

Simulation of an Electrical Power System

The goal of a country's electricity system is to always provide exactly as much electricity as is needed at the moment, and to do it as cheaply as possible.

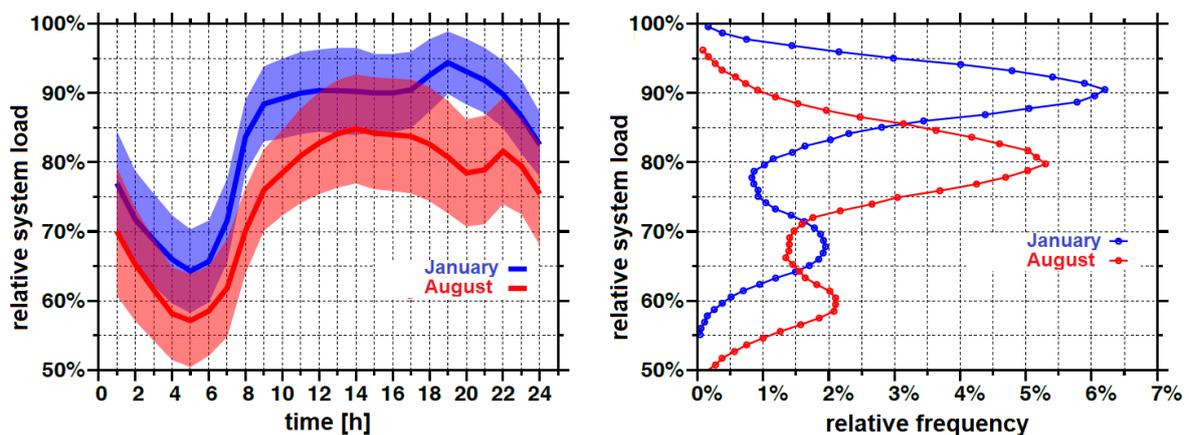
Currently, in most parts of the world, electricity systems are mainly based on fossil fuel. The reason for this is the historical background on the one hand, and the relative cheapness, simplicity and controllability on the other. The renewables are favourable in terms of CO₂ emissions, however, they have the disadvantage that their performance depends on the weather; they are also dependent on the time of year and time of the day. Nuclear energy requires large investments, and hydropower plants cannot be built everywhere; they need specific geological conditions (large rivers with sufficiently steep riverbed).

In the course of this task, we will investigate the electrical power system of a self-supplying, imaginary “island-like” country (island-like means that no export and import of electricity is allowed. The weather and the electricity consumption of this sample-country are similar to Hungary. Our task is to design (construct) a system with which we can produce exactly the amount of energy that is needed all the time, as cheaply as possible and with as little CO₂ emissions as possible.

The electricity demand

The electricity demand changes during the day, and the expected demand also depends on whether it is a weekday or a weekend, as well as on what time of the year it is. For the sake of simplicity, the program only simulates weekdays, in winter and summer conditions. The built-in database uses real data of the Hungarian electrical power system: the hourly electrical consumption on 31 days in August and January between 2007 and 2016 (10 years). The highest load is 6.5 GW and the lowest is 47% of this. The hourly and total distribution of the expected demand can be seen in the attached figures. Next to the average, we have indicated that in 95% of cases the performance is expected to fall into the shaded band (95% confidence interval). The figure on the right has been rotated by 90 degrees.

The power demand of the examined electricity system **at 100% load is 6.5 GW**.



Electricity production units

To construct the system you can choose from 7 types of energy generating units: coal, gas, nuclear, wind, solar, hydro and pumped-storage hydroelectric power plant. The characteristics of the power plant types are summarized in the table below.

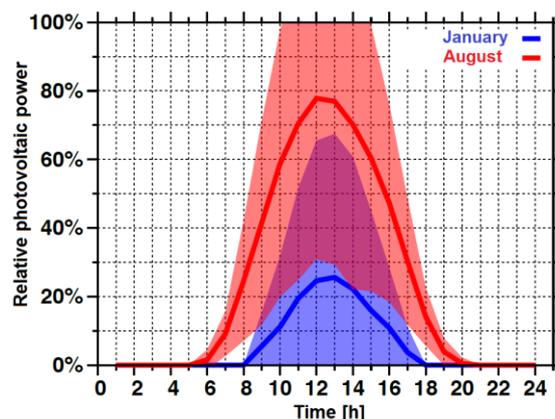
„Leo Szilárd” National Physics Competition – Final 2019 – Simulation task

Type	N_{\max}	P_{\max} [GW]	P_{\min} [GW]	Flex [GW/h]	Fix cost [M\$/GWd]	Var cost [M\$/GWd]	CO ₂ [t/GWh]
Coal powered unit	10	0.6	0.3	0.3	0.6	1.2	900
Gas powered unit	10	0.5	0	0.5	0.3	2.2	500
Nuclear unit	4	1.0	1	0	1.6	0.25	10
Wind turbine unit	15	0.3	-	-	1.0	-	10
Solar (photovoltaic) unit	20	0.2	-	-	0.6	-	40
Hydro power plant	3	0.6	0.2	0.6	1.3	-	20
Pumped-storage hydro	4	0.5	-0.5	1.0	1.3	-	20

