Project 1 (PRO 1) description

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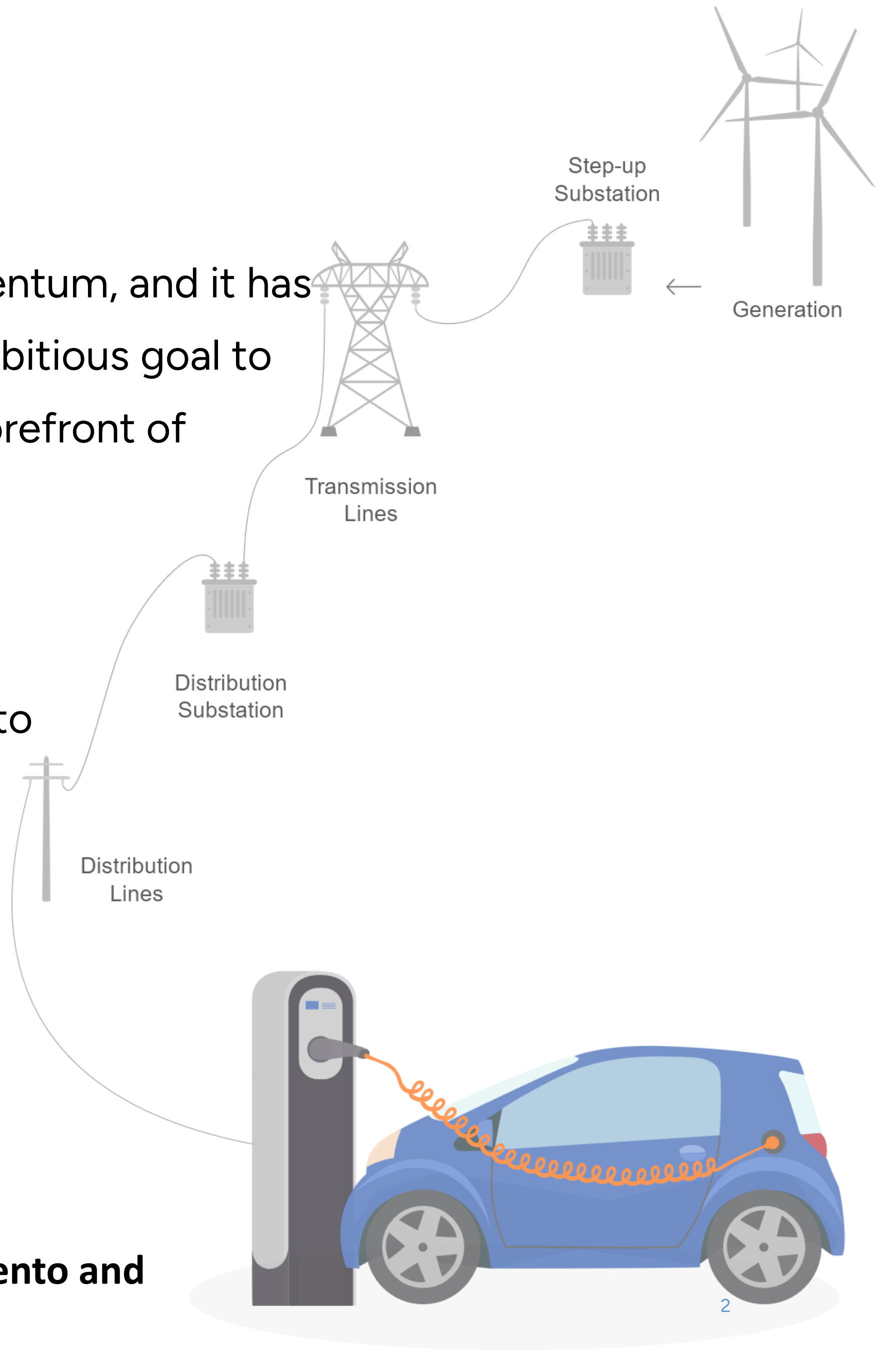
Preamble

The electrification of Sweden's transport sector is rapidly gaining momentum, and it has the potential to revolutionize the nation's energy landscape. With an ambitious goal to achieve a fossil-fuel-free transport system by 2030, Sweden is at the forefront of sustainable transportation. However,
this transition requires a forward-thinking approach to manage the increased electricity demand. In this project, you will work on impact of increased penetration of EVs on the network and develop strategies to mitigate any adverse impacts on the grid.



