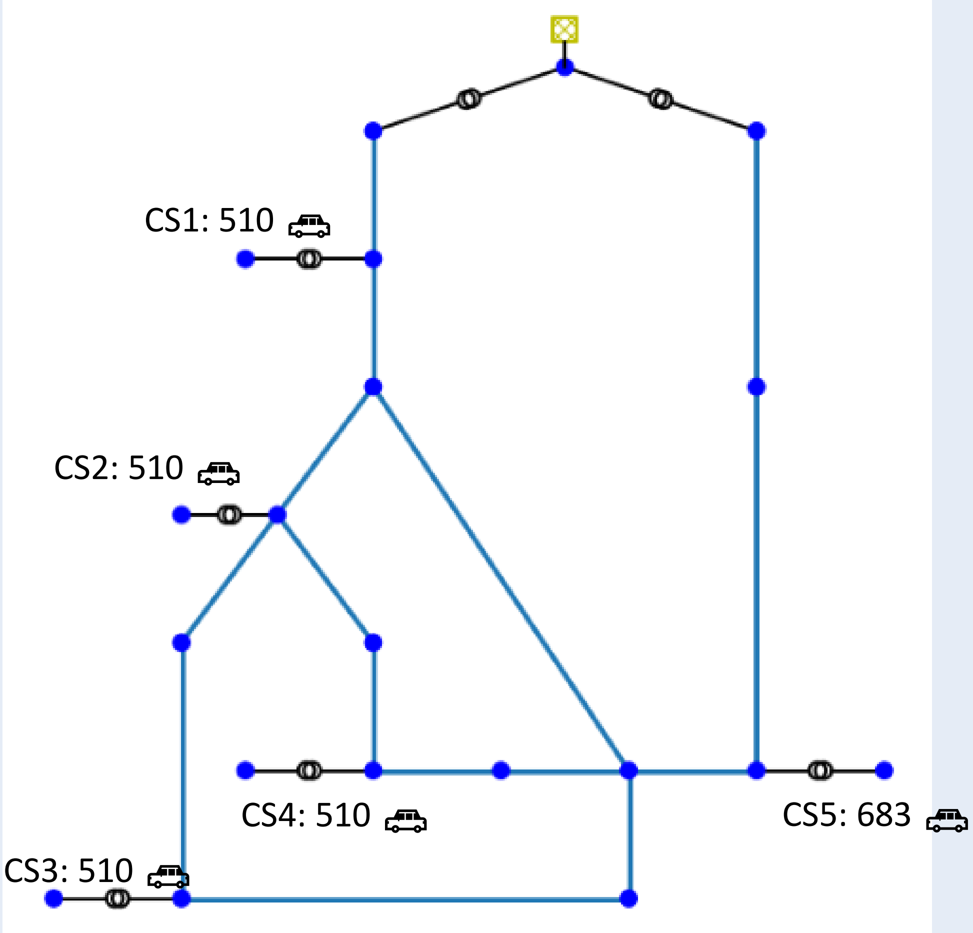
Step 4 - Sensitivity studies

Scenario 5 : L0 and L1 upgraded : 510 EV on each charging stations (CS1-4) and 683 on CS5

