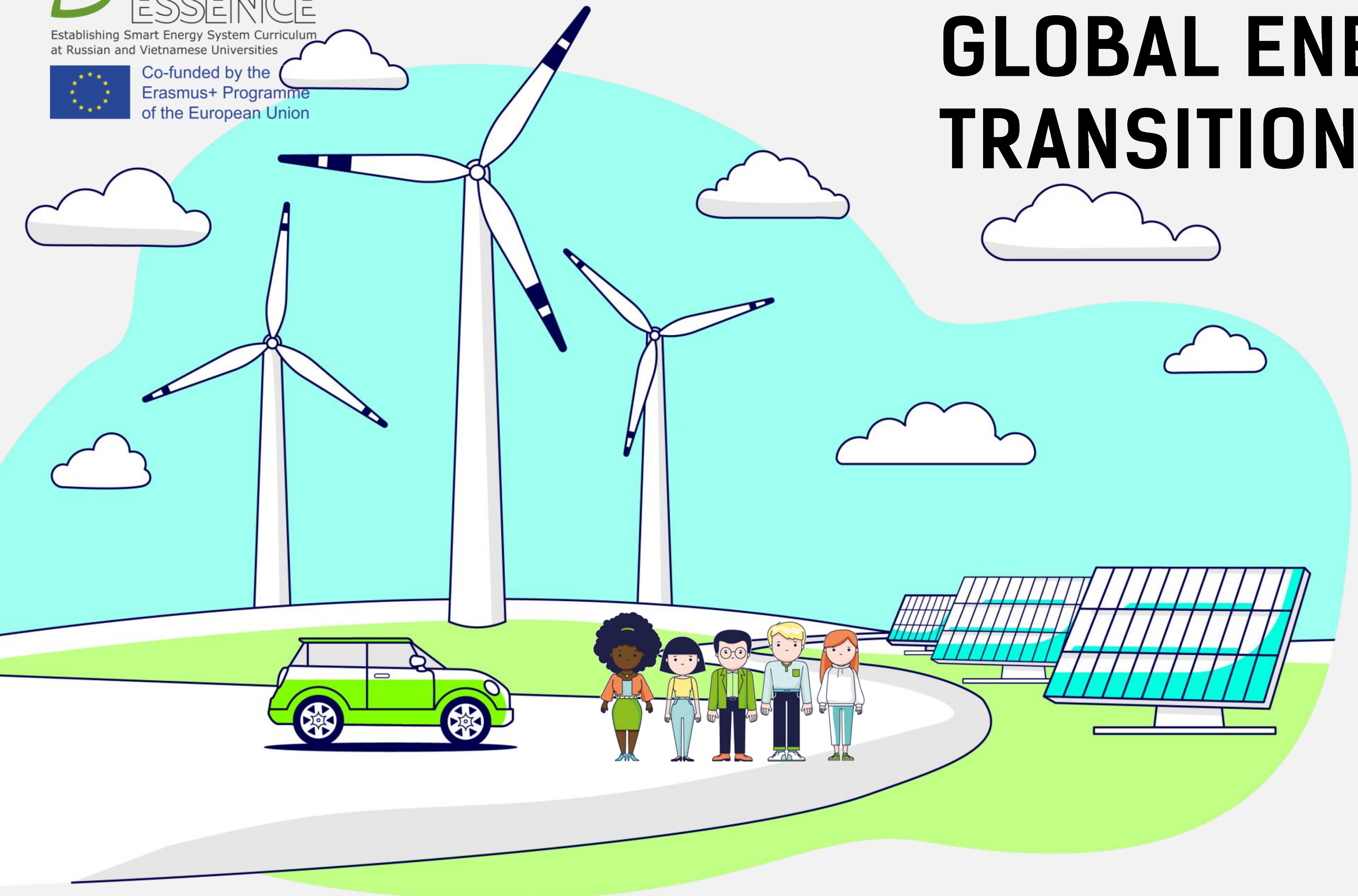
ESSENCE

Establishing Smart Energy System Curriculum at Russian and Vietnamese Universities

Co-funded by the Erasmus+ Programme of the European Union

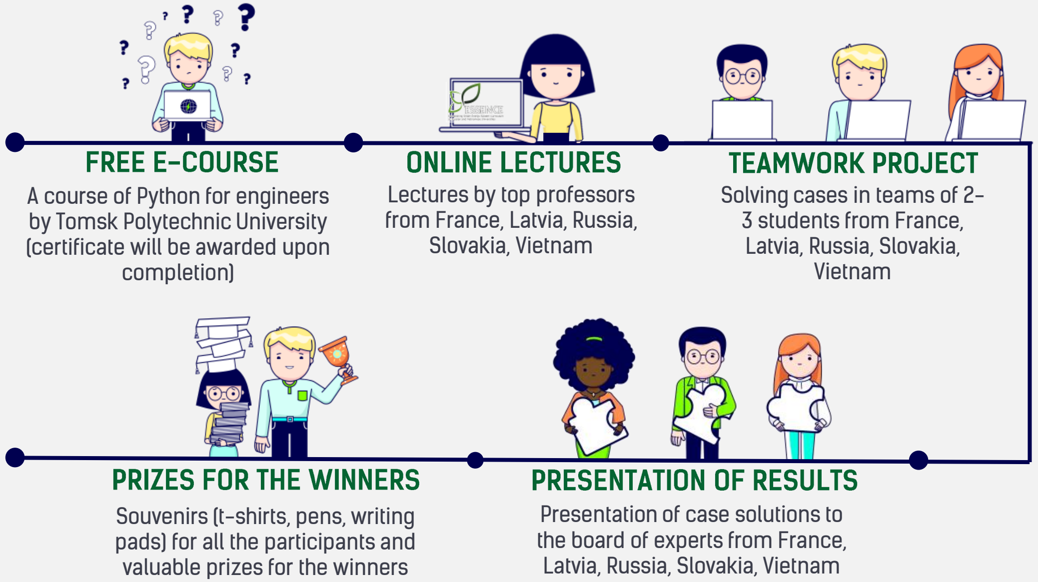
GLOBAL ENERGY TRANSITION



CASE FOR THE SUMMER SCHOOL

ABOUT THE SUMMER SCHOOL

The ESSENCE Summer School is an extra-curricular educational course where student teams will work on real-life smart energy cases and use the knowledge, skills and competences learnt and trained via video lectures, practical trainings and expert support by the academic staff of the **ESSENCE** consortium.



More about the **ESSENCE** project: http://essence-erasmus.org/new/

ORGANIZERS

Riga Technical University (Riga, Latvia)
https://www.rtu.lv/en

Grenoble INP (Grenoble, France)
https://www.grenoble-inp.fr/

Technical University of Košice (Kosice, Slovakia)
https://www.tuke.sk/wps/portal/tuke

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http://en.hcmute.edu.vn/

FROM THE AUTHORS OF THE CASE

The case was designed solely for educational purposes and is used in the ESSENCE summer school to assess students' knowledge in the field of smart grid.

The case is based on real-life data; however, some parameters, values and indicators were synthesized to complete the engineering case for educational and methodological purposes, as well as to maintain confidentiality. When solving the case, students should use and base on the case data.

It is important to understand that the case can have many alternative solutions, none of which is unequivocally correct or incorrect. The technical literacy and qualifications of the participants, the logic of the solution, the quality of presentation and other factors are of decisive importance.

WHAT IS THE CASE ABOUT?