This document incorporates and modifies content from Priscila Costa Nascimento and her project, 'Load Management of an Electricity Distribution Network'

Project questions- Step 1

- Network in its original state:
  - 1.1 *What is the state of the network? Check bus voltage [pu] and line/transformer loading [%].*
    - Consider that the maximum allowed voltage is 1.1 pu, the minimum is 0.9 pu, and the maximum line loading is 100%.
  - 1.2 *What happens in the system during a contingency (N-1) case? Are there lines overloaded? Buses above/under the limits?*
    - Consider that the maximum allowed voltage is 1.1 pu, the minimum is 0.9 pu, the maximum line loading is 100% AND all of the customers/loads should be supplied with power.
  - 1.3 *What happens with the system when we have a stricter power quality limits under a contingency (N-1) case?*
    - Consider that the maximum allowed voltage is 1.05 pu, the minimum is 0.95 pu, the maximum line loading is 100% AND all of the customers/loads should be supplied with power.

The overall aim of this step is:

- Be able to run a power flow and understand the elements outcomes.
- Understand how a contingency analyses work.

Project questions- Step 2

- Using the default CIGRE network (S1, S2, S3 open) –and add a loadshape to existing customers (time series simulation):
  - 2.1 *Perform load flow analysis with new load profile and discuss results as compared to Step 1? Is it better, worse, or the same as before?*
- The overall aim of this step is:
  - Be able to run a time series power flow and assess the network.

Project questions- Step 3

- Implement the electric vehicle (EV) charging stations (CS) and connect EVs in the system:
  - *3.1 Estimate the number of CS and then estimate the number of EVs, that can be connected to each CS.*
  - *3.2 Perform load flow analysis with new load profile and discuss results. Compare with results from Step 2.1. Are there any node, where voltage and line limits are violated. In case, it is not violated, re-evaluate the maximum number of EVs that can be hosted by network and perform load flow analysis again and evaluate the results.*
  - *3.3 What happens in an N-1 case considering the maximum number of EVs in the system (max_pu=1.1, min_pu=0.9, line_loading=100)?*
  - *3.4 If there are critical lines identified in 3.3, determine how many EVs should be connected to avoid violations in an N-1 situation.*
- The overall aim of this step is:
  - Evaluate the power quality impacts under the charging of electric vehicles.
  - Understand what happens for a contingency analyses under the charging of electric vehicles.
  - Find the hosting capacity of your grid. Meaning, finding the number of vehicles that can charge on your network without providing any power quality violations (for the default grid).

Project questions- Step 4

- *4.1 Perform operational optimization on load to minimize the costs for consumers and perform load flow analysis with optimized load profile*
- *4.2 Compare the impact of optimized load profiles on network with the results of Step 3.2.*
- *4.3 Consider all CS nodes have PV (decide on the size of PV based on your own assumptions, justify)*
- *4.4 Perform Steps 4.1 and 4.2 for new configuration based on Step 4.3*
- *4.5 Add storage to the Step 4.4 (can be battery or V2G)- again decide the sizing and justify. Perform steps 4.1 and 4.2.*
- *4.6 Finally evaluate the coincident factors for the transformer from network analysis results of steps 3.2, 4.2, 4.4 and 4.5*

