31761 – Assignment 1

Deadline: March 14, 2022

February 7, 2022

Select a case study

Please select an electric power network. Potential options:

1. IEEE 24-bus reliability test system: link
2. The IEEE reliability test system: A proposed 2019 update: link
3. IEEE power systems test cases (different cases with 14, 30, 57, 118, and 300 buses): link
4. Several case studies are available in the open-source Julia platform PowerModels.jl: link

Please feel free to choose another case study. In case there is the lack of data for some items, **please select arbitrary (reasonable) values.** For the technical details of conventional generators and transmission lines, this link might be helpful (it corresponds to the IEEE 24-bus case study, but one can use similar data for other cases, too). Please assume the production cost of renewable units is zero. For the bid price of price-elastic demands, please consider comparatively high prices (compared to the generation cost of conventional units) such that the majority of demands will be supplied. For wind data, one potential data source is this link (you can normalize such data for your case study). For transmission lines, you can simply consider an identical reactance for all lines (e.g., 0.002 p.u. $\rightarrow$ susceptance = 500 p.u.).

Step 1

In lecture 2 you learn how to develop a market-clearing optimization model for a copper-plate power system (i.e., without modeling transmission network) and with a single time period. While discarding network, please extend this optimization model to include multiple time periods (24 hours). Clearly, some input data are varying across hours, e.g., wind and demand level. We are interested in enforcing new constraints that link hours, the so-called *inter-temporal* constraints. A very common inter-temporal constraint is the ramping up (down) limit of conventional generators, enforcing how much their power generation can be increased (decreased) in the current hour compared to that in the previous hour. Finally, please consider adding a new type of assets (or more if you desire to learn more) to your power system. Potential items are:

1. A battery energy storage system. This item is likely the most straightforward one, as you do not need to consider another energy carrier. Potential reference: Section II of link. Please note that we are not interested in adding binary (0/1) variables to the model (to keep our optimization model convex). One simple solution is to consider an identical charging/discharging efficiency.

2. A combined heat and power (CHP) unit that simultaneously produces power and heat. In this case, you are going to add hourly heat demand to your model, ensuring the CHP fully supplies this demand. As an alternative, you can consider an additional heat pump that consumes power to produce heat. The most important part is to learn how to model the technical constraints of the CHP (and the heat pump). Potential reference: Sections 2.2 and 2.3 of link.

3. You can also think of other assets, e.g., electrolyzers and hydrogen tanks (perhaps a bit more complex than the first two options).

Considering a uniform pricing scheme, we are interested in deriving hourly market prices (for electricity, as well as for heat or hydrogen if relevant), total social welfare, total profit of every asset (conventional units, renewables, storage/CHP/electrolyzer, etc) and total utility of every demand.

Step 2

In lecture 3 you learn how to model power flow across network and enforce power transmission network limits. Please extend your market-clearing optimization model in Step 1 to enforce those constraints (only power network limits, while still discarding the heat/hydrogen network, if relevant). Now, please derive *nodal* market prices. Are nodal prices in every given hour necessarily identical? Please conduct a sensitivity analysis (by changing the capacity of one or more transmission lines) and discuss your results. Finally, switch to a *zonal* setting by splitting your power network to two or three (or more) zones. For different values of ATCs, derive zonal market prices. How different are they compared to nodal prices? What are the implications of nodal vs zonal frameworks to market participants (e.g., in terms of profit for generators)?

Step 3

In lecture 4 you learn about the balancing market. Pick one hour (out of 24 hours). While discarding network constraints and intra-day market (for simplicity), please assume there is an unexpected failure (outage) in one of conventional generators. The actual production of some wind farms is lower than their day-ahead forecast (e.g., 10%), while that of others is higher than their day-ahead forecast (e.g., 15%). All remaining conventional generators (but not demands) are potential balancing service providers. Each conventional generator as the balancing service provider offers the upward balancing service at a price equal to the day-ahead price plus 10% of her production cost. Similarly, she offers the downward balancing service (if she can, depending on her day-ahead schedule) at a price equal to the day-ahead price minus 12% of her production cost. The load curtailment cost is \$500/MWh. Please clear the balancing market for the given hour, and derive the balancing price, if the balancing settlement is *i*) one-price, and *ii*) two-price. Finally, please calculate the total profit of conventional generators in the given hour (in day-ahead and balancing).

Step 4

In lecture 5 you learn about the reserve market. Imagine, according to the TSO's quantification, the hourly upward reserve requirement in the reserve market is 15% and the hourly downward reserve requirement is 10% of the total demand in the corresponding hour. While discarding network constraints, please clear reserve and day-ahead markets *sequentially* (following the current practice in the European electricity markets) and report hourly market-clearing outcomes (for 24 hours). As optional task (with extra 10% point), please clear the US-style market (the *joint* reserve and energy market in the day-ahead stage). Compare the market-clearing outcomes (schedules and prices) achieved with those of the European style.