1 Overview

This project is designed to train the students into using computational tools to investigate the connection of distributed energy resources (DER) into the distribution grid. It is split into three parts:

1. Scenario-based analysis, separate for the MV and LV level.
2. Time series analysis, combined for MV and LV level.
3. Optimization using innovative planning and operation schemes.

1.1 Delivery

At the end of the project, the students will need to submit a report and a Jupyter Notebook file with the implementation. The report can be embedded in the Jupyter notebook, if you want, or submitted as two separate files. Submission in moodle is due no later than March 30, 2022.

The report is individual for each student.

1.2 Preliminaries

– The project should be completed with the Python-based tool pandapower. The full documentation can be found here.
– You can find a short introduction, several interactive tutorials, and some YouTube tutorial videos.

2 Network

The benchmark networks provided by Cigre TB 575 [1] shall be used as test cases. A copy of the brochure can be found in the moodle course page. It may only be used for the purpose of this course; further distribution is not allowed.

You will need to enter custom data for the DER. You may do so directly in Python or using the import function from Excel available for panda data frames [1]

2.1 MV level

The network is given in Figure 1 below. Bus and line data are implemented already in the respective pandapower benchmark case which can be imported directly. However, you need to enter the data for the tap changer of the HV/MV transformers according to [1].

Data on the DER to be connected at the MV level is given in Table 1. Note that loads and DER connected directly to the primary MV buses stand for several MV feeders, not shown in detail in the network.

[1] Refer to the read_excel function and this tutorial video.

Table 1: Data of MV DER

	bus	p_mw	q_mvar	sn_mva	name	type
0	1	10	0	10	PV 1	PV
1	1	12	0	12	WKA 1	WP
2	3	0.15	0	0.15	PV 3	PV
3	4	0.3	0	0.3	PV 4	PV
4	8	0.15	0	0.15	PV 8	PV
5	9	0.45	0	0.45	PV 9	PV
6	11	0.3	0	0.3	PV 11	PV
7	7	3	0	3	WKA 7	WP
8	12	15	0	15	PV 12	PV
9	12	12	0	12	WKA 12	WP