Project questions- Step 5

- *5.1 Perform operational optimization on load to minimize the network losses and perform load flow analysis with optimized load profile*
- *5.2 Compare the impact of optimized load profiles on network with the results of Step 3.2.*
- *5.3 Consider all CS nodes have PV (decide on the size of PV based on your own assumptions, justify).*
- *5.4 Perform Steps 4.1 and 4.2 for new configuration based on Step 4.3*
- *5.5 Now add storage to the Step 4.4 (can be battery or V2G)- again decide the sizing and justify. Perform steps 4.1 and 4.2.*
- *5.6 Now evaluate the coincident factors for the transformer from network analysis results of steps 3.2, 4.2, 4.4 and 4.5*

Data

Step 1: CIGRE Networks

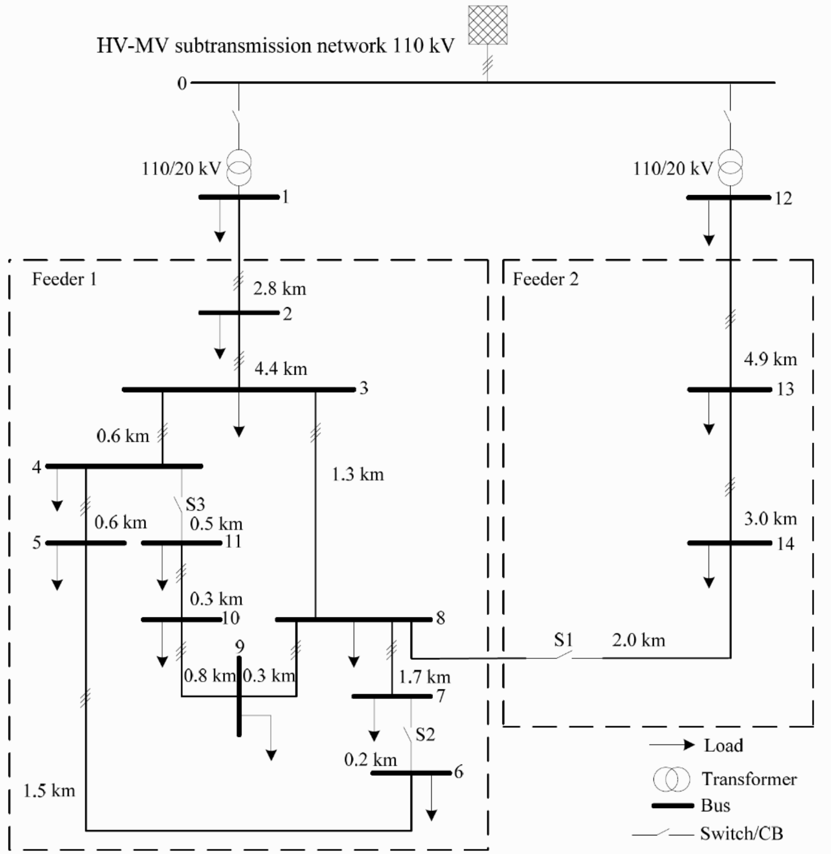
Medium voltage distribution network

[Link to the Network information in pandapower]()

This Pandapower network includes the following parameter tables:

- switch (8 elements)
- load (18 elements)
- ext_grid (1 elements)
- line (15 elements)
- trafo (2 elements)
- bus (15 elements)

All of you will be working with the same network



Step 1: CIGRE Networks
Medium voltage distribution network

To use this Network in Pandapower, you can use the following code:

```
import pandapower.networks as nw
net = nw.create_cigre_network_mv()
```

After that, you can see that the network is already implemented.