- N_{\max} is the maximum number of units that can be built in the country.
- P_{\max} is the maximum (built-in) power of one unit.
- P_{\min} is the minimum power of one unit, below which it cannot operate.
- **Flexibility:** a unit can change its output by so many GW in 1 hour.
- **Fixed cost:** Specifies how many M\$ per day is necessary to keep 1 GWday installed production capacity of the given power plant (comprises the daily fraction of the investment cost, maintenance cost etc.). This type of cost is incurred even if the unit is not operating.
- **Var cost** (variable cost): Specifies how much costs producing 1 GWday (i.e. 24 GWh) of electricity. It comprises fuel and other production-related costs. The total cost is the sum of the two cost factors.
- **CO₂** indicates how many tons of CO₂ are emitted for each GWh produced.

If more than one unit is installed, these variables are multiplied by the number of units.

The electricity produced by wind and solar power plants is affected by the weather, by the time of the day and by the season, and we have no influence on these. Furthermore, due to the green electricity subsidy, we are always obliged to accept the electricity produced in these units! The missing flexibility data reflects this policy. The figure nearby shows the expected distribution of electricity produced in **solar power plants** (average and 95% confidence interval). The figure also shows that in winter 62% of the time and in summer 42% of the time the photovoltaic solar power plants do not produce anything (at night).



The performance of **wind turbines** is a non-monotonic function of randomly varying wind speed. If the wind speed is too high or too low, the wind farm cannot produce. Furthermore, above a certain wind speed its performance does not increase further with wind speed. As a consequence of this, the wind turbines used in the simulation do not produce anything 31.6% of the time, they operate at 100% power during 16.7% of the time, and deliver some power between the two extremes in the remaining 51.7%. Their performance can vary randomly from hour to hour. The average power of the wind power plants $P_{\text{wind}} = 30.55\% \pm 38.2\%$, and the median power is 9.2% (i.e. they deliver power above 9.2% during half of the time and below 9.2% during the other half of the time).

Pumped storage hydropower plants are also available to help smooth out power fluctuations. The storage capacity of a reservoir is 6 GWh. The reservoir at the beginning of the simulation is 50%. We receive it halfway filled up, and by the end of the day it should ideally be brought back to a filling level between 20-80%. The efficiency of the reservoir is $\eta = 90\%$, (both during filling and during production). A reservoir can be “filled up” with maximum 0.5 GW power (in this case, its power is “negative”, since it does not add but it takes off electrical power from the grid).

The use of the program

- 1) Enter the chosen language when starting the simulation (currently available in English and Hungarian). Also enter a numeric “code”. This was the secret code of the students in the competition. After that, the main window of the program will appear.
- 2) The first column on the left side of the program shows the individual power plant types. The number of installed units and their maximum power are shown. During the operation of the simulation also the current power is displayed here. In the "Manual control" mode, we can set the production of the given type here in units of 0.1 GW (see point 5).
- 3) By clicking on the icon of the power plants, a window shows the detailed data of the power plant. Here you can set the number of power plants and whether the power plant can be controlled automatically or follows only manual control. The maximum number of power plants is shown in the table and a pop-up hint is shown when the cursor is moved over the input field. To select a new power plant type, it is not necessary to close the window, just click over to the other power plant.
- 4) Column 2 contains the data about the average CO₂ emission (t/GWh) and the (\$/MWh) electricity price after each simulation. Underneath, we can choose whether we are running a winter or summer simulation. The **randomly chosen day** is also displayed, for which the electric energy consumption and solar energy data are taken from the database.
- 5) In the middle, on the 3rd panel, we can start, step and stop the simulation. We have the option to simulate a full day or every single hour with manual control. When the simulation stops, we have an opportunity to manually adjust the output of power plants, which were set to manual control (within the given limits).
- 6) The priorities of the automatic control can be found somewhat lower in the middle of the page. In case of too low energy production (“shortage”), the automatic controller will increase the output of the power plants in the given order. In case of overproduction, the output of the power plant listed at the top is reduced first. If e.g. we favour hydropower to carbon, then put hydro on the top in the “shortage priority list”, and put coal on the top at the overproduction priority list.
- 7) All installed capacity (max. 20 GW!) and the installed storage capacity is shown at the top right.
- 8) The top figure shows the output (MW) of each type as a function of the hours of the day. A colour code indicates each type.
- 9) The lower figure shows the total production and demand, as well as the amount of energy in the storage (the latter is a normalized value).
- 10) In the top menu, under the "Statistics" item detailed operating statistics can be seen for information after every simulation run.
- 11) A complete configuration can also be saved and a saved configuration can be loaded again. The save also creates a screenshot to show the graphs.