Thanks to the government's support for the construction of renewable energy facilities and the growing demand from consumers in developed and developing countries around the world, wind and solar energy is nowadays competing with traditional energy. In the future, this trend will intensify and new technology will be used to reduce the costs of building, operating and integrating renewable energy facilities into large energy systems. This, in turn, will further increase the number of consumers of renewable energy sources and may accelerate the transition to renewable energy in different energy systems of the world. Global trends in renewable energy generation suggest that the world will move to carbon-free energy by 2050.

The ESSENCE case was developed taking into account the current trends in the global power sector with the aim to give students basic knowledge of renewable energy generation and smart grids, as well as to share the best European experience in distributed generation.

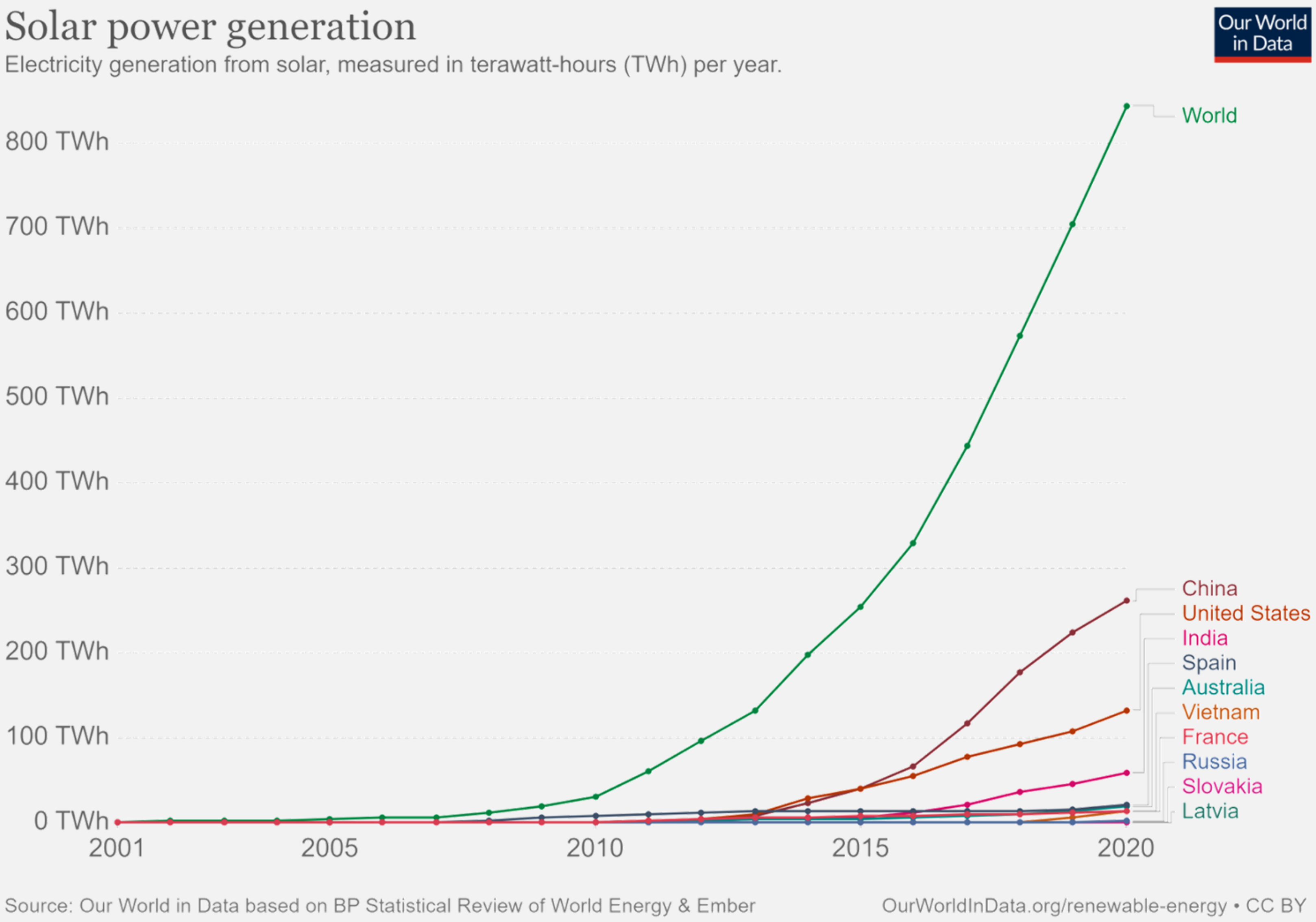




RENEWABLE ENERGY

Global renewable energy capacity additions in 2020 beat earlier estimates and all previous records despite the economic slowdown that resulted from the COVID-19 pandemic. According to data released recently by the International Renewable Energy Agency (IRENA), the world added more than 260 gigawatts (GW) of renewable energy capacity last year, exceeding expansion in 2019 by close to 50 %.

IRENA's annual Renewable Capacity Statistics 2021 shows that renewable energy's share of all new generating capacity rose considerably for the second year in a row. More than 80 % of all new electricity capacity added last year was renewable, with solar and wind accounting for 91 % of new renewables.