- For this step, we added 15% additional EVs from step 3

--> The network is overloaded

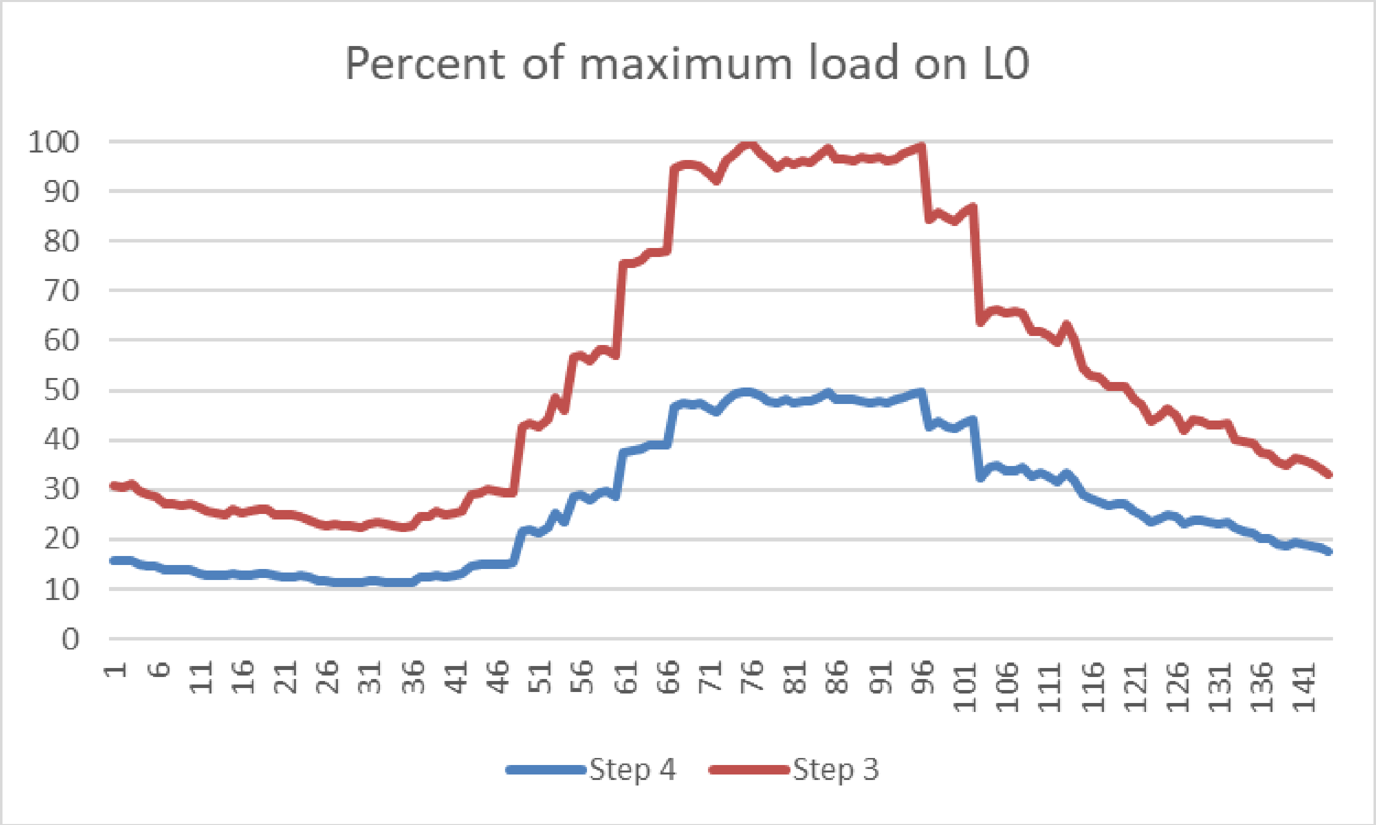
- OPTION 1 : Upgrade L0 and L1 to have the same characteristics as line 10
  = changed resistance, impedance, capacitance, and maximum current in the lines to the same values of line 10
- OPTION 2: Add parallel lines 0 and 1
- We could also have implemented smart charging
- Only the chargers on the left can be increased due to the tranformer sizes, the right transformer is at maximum load and the left transformer needs to be bigger than the smallest size