If you run ‘net’, you will receive the network parameters, as follow:

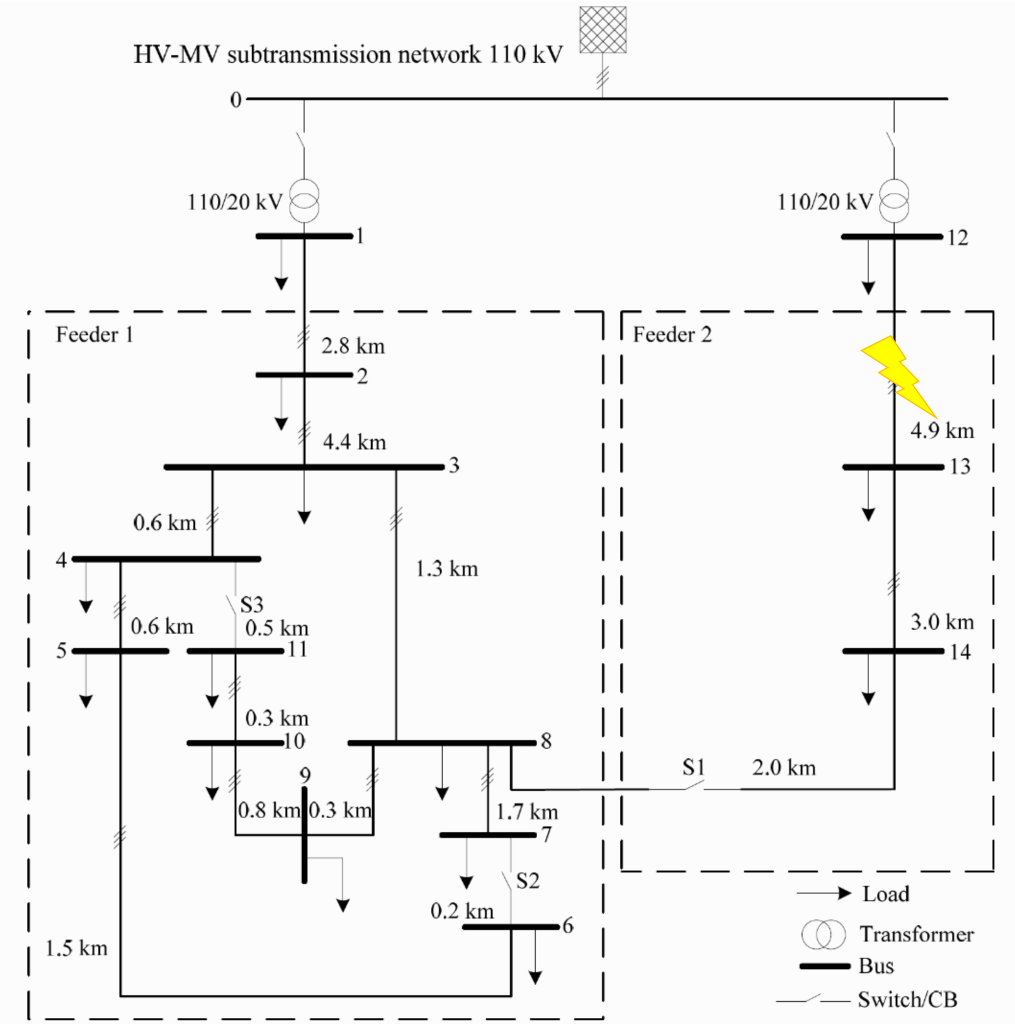
```
import pandapower.networks as nw
net = nw.create_cigre_network_mv()
✓ 10.3s

net
✓ 0.4s
This pandapower network includes the following parameter tables:
   - bus (15 elements)
   - load (18 elements)
   - switch (8 elements)
   - ext_grid (1 element)
   - line (15 elements)
   - trafo (2 elements)
   - bus_geodata (15 elements)
```

Step 1: CIGRE Networks

1.2 Contingency (N-1) case

- Put one line out of service
- Operating the switches to provide supply to the customer/load
- Run a power flow
- Access the results
- There are buses/lines violating the power quality limits? If yes, the line you just put out of service is a critical line. If no, it is not.
- Put the line in service again

Do this for all the 12 lines (do not consider Line 6-7, Line 11-4, Line 14-8. They are the switches).