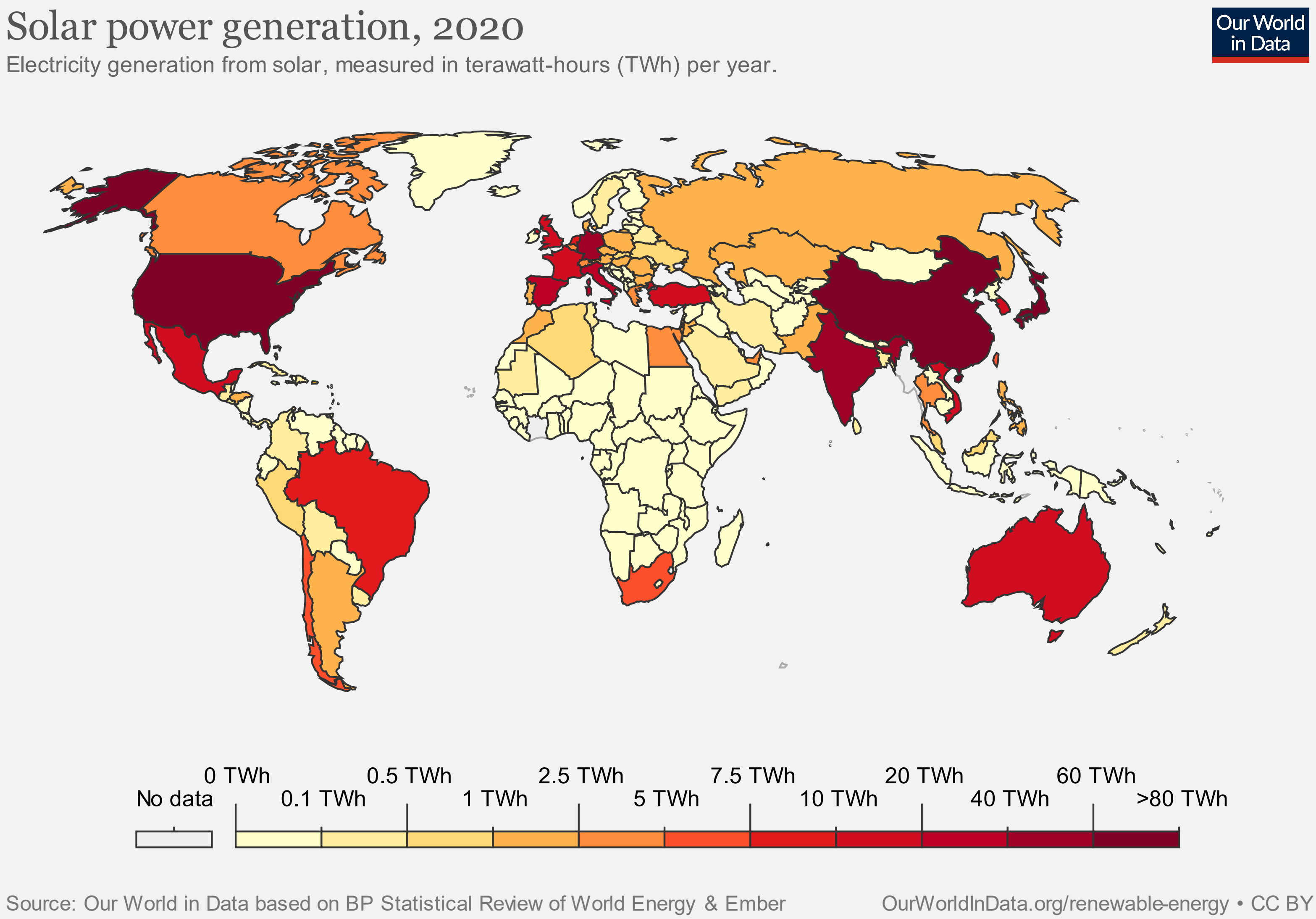
SOLAR STATISTICS

SOLAR ENERGY

Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available.

SOLAR TECHNOLOGIES

There are three main ways to harness solar energy: photovoltaics, solar heating & cooling, and concentrating solar power. Photovoltaics generate electricity directly from sunlight via an electronic process and can be used to power anything from small electronics such as calculators and road signs up to homes and large commercial businesses. Both solar heating & cooling (SHC) and concentrating solar power (CSP) applications use the heat generated by the sun to provide space or water heating in the case of SHC systems, or to run traditional electricity-generating turbines in the case of CSP power plants.



ABOUT PV POWER PLANTS

The main element of any SPP is a solar panel (photovoltaic panel (PVP)). Fig. 1 shows a typical construction of a solar panel. The main element of a solar panel is a photocell. A photocell is a semiconductor device that converts photon energy into electrical energy.

Solar panels have non-linear characteristics and change power and current-voltage characteristics depending on changes in solar radiation and ambient temperature (Fig. 2).

There are different types of connecting solar panels; the specific configuration is determined during the design. The most commonly used type is string configuration where multiple panels are connected in series to form a 12-240 Vdc string (Fig. 3).

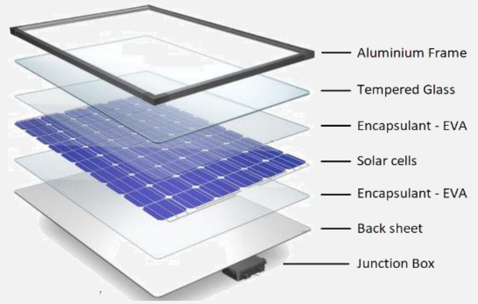


Figure 1. Solar panel

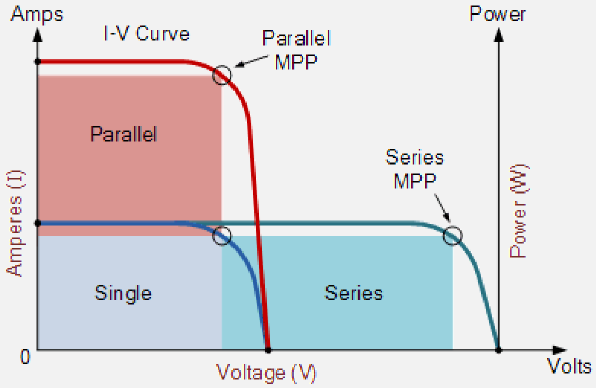


Figure 2. Solar panel I-V characteristic curves

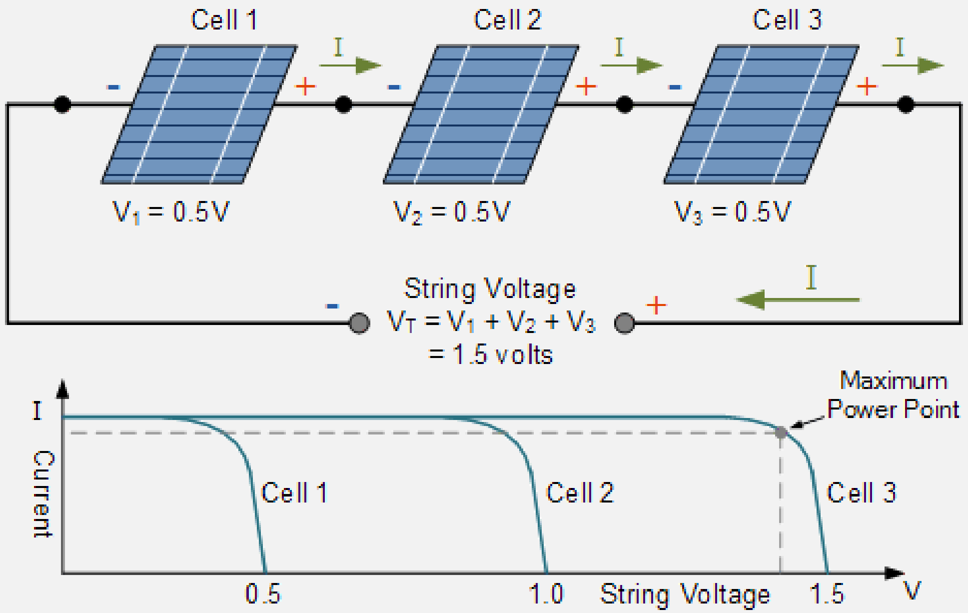


Figure 3. Series-connected PV cells

ABOUT PV POWER PLANTS

The portion of solar radiation falling on a solar panel, taking into account its spatial orientation and the sun position, depends on the angle θ between the panel surface normal and the direct sunlight. The angle θ is determined by the following parameters: the geographic latitude of the object, the inclination of the panel to the horizontal surface, panel azimuth, the sun astronomical declination (it is determined by counting the time of the year and the ordinal number of the day in the year), the solar hour angle. Fig. 4 shows a graphical representation of the sun relative to the solar panel.

The power of a photovoltaic panel is calculated by the following equation (Fig.5), where Y_{PV} is the rated power of the solar panel under standard conditions [W], f_{PV} is the derating factor of the overall panel efficiency, $\bar{G}_T$ is the solar flux density on the panel surface [W/m^2], $\bar{G}_{T,STC}$ is the solar flux density on the panel surface under standard conditions [W/m^2], a_p is the temperature coefficient [%/^{0}C] reflecting the change in power when the temperature changes by 1°C, T_c is the photocell temperature at the current time ^{0}C, $T_{c,STC}$ is the photocell temperature in the panel under standard conditions [25 ^{0}C].