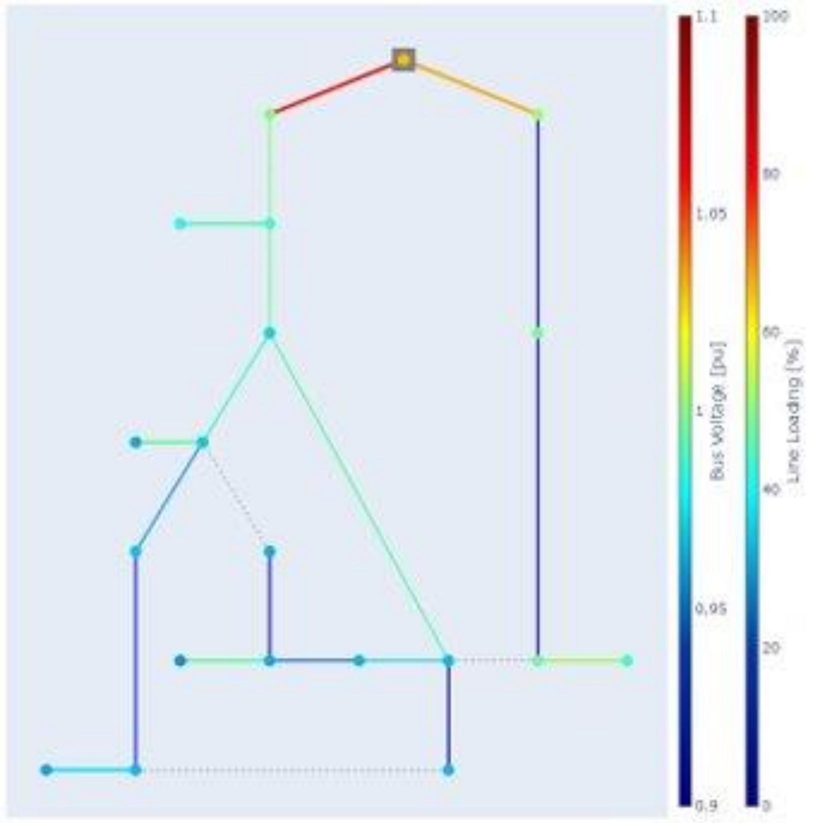


Step 4 - Sensitivity studies

State of the network with parallel-line solution:

The maximum load of the entire network is on L0, which has its maximum value at about 49,7%. Compared to Step 3, which has a maximum load of 99,85%, this leaves a lot more "wiggle room".





Conclusion

- There are different approaches to optimizing the network
- These approaches are different in robustness, cost, and operational complexity
- What is ideal in one network might not be feasible in another
- In our network and with our chosen EVs, we could fit 2355 EVs without installing parallel lines on L0 and L1, and 2723+ (115%) EVs with that solution
- If the number of EVs continue to increase in Sweden, the network will have to be upgraded at some point, which we have seen for ourselves in this study

Thank you for listening!

Questions?

Step 1.2: N-1 analysis

0.9 < Maximum voltage < 1.1	
Line dropped	Critical situation
Line 0 dropped	Vm_pu bus 5 = 0.899 pu Vm_pu bus 6 = 0.898 pu
Line 1 dropped	Vm_pu bus 4 = 0.899 pu Vm_pu bus 5 = 0.898 pu Vm_pu bus 6 = 0.896 pu
Line 2 dropped	No critical situation
Line 3 dropped	No critical situation
Line 4 dropped	No critical situation
Line 5 dropped	No critical situation
Line 6 dropped	No critical situation
Line 7 dropped	No critical situation
Line 8 dropped	No critical situation
Line 9 dropped	No critical situation
Line 10 dropped	line 0 overloaded: 111.812 % line 1 overloaded: 112.318 %
line 11 dropped	line 0 overloaded: 110.868 % line 1 overloaded: 111.37 2%

0.95 < Maximum voltage < 1.05	
Line dropped	Critical situation
Line 0 dropped	Vm_pu bus 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14 < 0.95 pu
Line 1 dropped	Vm_pu bus 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14 < 0.95 pu
Line 2 dropped	Vm_pu bus 3, 4, 5, 6, 7, 8, 9, 10, 11 < 0.95 pu (both cases)
Line 3 dropped	Vm_pu bus 3, 4, 5, 6, 7, 8, 9, 10, 11 < 0.95 pu
Line 4 dropped	Vm_pu bus 3, 4, 5, 7, 8, 9, 10, 11 < 0.95 pu
Line 5 dropped	Vm_pu bus 3, 4, 5, 6, 8, 9, 10, 11 < 0.95 pu
Line 6 dropped	Vm_pu bus 3, 4, 5, 6, 7, 8, 9, 10, 11 < 0.95 pu
Line 7 dropped	Vm_pu bus 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 < 0.95 pu
Line 8 dropped	Vm_pu bus 3, 4, 5, 6, 7, 8, 9, 10, 11 < 0.95 pu
Line 9 dropped	Vm_pu bus 10, 11 < 0.95 pu
Line 10 dropped	line 0 overloaded: 111.812 % line 1 overloaded: 112.318 % Vm_pu bus 3, 4, 5, 6, 8, 9, 10, 11, 13, 14 < 0.95 pu
line 11 dropped	line 0 overloaded: 110.868 % line 1 overloaded: 111.372 % Vm_pu bus 3, 4, 5, 6, 8, 9, 10, 11, 14 < 0.95 pu

Step 4 : Lines characteristics (option 2)

	name	std_type	from_bus	to_bus	length_km	r_ohm_per_km	x_ohm_per_km	c_nf_per_km	g_us_per_km	max_i_ka	df	parallel	type
0	Line 1-2	CABLE_CIGRE_MV	1	2	2.82	0.501	0.716	151.17490	0.0	0.145	1.0	1	cs
1	Line 2-3	CABLE_CIGRE_MV	2	3	4.42	0.501	0.716	151.17490	0.0	0.145	1.0	1	cs
10	Line 12-13	OHL_CIGRE_MV	12	13	4.89	0.510	0.366	10.09679	0.0	0.195	1.0	1	ol