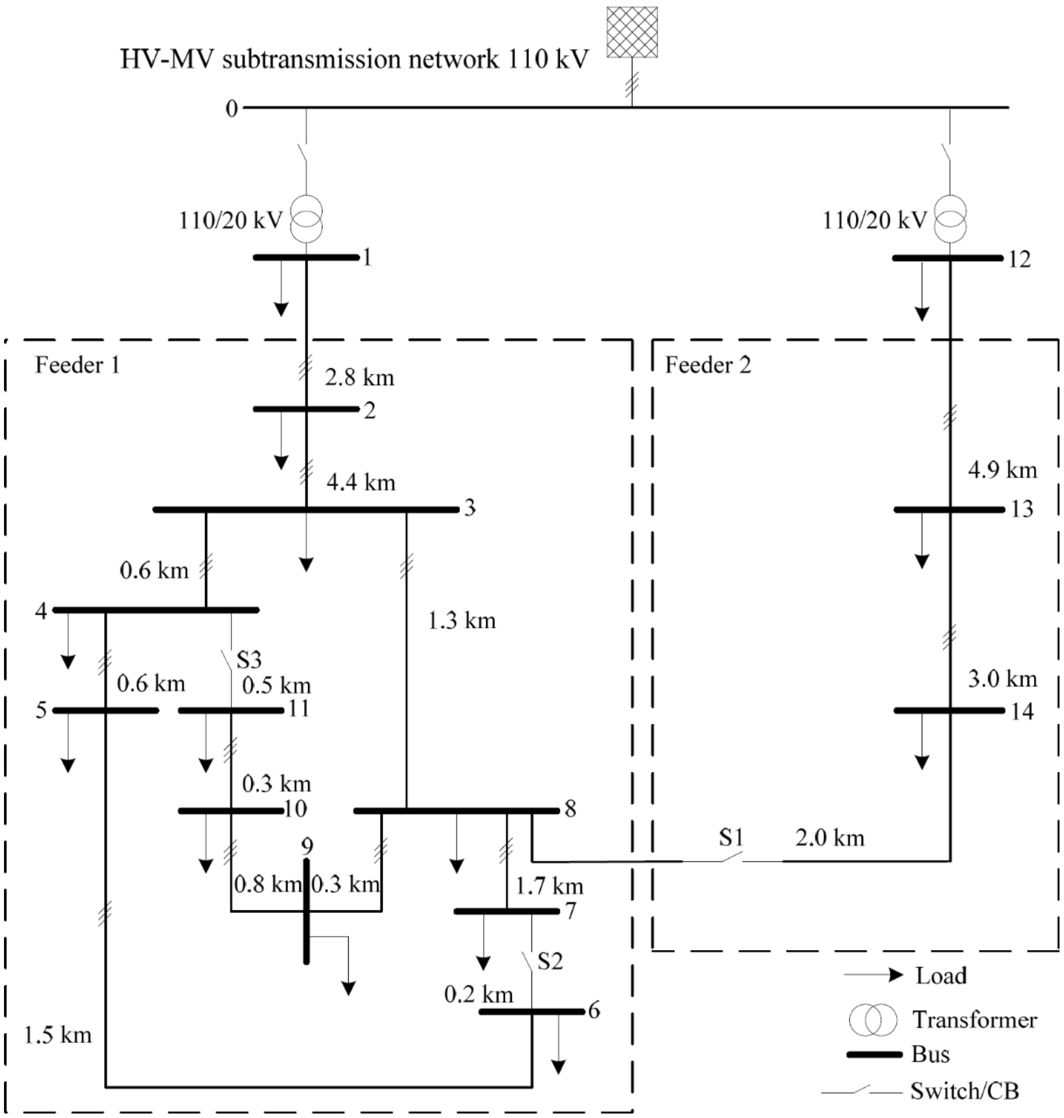

Figure 1: Single-Line Diagram of the MV network [1].

2.2 LV level

The network is given in Figure 2 below. Bus and line data are implemented already in the respective pandapower benchmark case and can be used. You only need to consider the residential subnetwork[2]. Data on the DER to be connected at the LV level is given in Table 2.

Table 2: Data of LV DER

	bus	p_mw	q_mvar	sn_mva	name	type
0	2	0.1	0	0.1	PV R1	PV
1	12	0.03	0	0.03	PV R11	PV
2	16	0.03	0	0.03	PV R15	PV
3	17	0.03	0	0.03	PV R16	PV
4	18	0.05	0	0.05	PV R17	PV
5	19	0.05	0	0.05	PV R18	PV

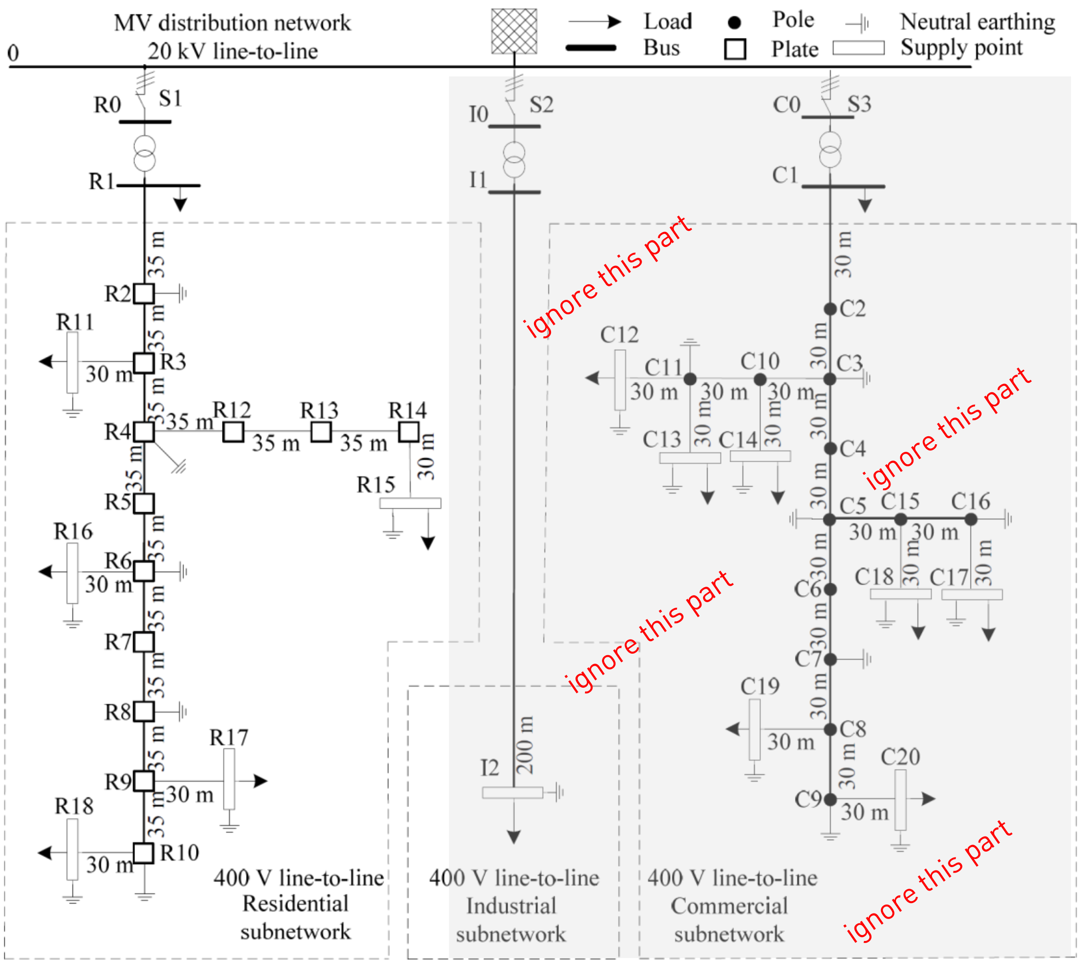

Figure 2: Single-Line Diagram of the LV network [1].