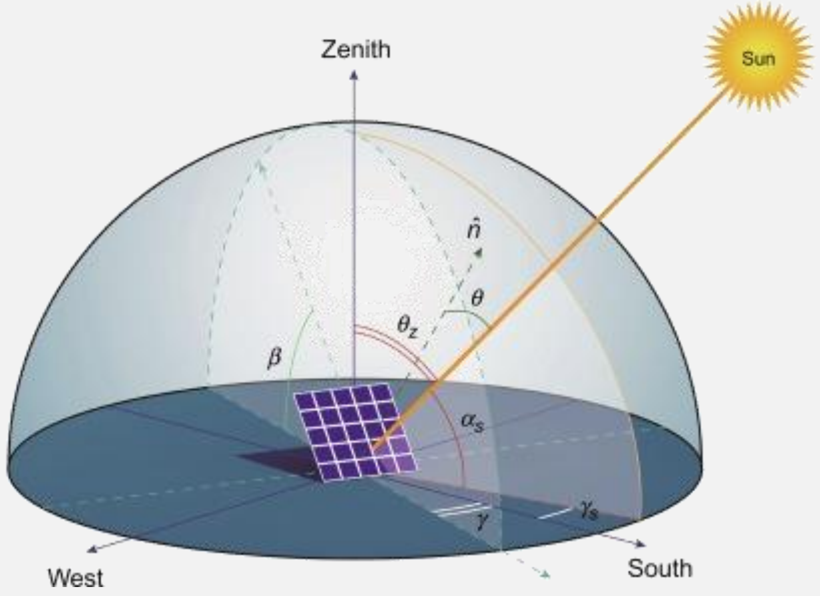


Figure 4. Position of the sun relative to the solar panel

D.C. power output of the solar panel

$$P_{PV} = Y_{PV} f_{PV} \left(\bar{G}_T / \bar{G}_{T,STC} \right) [1 + \alpha_p (\bar{T}_c - T_{c,STC})]$$

$$T_c = \bar{T}_a + \frac{\alpha \cdot \bar{G}_T (1 - \eta_m)}{U_0 + U_1 \cdot \overline{WS}}$$

$$P_a = P_{PV} \cdot n_p \cdot n_s$$

Figure 5. Power output of the solar panel

MEASUREMENT OF SOLAR RADIATION

The exoatmospheric solar radiation power is 1367 W/m^2 (solar constant). The spectral range of the solar electromagnetic radiation is very wide, but its maximum intensity falls on the visible (yellow and green) part of the energy spectrum.

As solar radiation passes through the atmosphere, the photon energy is absorbed by atmospheric gases, including ozone (O_3), carbon dioxide (CO_2) and water vapor (H_2O). The solar spectrum is shown in Fig.6., where it can be seen that the infrared solar radiation is absorbed more by water vapor and carbon dioxide, and ultraviolet radiation is absorbed by the ozone layer. Thus, the change in the intensity of solar radiation on the Earth's surface depends to a greater extent on the path length of the sun rays through the atmosphere and/or on weather conditions, which is the reason for the solar activity decays in the evening and in the morning.

Solar radiation falling on a photovoltaic panel is formed from three components:

- Insolation – the irradiation of a surface or space with a narrow beam coming from the direction in which the sun's center is located at the moment.
- Sky radiation, which is formed in the atmospheric constituents, such as clouds and dust. An isotropic model of sky radiation is usually used when measuring the solar radiation energy potential.
- Reflected radiation, which is formed when solar radiation is reflected from the ground, water, etc. It is described by the albedo in calculations .

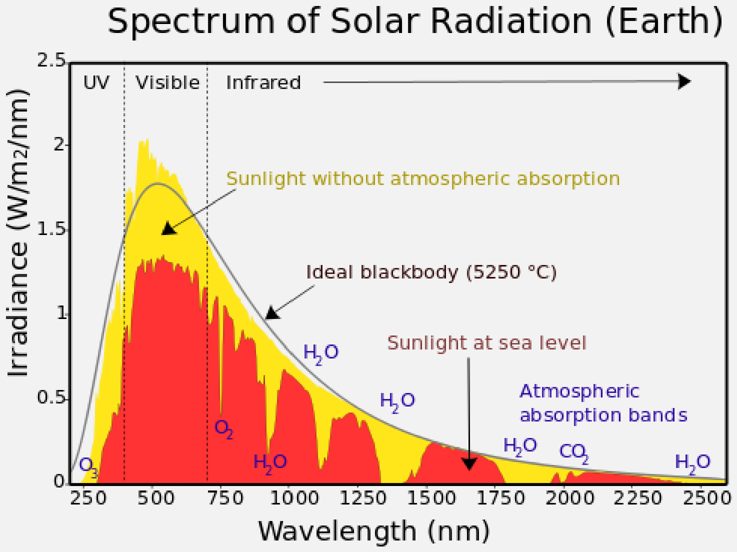


Figure 6. Solar spectrum and atmospheric absorbing gases from 240 nm to 2.5 μm wavelengths.

SOLAR RADIATION

Power generation by a solar panel is determined not only by the efficiency and current-voltage characteristic of a photocell, but also by a large number of other factors (Fig. 7), among which there are:

- Energy flux density of solar radiation falling on the photovoltaic panel;
- Changes in the solar spectrum during the day;
- Earth reflectivity around the panel (the albedo);
- Sun angle of the photovoltaic panel (taking into account the panel's spatial orientation);
- Wind speed and ambient temperature, which determine the photovoltaic panel efficiency;
- Shading and contamination of the surface of the photovoltaic panel;
- Losses associated with the DC/AC conversion, heat losses in conductors.

