Energy System Modelling

SS 2018, Karlsruhe Institute of Technology
Institute of Automation and Applied Informatics

Tutorial III: Storage Optimisation

Will be worked on in the exercise session on Monday, 16 July 2018.

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 $L_{N/S}(t)$:

$$G_{N,w}(t) = Cf_w(1 + A_w \sin \omega_w t),$$
$$G_{S,s}(t) = Cf_s(1 + A_s \sin \omega_s t),$$
$$L_{N/S}(t) = A_{l,N/S}.$$

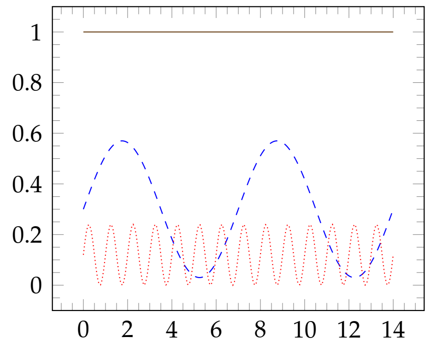

Figure 1: Diurnal and synoptic variations of wind and solar power generation $G_{N,w}(t)$ - - - and $G_{S,s}(t)$ ·········, and a constant load (all in per-unit) $L(t)$ ——.

The capacity factors and constants are

$$A_{l,N} = 20\text{GW}, \quad A_{l,S} = 30\text{GW}, \quad \omega_w = \frac{2\pi}{7\text{d}},$$
$$Cf_w = 0.3, \quad A_w = 0.9, \quad \omega_s = \frac{2\pi}{1\text{d}}.$$
$$Cf_s = 0.12, \quad A_s = 1.0,$$

For now, assume the stores are lossless. Losses will be considered in III.2.

(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?

$$E_s = \max_t e_s(t) = \max_t \int_0^t (-g_s(t'))\, dt'$$

(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?

(e) What do you imagine would change if you considered the storage losses given in Table 1 in your results (a)-(d)? Support your statement with a graphical illustration.

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

	€ per kW	€ per kWh	η_{store}	$\eta_{dispatch}$
Battery	300	200	0.9	0.9
Hydrogen	750	10	0.75	0.58
Solar	600			
Wind	1200			
Transmission line (500 km)	200			

Table 1: Investment costs of renewable energy infrastructure.

(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 would happen if you dropped that assumption?

PROBLEM III.2 (STORAGE OPTIMIZATION WITH PYPSA).

Python for Power System Analysis (PyPSA) is a free software toolbox for optimising modern power systems that include features such as variable wind and solar generation, storage units, etc. Use the toolbox to extend on your findings in Problem III.1.

(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 $G_{N,w}(t) = Cf_w(1 + A_w \sin \omega_w t)$ and $G_{S,s}(t) = Cf_s(1 + A_s \sin \omega_s t)$ 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 `Link` where `p_nom_extendable=True` 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) Now lift the restriction against transmission and allow North and South to bridge their 500 km separation with a transmission line. How does the cost optimal technology mix change compared to III.1(f)?

(f) 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 homepage[4] 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
[4] https://nworbmot.org/courses/complex_renewable_energy_networks/