Energy Systems
Technical University of Berlin
Department of Digital Transformation in Energy Systems
Summer Term 2021

TUTORIAL I: TIME SERIES ANALYSIS

Will be worked on in the exercise session on Thursday, 4 June 2020.

> Problems which are discussed in the tutorial are marked with 👥.
> Exercises to study at home are marked with 🏠.
> Questions on both kind of tasks are answered in the tutorial and **all exercises are relevant for the exam**.

PROBLEM I.1 (PROGRAMMING) – DATA ANALYSIS 👥

The following data are made available to you on the course home page[1] and the github repository [2] :

`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) Resample the time series to daily, weekly and monthly data points and visualise them in plots. Can you identify some recurring patterns?

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

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

(g) Recurring patterns of time series can also be visualised more rigorously by applying a Fourier Transform. Apply a (Fast) Fourier Transform to the the three time series $X \in W(t), S(t), L(t)$:

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

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

[1] https://nworbmot.org/courses/esm-2020/

[2] https://github.com/lisazeyen/ESM_tutorial/tree/master/tutorial/01-tutorial-04.06.2020/notebooks/data

(h) 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 $\alpha = 0.75$.

Which configuration entails the lowest mismatch on average and in extremes?

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

PROBLEM I.2 (ANALYTICAL) – EFFECT OF SEASONALITY

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

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

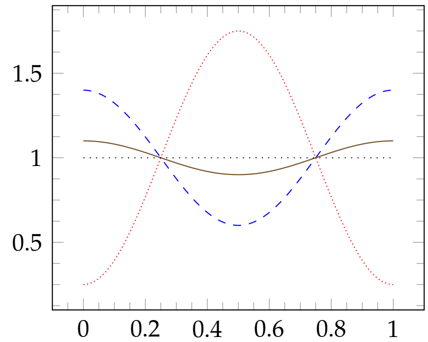

Figure 1: Seasonal variations of wind and solar power generation $W(t)$ - - - and $S(t)$ ·········, and load $L(t)$ —— around the mean 1 ·········.

(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 $0 \le \gamma \le 1$, which minimizes $\langle \Delta^2 \rangle$.