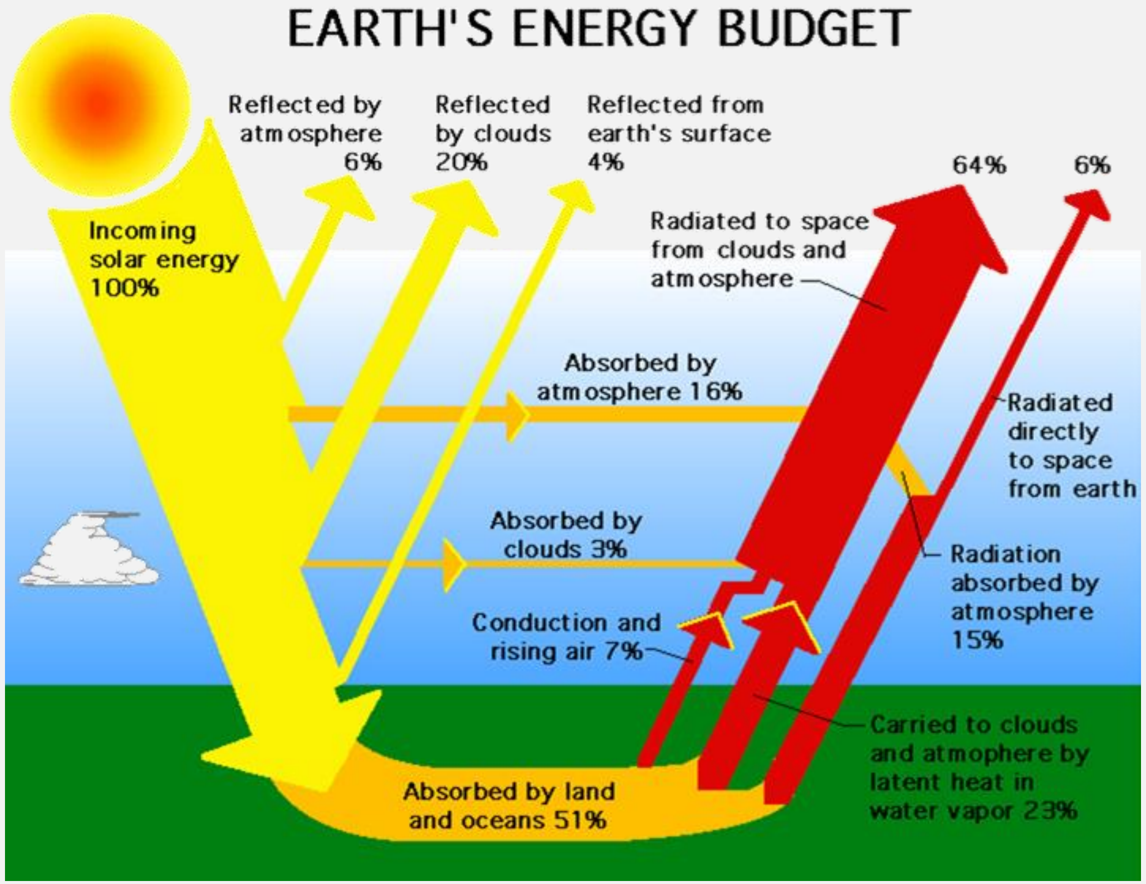


Figure 7. Earth's energy budget

ABOUT PV POWER PLANTS

The growing capacity of solar power plants increases their impact on power system operation; therefore, new challenges arise in forecasting power generation.

Forecasting power generation is mainly based on predicting weather conditions for a given area taking into account the probabilistic nature of the forecast values. To apply the obtained indicators at various stages of EPS operation, it is necessary to distinguish the following types of forecasts:

- Intra-hour and Intra-day forecasting for real-time control and regulation;
- Day ahead forecasting for planning, monitoring plant operation, participating in market trades;
- Long-term forecasting (week, season, year (or more) ahead)

Most studies are aimed at forecasting the energy flux density of solar radiation and the subsequent assessment of solar power plant generation. At the same time, random weather conditions, such as cloudiness, fog, smoke, etc. used in forecasting models are often simulated.

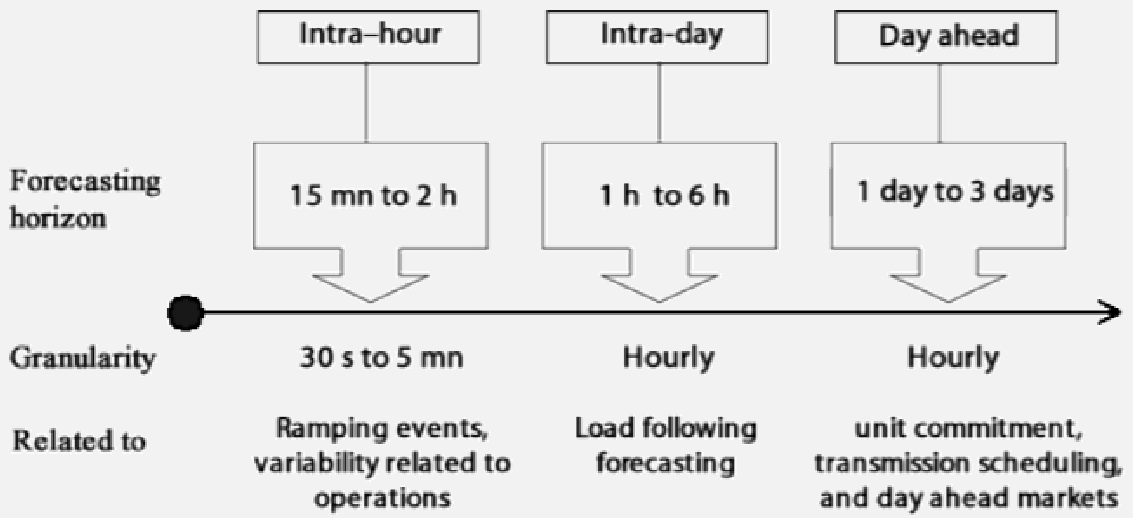


Figure 8. Relation between horizons

The main approaches used in forecasting are:

- statistical models;
- time series models;
- artificial intelligence-based models;
- hybrid models that combine different approaches.

The methods used to forecast SPP generation are largely determined by the forecasting horizon and the purposes for which the results are used.

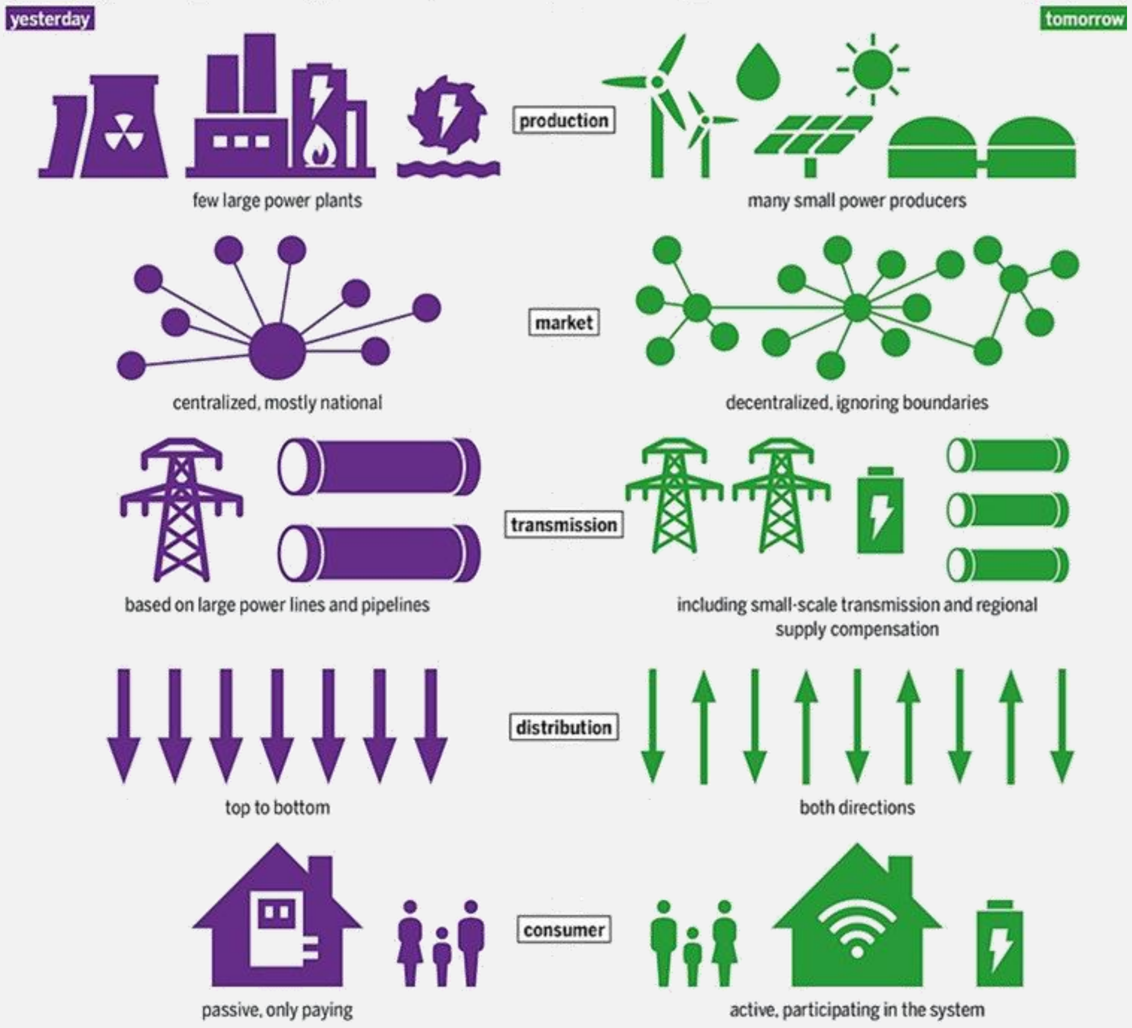
SMART GRIDS

ABOUT SMART GRIDS

A SMART GRID is an electrical network that enables a two-way flow of electricity and data. It is equipped with digital communication technology used to detect, react and prevent changes and any issues in the use of the grid. Smart grids have self-healing capabilities and enable active consumer participation.