Step 2: Network Modifications – Loadshape

The CIGRE network already has 18 loads (customers) implemented (you can check the active and reactive power with the 'net.load' command).

There is no time series simulation data available (daily, yearly, etc.).

All you have to do is use this loadshape with your existing loads:

00h: 0.28285
0.272295
0.2613828
0.261328
0.254316
0.259789
0.272966
0.30915
0.433979
0.542955
0.717333
0.851829
0.864118
0.854116
0.853815
0.852508
0.723452
0.490362
0.428271
0.361402
0.336596
0.328176
0.307331
23h: 0.297966

- The loadshape consists of values that range from 0 to 1.
- To use it with your actual power, you need to multiply these values.
- After that, you will have the load shape for your specific load over the 24 time steps.
- For example, for load R1, we have an active power of 14.99400 and a reactive power of 3.044662. Therefore, the daily power profile for this load will be as follows:

Load R1		
loadshape	p_mw	q_mvar
0.28285	4.2410529	0.861182647
0.272295	4.08279123	0.829046239
0.2613828	3.919173703	0.795822279
0.261328	3.918352032	0.795655431
0.254316	3.813214104	0.774306261
0.259789	3.895276266	0.790969696
0.272966	4.092852204	0.831089207
0.30915	4.6353951	0.941257257
0.433979	6.507081126	1.32131937
0.542955	8.14106727	1.653114456
0.717333	10.755691	2.184036526
0.851829	12.77232403	2.593531387
0.864118	12.95658529	2.630947238
0.854116	12.8066153	2.600494529
0.853815	12.80210211	2.599578086
0.852508	12.78250495	2.595598712
0.723452	10.84743929	2.202666813
0.490362	7.352487828	1.492986548
0.428271	6.421495374	1.303940439
0.361402	5.418861588	1.100346936
0.336596	5.046920424	1.024821051
0.328176	4.920670944	0.999184997
0.307331	4.608121014	0.935719017

2. How's the state of the network if compared with step 1? Better, worse, same as before..
For you to run a time series simulation you can find more information and the code **here**.

Step 3: Network Modifications - CS

The idea here is to connect EVs to the low-voltage side of the network (0.4 kV). Since the voltage at the customer's level is 20 kV right now, transformers are necessary.

We will use Basic Standard Types, and you can choose from three different types:

- 0.25 MVA 20/0.4 kV
- 0.4 MVA 20/0.4 kV
- 0.63 MVA 20/0.4 kV

These types differ only in their rated apparent power; more power means a greater capacity to support loads. You can select the type that best suits your needs to answer the project questions.

We will allocate the EVs to charging stations (CS). Therefore, you can create the CS wherever you prefer (which means you have 15 options, corresponding to the buses).

Step 3: Network Modifications - CS

The geodata information for the buses that you need to create will depend on which buses you choose for the high-voltage side of the transformer in your specific case. For instance, if you run the 'net.bus_geodata' command before creating the new buses, you will obtain the following data:

	x	y
0	7.0	16
1	4.0	15
2	4.0	13
3	4.0	11
4	2.5	9
5	1.0	7
6	1.0	3
7	8.0	3
8	8.0	5
9	6.0	5
10	4.0	5
11	4.0	7
12	10.0	15
13	10.0	11
14	10.0	5

Here, you can observe the geodata for the 15 original buses. In my case, I simply subtracted 1 point in each direction when creating the low-voltage bus. For example:

- Bus CS 3 is connected to the hv_bus 5, which has the geodata as (1, 7). Therefore, for the lv_bus, I used (0, 6). When you plot this network, you will notice that the buses are no longer overcrowded. This simplifies the analysis for future reference. You can experiment with the coordinates to find the best option for your situation. The code to view the network plot is as follows:

```
ax = pplt.simple_plot(net, show_plot=False)
clc = pplt.create_line_collection(net, linewidth=3., use_bus_geodata=True)
pplt.draw_collections([clc], ax=ax)
plt.show()
```

