Energy System Modelling

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

TUTORIAL I: TIME SERIES ANALYSIS

Will be worked on in the exercise session on Wednesday, 11 July 2018.

PROBLEM I.1 (DATA ANALYSIS).

The following data are made available to you on the course home page[1]:

`de_data.csv, gb_data.csv, eu_data.csv, (wind.csv, solar.csv, load.csv).`

They describe (quasi-real) time series for wind power generation $W(t)$, solar power generation $S(t)$ and load $L(t)$ in Great Britain (GB), Germany (DE) and Europe (EU). The time step is 1 h and the time series are several years long.

(a) Check that the wind and solar time series are normalized to 'per-unit of installed capacity', and that the load time series is normalized to MW.

(b) For all three regions, calculate the maximum, mean, and variance of the time series.

(c) For all three regions, plot the time series $W(t)$, $S(t)$, $L(t)$ for a winter month (January) and a summer month (July).

(d) For all three regions, plot the duration curve for $W(t)$, $S(t)$, $L(t)$.

(e) For all three regions, plot the probability density function of $W(t)$, $S(t)$, $L(t)$.

(f) Apply a (Fast) Fourier Transform to the the three time series $X \in W(t), S(t), L(t)$:

$$\tilde{X}(\omega) = \int_0^T X(t) e^{i\omega t} \, \mathrm{d}t \, .$$

For all three regions, plot the energy spectrum $\left|\tilde{\Delta}(\omega)\right|^2$ as a function of ω. Discuss the relationship of these results with the findings obtained in (b)-(e).

(g) Normalize the time series to one, so that $\langle W \rangle = \langle S \rangle = \langle L \rangle = 1$. Now, for all three regions, plot the mismatch time series

$$\Delta(t) = \gamma \alpha W(t) + \gamma(1-\alpha) S(t) - L(t)$$

for the same winter and summer months as in (c). Choose $\alpha \in \{0.0, 0.5, 0.75, 1.0\}$ with $\gamma = 1$, and $\gamma \in \{0.5, 0.75, 1.0, 1.25, 1.5\}$ with $\alpha = 0.75$.

(h) For all three regions, repeat (b)-(f) for the mismatch time series.

[1] https://nworbmot.org/courses/esm-2018/

PROBLEM I.2 (ANALYTICAL).

Figure 1 shows approximations to the seasonal variations of wind and solar power generation $W(t)$ and $S(t)$ and load $L(t)$:

$$W(t) = 1 + A_W \cos \omega t$$
$$S(t) = 1 - A_S \cos \omega t$$
$$L(t) = 1 + A_L \cos \omega t$$

The time series are normalized to $\langle W \rangle = \langle S \rangle = \langle L \rangle := \frac{1}{T} \int_0^T L(t) \mathrm{d}t = 1$, and the constants have the values

$$\omega = \frac{2\pi}{T} \qquad T = 1\,\text{year}$$
$$A_W = 0.4 \qquad A_S = 0.75 \qquad A_L = 0.1$$

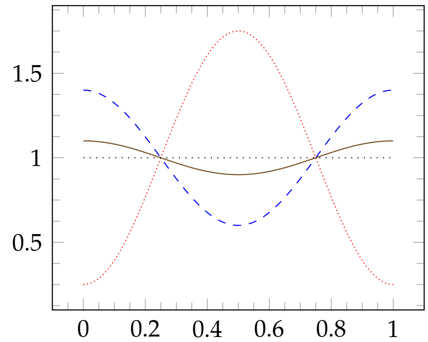

Figure 1: Seasonal variations of wind and solar power generation $W(t)$ - - - and $S(t)$ ········, and load $L(t)$ —— around the mean 1 ········.

(a) What is the seasonal optimal mix α, which minimizes

$$\langle [\alpha W(t) + (1-\alpha)S(t) - L(t)]^2 \rangle = \frac{1}{T} \int_0^T [\alpha W(t) + (1-\alpha)S(t) - L(t)]^2 \,\mathrm{d}t,$$

(b) How does the optimal mix change if we replace $A_L \to -A_L$?

(c) Now assume that there is a seasonal shift in the wind signal

$$W(t) = 1 + A_W \cos(\omega t - \phi)\,.$$

Express the optimal mix α as a function of ϕ.

(d) A constant conventional power source $C(t) = 1 - \gamma$ is now introduced. The mismatch then becomes

$$\Delta(t) = \gamma\,[\alpha W(t) + (1-\alpha)S(t)] + C(t) - L(t).$$

Analogously to (a), find the optimal mix α as a function of $0 \leq \gamma \leq 1$, which minimizes $\langle \Delta^2 \rangle$.

REMARKS (PYTHON POINTERS OR WHERE TO START).

I found the python notebook based notes of Robert Johansson to be a comprehensive kick starter[2].

- Lecture 0 covers installation and getting ready.
- Lecture 1 zooms through most basic general python control structures (only brush over it and stop reading early, i.e. if you read the word `classes` you already know too much).
- Lecture 2 is the most important and closely connected to the exercises.
- You might as well stop now, but if you *are* hooked, I recommend Lecture 3 for more physics and Lecture 4 for prettier graphs.

Further reference material of help is:

- The website-books `http://python-course.eu/` (english), `http://python-kurs.eu/` (german); especially if you only *very* quickly skim over the python2 tutorial and switch over to the numerical python stuff early; especially of interest might be the pandas bit in the end, which will make the exercises a breeze at the expense of yet another package to learn.
- the exhaustive (overly so) official python tutorial[3] available in english and german; which will NOT introduce you to numpy or scipy.

[2] `http://nbviewer.jupyter.org/github/jrjohansson/scientific-python-lectures/tree/master/`

[3] `https://docs.python.org/2/tutorial/`