The concept of a smart grid became known over a decade ago and plays an essential role in digital transformation of the energy sector. Traditional electrical grids have extremely limited storage capabilities, are demand-driven and have a hierarchical structure. A smart grid serves several purposes. Moving from traditional electrical grids to smart grids is driven by multiple factors, including the deregulation of the energy market, evolution in metering, changes on the level of electricity production, decentralization (distributed energy), the advent of the involved 'prosumer', changing regulations, the rise of microgeneration and (isolated) microgrids, renewable energy mandates with more energy sources and new energy users (e.g. electric vehicle charging stations).

Microgrids play an important role in building a low-carbon future because they bring resilience to the main grid, optimize energy costs, allow for renewable energy hosting, increase electric vehicle integration, and improve energy accessibility.



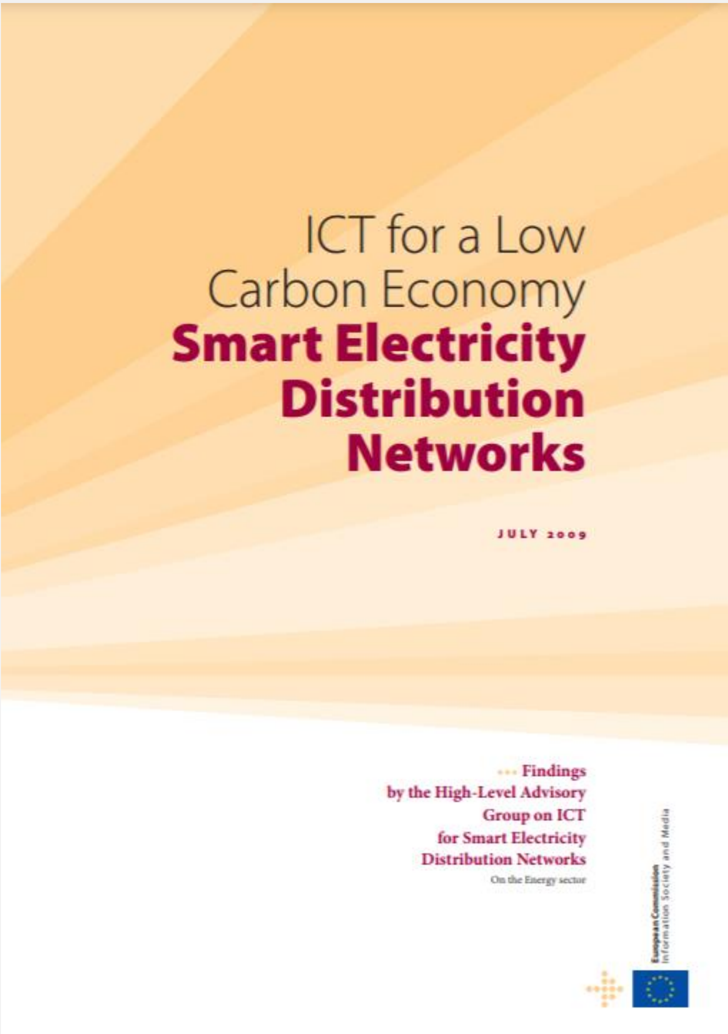
INFORMATION AND COMMUNICATION TECHNOLOGIES

ICT FOR SMART GRID

"Use of ICT can be evidenced in monitoring and control in real time of the MV and LV networks as well as integration of new devices with existing SCADA, GIS, asset repositories, outage management, etc. The networks which are mostly totally observed are the transmission ones. In distribution systems the status is quite different coming from the 100 % in the high voltage parts up to a certain degree in medium voltage and almost nothing in low voltage. There is a vast field for improvement in observability in distribution networks.

Expected projections for the solution currently being implemented include 25 %-50 % reduction in Non Delivered Energy (NDE), 35 % reduction in fault search time, up to 90 % reduction in network reinforcement costs, improved operations (safe overloading), improved network planning, and improved customer service. Non Delivered Energy (NDE) and Customer Minutes Lost (CML) are measurements of the availability of supply.

CML is the average number of minutes that end customers were without energy supply over a 12 month period. NDE puts a value on the time that energy was not available to the customer base. That value is a combination of several factors, including CMLs and the value to the economy of the kWh not delivered. This can help show the value of Smart Grid to society and the European / National economy."



ICT FOR NETWORK STABILITY

"Some possible developments expected at distribution system level may have a major impact on the network stability of the whole system. Active networks, microgrids, and virtual power plants may represent a possibility towards which today's distribution systems might evolve in presence of distributed generation. Also a hybrid combination of these might result. The scope of these developments is related to the need for ensuring adequate levels of reliability and security of supply in presence of increased DG penetration.

In all three system developments, modern control technologies may be very useful.

Particularly, soft controllers based on ICT and hard controllers based on power electronic devices like FACTS (Flexible AC Transmission System) can support the DSOs to control the system as this technology has been proven helpful for TSOs. In distribution networks the soft controllers have a very promising use. Analytic tools which will react in real time isolating a part of the network may be very useful.

ICT can be used to improve the communication between a DSO and a TSO and provide the DSO with more advanced monitoring tools, like SCADA. Power electronics-based devices like FACTS are able to control electrical parameters like the real and reactive power flows and the voltage amplitude at network nodes in a very smooth, fast way. FACTS devices are proven technologies for a flexible transmission system control.

At distribution level the equivalent devices are known as D-FACTS and may be useful for a better control of power flows, voltage level, power quality issues in distribution grids. Other advanced network controllers are given by WAMS (Wide Area Measurement System). These technologies include soft ware (ICT) and hardware PMU (Phasor Measurement Unit) tools. PMUs are devices able to remotely monitor phase voltages and currents and the corresponding. Each phasor is measured and coupled with a very precise time stamp derived from a GPS (Global Positioning System) satellite. WAMS systems are already used to control transmission systems."