- Don't forget to import the right libraries:

```
import pandapower.plotting as pplt
import matplotlib.pyplot as plt
```

Step 3: Network Modifications – EVs allocation

- Allocate the EVs for recharging in our system.
- You have the flexibility to create the EVs in the manner you prefer, either as 'loads' or as 'storage.' However, for both of these options, you will use the loadshapes provided by this source.
- Download the file named '**PEV-Profiles-L2.xlsx**'.
- Within this file, you will find annual loadshape information for 348 different EVs.
  Next, apply the same approach as you did for the existing loads/customers to create the EVs, assigning the appropriate loadshape to each EV (whether it's a storage or a load).
- Since you only need daily loadshapes, this file offers numerous options.
  You can decide how many vehicles you want at each CS in Step **3.1.**

Feel free to **be creative**! ☺ But also, keep it reasonable. So, then you are able to run the power flow and access the results.

So, now all you need to do is run this network and understand what's happening with it to be able to answer the questions from **Step 3**.

Step 4: Load management strategy

- For optimization, you will need electricity market prices. You can use the data provided in tutorial.
- You can find PV generation profiles on www.renewables.ninja . Consider Stockholm as location for PVs.
- For network losses calculation refer to
  - Khalid, Mutayab, Jagruti Thakur, Sivapriya Mothilal Bhagavathy, and Monika Topel. "Impact of public and residential smart EV charging on distribution power grid equipped with storage." *Sustainable Cities and Society* 104 (2024): 105272.

General tips

Last but not least, below is a piece of code that will help you visualize what is happening in the network.

```
import pandapower.plotting as pplt
import matplotlib.pyplot as plt
ax = pplt.simple_plot(net, show_plot=False)
clc = pplt.create_line_collection(net, color="r", linewidth=3., use_bus_geodata=True)
pplt.draw_collections([clc], ax=ax)
plt.show()
```

```
from pandapower.plotting.plotly import pf_res_plotly
pf_res_plotly(net)
```

However, do not limit yourself to these options. You can find a lot of information about Pandapower and how to visualize your ideas in the tutorials section.

Grading Matrix

	E (Step 1)	D (Step 2 in addition to Step 1)	C (Step 3 in addition to Steps 1, 2)	B(Step 4 in addition to Steps 1,2,3)	A (Step 5 in addition to Steps 1,2,3,4)
ILO3: Model	• Demonstrate understanding of Pandapower network • Discuss the main parameters/sizes of the network components and loads	• Detail the development of time series laod profile and model	• Justify the design of the CS implementation and calculation of number of EVS (e.g trafo size choice). Mention all the assumptions	• Demonstrate the optimization model design including objective function, constraints, parameters, decision variables.	Similar to grading criteria B with a change in objective function
ILO4: Evaluate	• Evaluate the results considering reference line loading, trafo loading and voltage levels • Highlight the power quality problems • Evaluate the results of steps 1.2 and 1.3 • Evaluate N-1 case	• Enumerate results from the timeseries analysis	• Demonstrate load flow analysis with EVs. • Perform the N-1 case with EVs	• Evaluate the results and present it in a clear manner.	
ILO5: Analyze	• Compare and contrast your results from 1.1 and 1.2 and 1.3 • Analyzing and discuss the results	• Analysis and discussion of results from the timeseries analysis. Compare with results from Step 1	• Critically analyse the results and discuss mitigation strategies.	• Analyze the results and compare them with results in Step 3.	

Q&A Sessions – LABs

- Four Q&A sessions

w37	Tuesday	2024-09-10	10:00	12:00
w37	Thursday	2024-09-12	10:00	12:00
w38	Wednesday	2024-09-18	10:00	12:00
w39	Thursday	2024-09-26	10:00	12:00

- Upload pre-final report by Oct 3, 2024
- Exam: presentation on Oct 7, 2024
- Final report submission on Oct 21, 2024