[2] You may use the `drop_buses` function to remove the buses you don't need and all connected elements.

3 Scenario-based analysis

In this part, you need to analyze each voltage level separately. The planning criteria for connection of new DER can be found in reference [2]. Review this paper before answering the following questions.

3.1 General questions

- What extreme scenarios must be analysed before deciding if the connection of DER is permissible?
- What tap-changer position (set-point value for voltage regulation on MV side) should be assumed for the HV/MV transformer depending on the scenario?
- What is the maximum permissible voltage rise (in % of nominal voltage) for the MV and LV level during normal operation? How does this threshold change during n-1 contingency conditions?
- What is the maximum permissible line loading under normal conditions for the MV and LV level?

3.2 Tasks

For this section, you need to load the networks one at a time i.e. first run all tasks for the MV network, and then for the LV network.

- Plot the network highlighting the different voltage levels[3]. Is the network n-1 secure from its structure?
- Add the DER as static generators based on the tables in section 2.
- Implement the scenarios from reference [2] using panda data frames [4]. Note that the power factor for the loads is assumed to be lower for light load conditions (0.9 compared to 0.93, both lagging).
- Run a power flow for the high load, low DER generation conditions and identify the maximum/mean/minimum bus voltage in the grid as well as the maximum line loading and the transformer loading (and current direction). Visualize the results using the `pf_res_plotly` function and note the buses with the highest/lowest voltage as well as the most loaded line and transformer.
- Based on the results for high load conditions, is the network n-1 secure? Which measures would you recommend for ensuring n-1 security?
- Repeat the power flow calculation for light load, very high PV conditions. What difference do you notice?
- Compare the voltage drop / voltage rise with the permissible bandwidth. Is the network well designed?

[3] Use the `vlevel_plotly` function for this purpose.

[4] Assign the scenarios to `net.loadcases`.

4 Time series analysis

For this analysis you will need to substitute the household load of the MV grid at bus 10 with the LV residential network from section 2.2. You may use pandapower's functions `merge_nets`, `fuse_buses` and `drop_ buses` for this purpose.

For all residential loads (both in MV and LV level) you must use the H0 load profile. For commercial loads, use the G0 profile instead. You can download the profiles from here. You will have to properly scale the profile with the peak load for each bus.

4.1 General questions

- Which annual consumptions is assumed for the H0 load profile? How do you scale the profile for different levels of consumption?
- What is the morning and evening peak in consumption?
- In which time of the year do you expect the peak household consumption? Is this the same for all countries, or rather specific to Germany?

4.2 Tasks

From the time series of the H0 and G0 load profile, choose following three days: week day in summer, Sunday in fall/spring, Saturday in winter. Perform the analysis below for all three cases:

- Save the time series for the loads (household and generation) with a 15-minutes resolution as a csv file and copy them into a DataSource. Refer to the timeseries example in the documentation for more instructions.
- Use constant controllers to scale the loads (active and reactive power to be scaled equally). Initially scale all static generators to zero (assume zero production) and perform a time series simulation.
- Plot the maximum, mean and minimum voltage of the buses at each voltage level (MV and LV) over time. Note down which are the most critical nodes for voltage control.
- Plot the mean and maximum line loading over time.

In a second step you need to define profiles also for the PV and wind power plants. Use information provided in the market transparency database for Germany to derive load profiles for Wind and PV solar for the three days mentioned above (summer, fall/spring, winter). You can download the 15-minute actual generation as tables from the website. Use appropriate scaling factors to relate the production to the respective installed (peak) capacity.

Alternatively, you can use the PV profile provided in the moodle course instead.

- Use additional constant controllers to scale the active power of the static generators. Do not scale their reactive power output. Perform a time series simulation and plot the same variables as above.
- Compare the maximum voltage drop/rise in the MV and LV network as well as the maximum line loading to the results from section 3. Which approach (scenario-based or time series) yields more onerous results?