THE MAIN STEPS OF THE CASE

Selecting photovoltaic power plant equipment

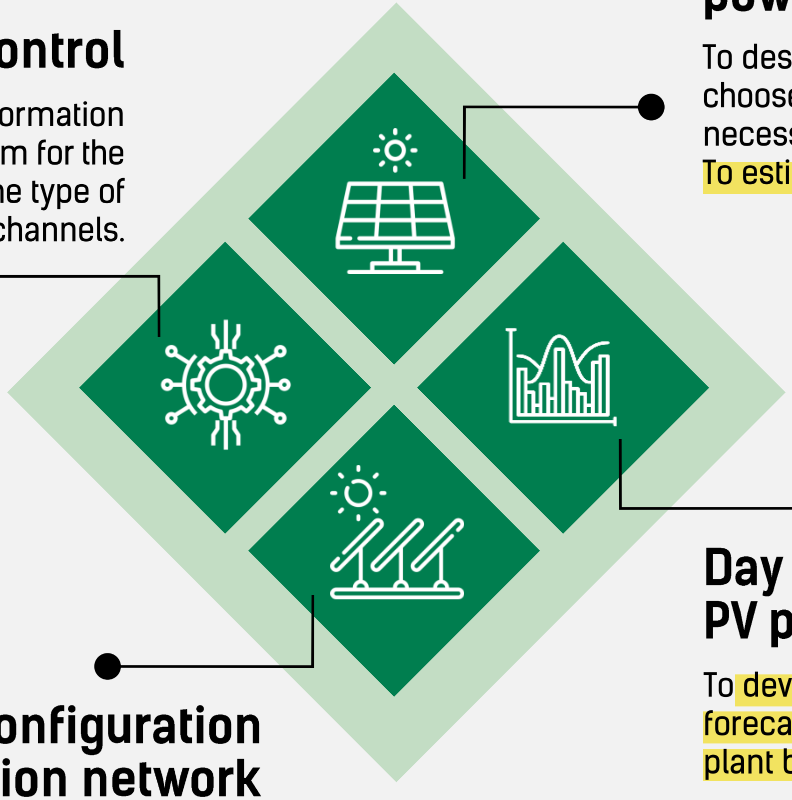
Day ahead forecasting of PV power plant

Optimal reconfiguration of the distribution network

Smart grid digital control

Smart grid digital control

To design the architecture of the information and communication system for the distribution feeder, select the type of communication controllers and channels.



Selecting photovoltaic power plant equipment

To design a photovoltaic power plant: to choose solar panels, inverters, converters (if necessary), alternating current equipment. To estimate PV construction expenses.

Day ahead forecasting of PV power plant

To develop a model for day ahead forecasting of the photovoltaic power plant based on machine learning.

Optimal dynamic reconfiguration of the distribution network

To find hourly optimal configuration of the distribution network using the given hourly values of active and reactive loads and PV plant generation forecast.

Step 1: Selecting photovoltaic power plant equipment

ABSTRACT:

The main goal of a solar system is to harvest available energy from PV panels and inject a sinusoidal current into a grid in phase with the grid voltage. The tasks to be addressed when designing a photovoltaic power plant include: to define a photovoltaic type, design a PV string, justify a solar tracking system, arrange field, select voltage, select the type and characteristics of an inverter, calculate the optimum performance of the solar cell and inverter size to match the distribution transformer, transmission line, bus bar, etc.

GOAL OF THE STEP:

To design a photovoltaic power plant*: to choose solar panels, inverters, converters (if necessary), alternating current equipment. To estimate PV construction expenses.

*similar configuration may be applied for another solar power plant

INPUT DATA:

- Photovoltaic power plants' capacities;
- Points of connection of the photovoltaic power plants to the distribution network;
- Solar radiation and meteorological data;
- Unit costs of photovoltaic power plant constructive parts.

TOOLS AND METHODS:

- May be calculated manually based on the recommendations of a lecturer;
- HOMER, Aurora Solar, PVsyst or other available software.

OBJECTIVES:

- To select the number and types of PV panels;
- To draft a connection scheme for the PV panels;
- To select inverters and converters;
- To select an alternating current switchgear and configuration;
- To estimate CAPEX of constructing the PV plant and annual OPEX.

Step 2: Day ahead forecasting of PV power plant

ABSTRACT:

The two main challenges to high penetration rates of PV systems are variability and uncertainty, i.e. the fact that PV output exhibits variability at all timescales (from seconds to years) and the fact that this variability itself is difficult to predict. Greater PV prediction accuracy favors better planning of power system operation due to the reduction of PV output uncertainty.

GOAL OF THE STEP:

The goal of this part is to develop a model for day ahead forecasting of the photovoltaic power plants allocated in the area with equal climatic and geographic conditions based on machine learning.

INPUT DATA:

- PV plant* and solar dataset (PV plant output data, solar geometry data, retrospective data on the solar radiation, etc.);
- Weather data (weather dataset: clouds, temperature, humidity, precipitation, etc.);
- PV configuration: panels, inverters, AC switchgear (from Step 1).

*the dataset for another power plant may be obtained in simplified form due to equal climatic and geographic conditions

TOOLS AND METHODS:

- Python programming environment (Google Colab) (https://colab.research.google.com/);
- MathWorks Matlab & Simulink (https://www.mathworks.com/products/matlab.html).

OBJECTIVES:

- To analyze the initial datasets;
- To process data (bad data, outliers, data gaps, etc.);
- To select some relevant features for forecasting PV generation;
- To implement feature engineering (create new features if needed);
- To predict PV generation using several machine learning methods;
- To justify PV forecast quality metrics;
- To compare the operation of different machine learning algorithms and select the best algorithm;
- To give sample-day forecasts for a sunny day, cloudy day, partly cloudy day.

Step 3: Optimal dynamic reconfiguration of the distribution network

ABSTRACT:

The distribution feeder reconfiguration is usually defined as altering the topological structure of distribution feeders by changing the open/closed status of automatic and tie switches. By changing the status of the sectionalizing and tie switches, the configuration of the distribution system is changed and loads are transferred among the feeders. Network reconfiguration is a very efficient way to balance load of network elements, improve system reliability and voltage profile, and reduce power losses.

GOAL OF THE STEP:

To find mean hourly optimal configuration of the distribution network using the given hourly values of active and reactive loads and PV plant generation forecast given radial configuration of the distribution network and recommended voltage level range [0.95 ; 1.05] V_{rated}

INPUT DATA:

- Data for IEEE 15 bus system;
- Load curves at power network buses;
- PV plant daily forecast and PV plant configuration (from Step 2);
- Optimization criteria (losses P and Q, voltage deviations).

TOOLS AND METHODS:

- INOR XL (https://inorxl.com/) Freeware;
- MathWorks Matlab & Simulink (https://www.mathworks.com/products/matlab.html);
- Palisade Decision Tools (https://www.palisade.com/decisiontools_suite);
- ETAP (https://etap.com/);
- Power Factory (https://www.digsilent.de/en/powerfactory.html);
- Other.

OBJECTIVES:

- To create a power flow model;
- To choose a solver for the power flow model (integrated in the power flow simulation software or external);
- To design the objective function of the optimization problem;
- To define constraints of the optimization problem;
- To define a type of optimization problem;
- To choose and implement an optimization solver (brute force, machine learning algorithms, etc.).

Step 4: Smart grid digital control

ABSTRACT:

ICT-related innovation represents between 17 % and 26 % of total innovative output in the EU. ICT plays an important role in modern power systems. ICT is used to exchange information between system components and thus to monitor and control power grids. Data communication and collection improve security of energy supply, which requires reliable data flow.

Multiple protocols exist for substation automation, which include many proprietary protocols with custom communication links. Interoperation of devices from different vendors would be an advantage to users of substation automation devices. IEC 61850 responds to most existing concerns and objectives, provides a single protocol for the whole substation and enables modelling of different data required for the substation.

GOAL OF THE STEP:

To design the architecture of the information and communication system for the distribution feeder, select the type of communication controllers and channels using the existing electrical circuit diagram, based on the results of optimal network reconfiguration.

INPUT DATA:

- Data for IEEE 15 bus system;
- Power network reconfiguration schedule (from Step 3).

TOOLS AND METHODS:

- No special tools are required.

OBJECTIVES:

To design the architecture of the information and communication system for the distribution feeder, select the type of communication controllers and channels.

