Note: Please make sure to submit a Jupyter Notebook containing the data preparation steps as well as the visualization of the results on Moodle. Since the LP is given this time, no upload on TutOR is necessary

The Scenario

The company Aluminum SmeltORs AB (AS AB) is interested in implementing demand side management, using the flexibility in the power intake of their electrolysis cells to save costs. Usually they run all their cells at nominal power, covering the constant power demand with cheap long-term contracts from their electricity provider. Now their electricity provider offers them the possibility to deviate from this nominal power demand, either selling or buying the saved/excess energy at spot market prices.

Your company bas been contracted to figure out if and how this demand side management could work, how much money could be saved and if results look promising, to implement it. As the newest member of the team you have been tasked by your boss to create a prototype model and create some pretty graphs (which he will use in his presentation to convince the management at AS AB that they should continue paying for this project).

The Plant

First data gathering suggests that all electrolysis cells combined can be run with a power deviation of $|\Delta P(t)| \leq 100 \text{ MW}$, so $P(t) \in [P_{\text{nom}} - 100 \text{ MW}, P_{\text{nom}} + 100 \text{ MW}]$. But if the energy difference relative to nominal operation $\Delta E(t) = \int_0^t P(t) - P_{\text{nom}} dt$ ever gets to high or to low, the cells could be damaged. The maximum allowable energy deviation has been determined to be $\pm 4800 \text{ MWh}$, so for example if we start from nominal operation we could run the power plant at maximum power deviation for up to 48h before getting into trouble. For our analysis we assume that we start and end with $E_{\text{rel}}(t) = 0$.

All other operational concerns are ignored for this first analysis.

The Electricity Market

Luckily for you, the power exchange Nord Pool AS provides historic electricity prices for the Nordic countries on their website. The plant of AS AB is in the market area `SE1`. Your boss decided (for reasons that you don't dare question) that you should use the hourly prices for this first analysis and use € as the currency for the analysis, so use the file Elspot Prices_2019_Hourly_EUR.

For simplification we assume that the spot market works like this: At the beginning of every hour t we know the electricity price for this hour in € / MWh and can decide how much power relative to nominal we want to buy/sell *for this hour*. We have no knowledge of prices beyond this point but know all past prices.

Future prices will have to be predicted based on past prices. Since you don't have enough time to implement a fancy prediction algorithm (which would consider market data, weather data, your horoscope etc.) your team decided to compare two very simple prediction methods:

1) We perfectly know all prices (which is the case for your analysis and resembles a best-case scenario if your predictions would be perfect).

2) We assume that the price for the next hours will be exactly the same as the prices for the same hours one week ago (this allows us to capture some weekly and daily price patterns but is obviously a weak prediction).

Your intern has already implemented these two "prediction" methods - if you have time, you can implement better methods, but your boss will be perfectly satisfied if you only use these two methods for the analysis.

Your task

You should create code that simulates two months of operation and create graphs from your results. The time frame for your analysis is $t_{\text{start}} =$ `2019-10-22 00:00:00` until $t_{\text{end}} =$ `2019-12-22 00:00:00` with hourly time-steps $t \in T$.

The proposed DSM scheme is as follows:

- For the current time-step t we use the information we have to optimize plant operation over a time horizon of $t_{\text{horizon}} = 7 \cdot 24\text{h} = 1\text{ week}$ (unless $t + t_{\text{horizon}} > t_{\text{end}}$, in which case we only optimize until t_{end}). The electricity price p_t is known only for the current time-step t and predicted for the others.
- The results of the optimization tell tell us how much power we should buy or sell for the current hour ΔP_t
- We "simulate" running the plant with this power for one hour by updating the energy difference at the end of the current hour$\Delta E_t = \Delta E_{t-1} + \Delta P_t \cdot 1\text{h}$
- Repeat the process for $t + 1$ until we arrive at t_{end}

For your bosses presentation you have to create some graphs:

- To get a feel for how the DSM would influence plant operations and how much money could be earned, you have to plot (for both given prediction methods)...
  - ... ΔP_t and ΔE_t for the first 100 hours of the considered time-frame. Think about what values you would expect ΔP_t to take and how could you justify this?
  - ... your earnings (profit) over the entire time, so $e_t = -\sum_{t_{\text{start}}}^{t} p_t \cdot \Delta P_t \cdot 1\text{h}$ (the negative sign is necessary since you have to pay for using more power and make money if you use less).
- To demonstrate that this approach uses both daily and weekly price patterns, plot (using only the "last week" prediction method)...
  - ... the average hourly electricity price and ΔP_t for each hour of the day
  - ... the average daily electricity price and ΔP_t for each day of the week
- And last but not least, to show that the planned plant operation changes over time, plot ΔE_t versus $\Delta E_t|_{t_{\text{start}}}$ (the energy difference as it was planned in the first time-step)

Hints

- The files you download should not be modified. All data manipulation has to happen in your code
- Please ensure that your model is linear. If you multiply different variables, this will result in 0 points.
- Please ensure that your code runs in Python 3.6 or higher.
- You can NOT add additional variables - use the model as shown in the accompanying material.
- Don't hesitate to ask questions in the forum or on the Internet.