Complex Renewable Energy Networks

(SoSe 2017, FIAS & Goethe-Universität Frankfurt)

HomeWork Sheet III

To be prepared for the exercise session on Wednesday, 31.05.2017.

Problem III.1 (storage adequacy). Imagine a two-node Germany. The South can install solar panels with a capacity factor Cf_s to cover its load L_S, while the North uses wind turbines that have a capacity factor Cf_w to feed their load L_N.

Figure 1 shows approximations to the daily and synoptic variations of per-unit wind and solar power generation $G_{N,w}(t)$ and $G_{S,s}(t)$ and a constant load $L_{N/S}(t) = A_{l,N/S}$:

$$G_{N,w}(t) = \mathrm{Cf}_w(1 + A_w \sin \omega_w t) \ , \quad (1)$$
$$G_{S,s}(t) = \mathrm{Cf}_s(1 + A_s \sin \omega_s t) \ , \quad (2)$$
$$L_{N/S}(t) = A_{l,N/S} \ . \quad (3)$$

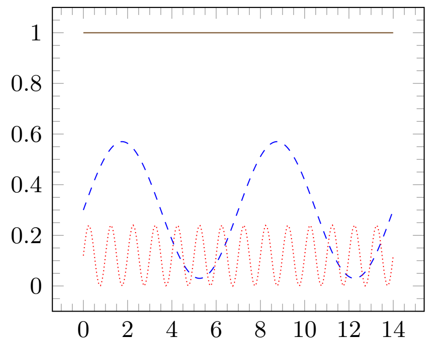

Figure 1: Diurnal and synoptic variations of wind and solar power generation $G_{N,w}(t)$ - - - and $G_{S,s}(t)$ ········ and a constant load (all in per-unit) $L(t)$ ——.

The capacity factors and constants are

$$A_{l,N} = 20\,\mathrm{GW} \ , \qquad A_{l,S} = 30\,\mathrm{GW} \ ,$$
$$\mathrm{Cf}_w = 0.3 \ , \qquad A_w = 0.9 \ , \qquad \omega_w = \frac{2\pi}{7\,\mathrm{d}} \ ,$$
$$\mathrm{Cf}_s = 0.12 \ , \qquad A_s = 1.0 \ , \qquad \omega_s = \frac{2\pi}{1\,\mathrm{d}} \ .$$

Assume there is no transmission between the North and the South, so that both need storages to cover their load in every hour. Further assume that the storages do not have any losses.

(a) How much wind capacity $G_{N,w}$ must be installed in the North and solar capacity $G_{S,s}$ in the South?

(b) What is the amount of store and dispatch power capacity $G_{s,store} = \max(-g_s(t))$ and $G_{s,dispatch} = \max g_s(t)$ the storages must have in the North and in the South?

(c) What is the amount of energy capacity one needs in the North and in the South?

$$E_s = \max_t e_s(t) = \max_t \int_0^t (-g_s(t'))\,\mathrm{d}t'$$

(d) Should they choose hydrogen or battery storages? And how much would it cost them with the prices in Table 1? Is the South or the North paying more for their energy?

Now we lift the restriction against transmission and allow them to bridge their 500 km separation with a transmission line.

(e) Estimate the cost-optimal technology mix by assuming wind energy in the North is only stored in the North and solar energy in the South is likewise only stored in the South! (What happens if you dropped that assumption?)

	€ per kW	€ per kWh	η_{store}	η_{dispatch}
Battery	300	200	0.9	0.9
Hydrogen	$300 + 450$	10	0.75	0.58
Solar	600	-		
Wind	1200	-		
Transmission Line (500 km)	200	-		

Table 1: Investment costs of renewable energy infrastructure. The storage power capacity prices comprise storing and dispatching.

Problem III.2 (Optimization with PyPSA). Python for Power System Analysis is a free software toolbox for optimising modern power systems that include features such as variable wind and solar generation, storage units, [...] (from https://pypsa.org/).

As preparation install `glpk` either using your linux systems' package manager (i.e. `apt install glpk-utils` on Debian derivates like Ubuntu) or using the Anaconda package manager (i.e. `conda install glpk`) for optimization and `pypsa` from the python package index (i.e. using `pip install pypsa`). *It would be wonderful, if you did that while still at home, since installation tends be a rather individual problem and the wireless network quite a bottleneck.*

(a) Build a network in PyPSA with the two buses North and South and attach the load at each bus and attach the wind and solar generators with availability according to Eqs.(1) and (2)g for a year (you have to call `set_snapshots` for the year) and with `p_nom_extendable` set to True. As help you should have a look at the minimal lopf example[1], understand what the components documentation[2] of pypsa gives you and that you can find the underlying objective function and constraints in the lopf documentation[3].

(b) Attach extendable storages at the North and the South! The storages have to be modelled as an `H2-bus` (a bus with carrier='H2') linked to the `AC-bus` North with a `p_nom_extendable` `Link` with the `capital_cost` of the power capacity and an also extendable `Store` with the `capital_cost` of the energy capacity, for instance. The losses can be set on the links as `efficiency`.

(c) Run an investment optimization by calling the `lopf` function!

(d) How do your results `objective` and `{generators,stores,links}.p_nom_opt` compare with the results of III.1(d)?

(e) Replace the approximated availability time-series of the wind and the solar generators with the ones from `availability.csv` computed from reanalysis weather data available on the course website and re-run the LOPF. Compare the results! Explain the differences by looking at the cumulative variations relative to the mean of the availability time-series!

[1] https://www.pypsa.org/examples/minimal_example_lopf.html
[2] https://pypsa.org/doc/components.html
[3] https://pypsa.org/doc/optimal_power_flow.html#linear-optimal-power-flow