5 Summary of results

Fill in the table below with your results from sections 3 and 4 above.

network	measurement		scenario MV	scenario LV	scenario combined	time series
MV	bus voltage	min				
		max				
		mean				
	line loading	max				
		mean				
LV	bus voltage	min				
		max				
		mean				
	line loading	max				
		mean				

6 Optimization using innovative planning and operation schemes

6.1 Reactive power control

So far you have assumed no reactive power supply from the DER units. Repeat the calculations in section 3 and 4 by now implementing following options for reactive power supply by the DER units:

- constant power factor 0.95 lagging,
- adaptive power factor between 0.9 lagging (untererregt) and 0.9 leading (übererregt) based on Figure 3 below.

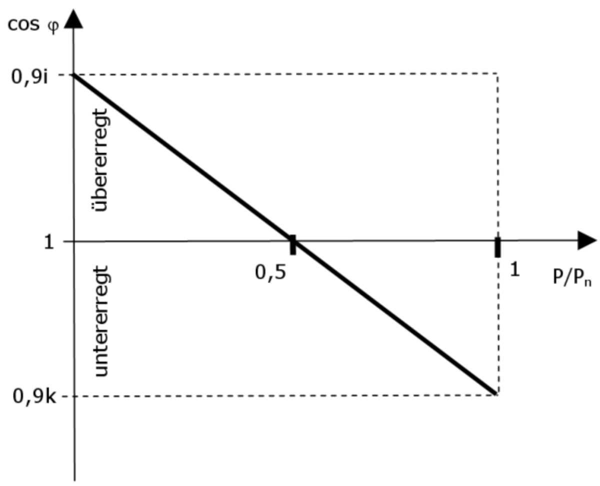

Figure 3: Power Factor droop characteristic.

For the scenario-based analysis, only consider the "light load, high PV" scenario for the LV network. For the time-series analysis, only consider the case with all DER connected and the representative date which gave the most onerous results in section 4 above. Quantify the improvements with regards to voltage control.

6.2 MV/LV transformer with on-load tap changer.

Another effective solution for voltage control in the LV network is to use MV/LV transformers with tap changer[5]. Add a tap changer with ±5 steps of 1.25% per step to the transformer between MV and LV network. The regulating transformer can be controlled in several ways:

- Fixed set-point value on the LV side e.g. at 102% of nominal value,
- Adaptive set-point based on the magnitude and direction of the current through the transformer. For larger current downwards (to the load) the set-point is increased (up to 105% at nominal current), for backwards infeed from the LV to the MV network, the set-point is decreased (to 95% at nominal reverse current).

Use a tap changer controller to implement the different control schemes and re-run the time series simulations from section 4. Quantify the improvements in voltage control by plotting the worst case voltage rise over time.

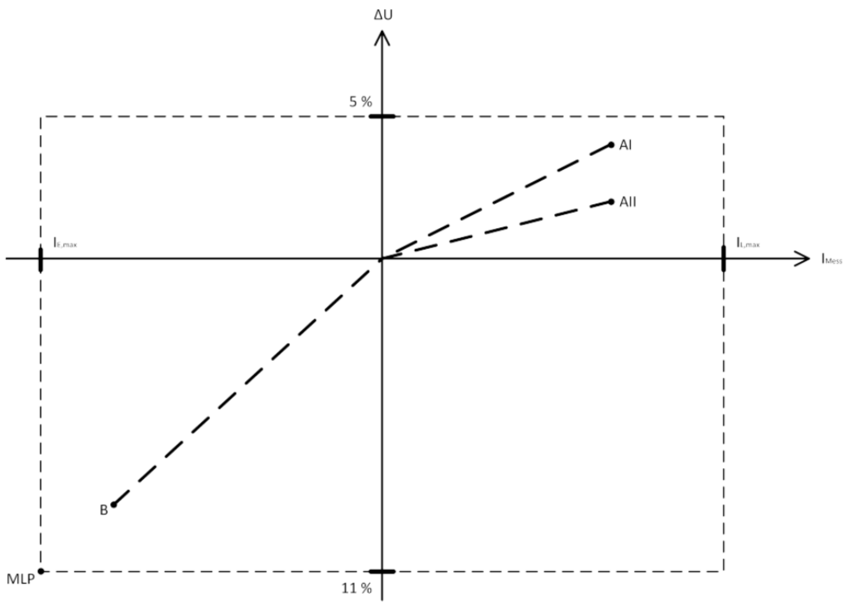

Figure 4: Droop characteristic for OLTC control.

7 References

[1] Cigre Technical Brochure 575: "Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources", April 2014, ISBN: 978-285-873-270-8

[2] S. Meinecke et al.: "General planning and operational principles in German distribution systems using Simbench", 25th International Conference on Electricity Distribution Madrid, 3-6 June 2019

[5] This website (in German) provides useful information about such „regulating distribution transformers".