Initial data: power network data

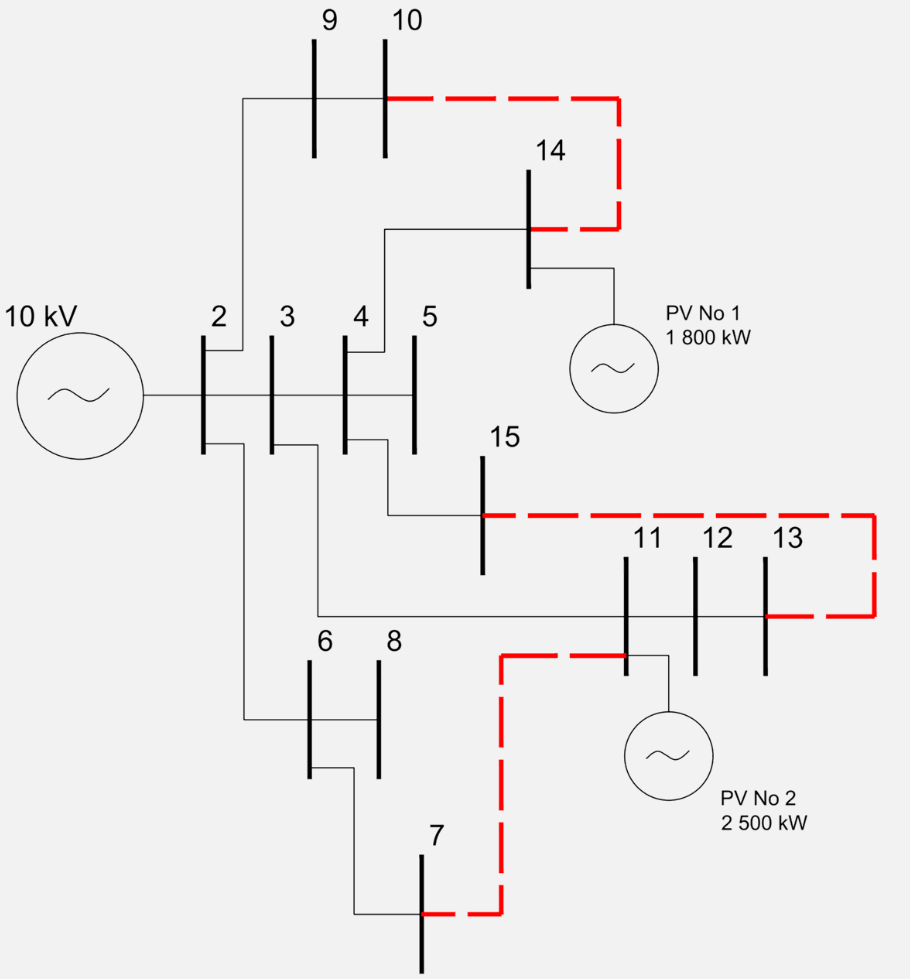
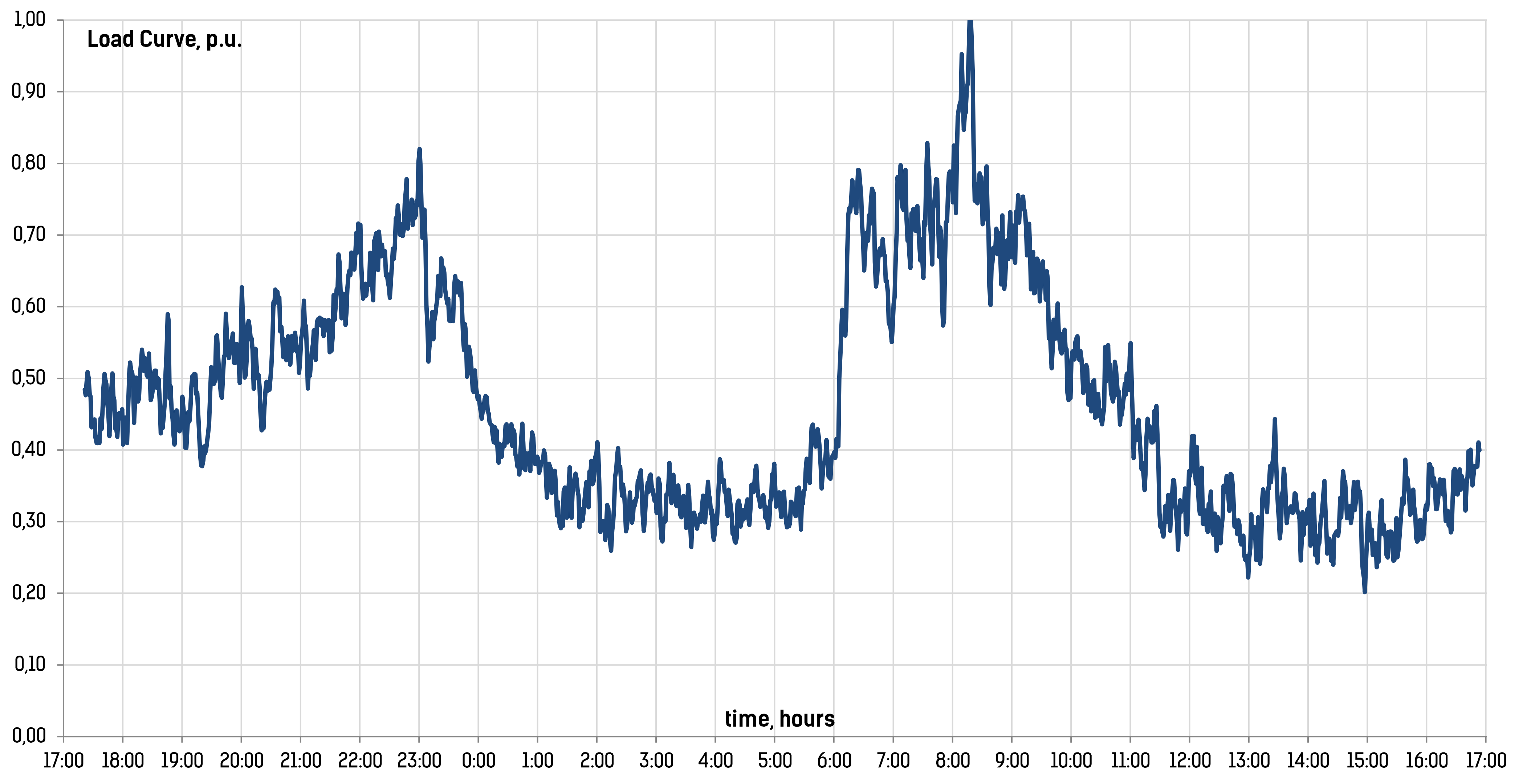


Figure 9. Single-line diagram of a 15-bus system

Bus		Line data		
From	To	Resistance (Ohms)	Reactance (Ohms)	Imax (A)
1	2	1.35	1.32	265.00
2	3	1.17	1.14	265.00
3	4	0.84	0.82	265.00
4	5	1.52	1.02	298.00
2	9	2.01	1.32	298.00
9	10	1.68	1.13	298.00
2	6	2.55	1.72	298.00
6	7	1.08	0.73	298.00
6	8	1.25	0.84	298.00
3	11	1.79	1.21	298.00
11	12	2.45	1.65	298.00
12	13	2.01	1.36	298.00
4	14	2.23	1.50	298.00
4	15	1.97	0.80	240.00
10	14	1.90	1.12	298.00
13	15	2.18	2.12	265.00
7	11	2.98	1.54	263.00

Bus	Load data		
	Active Power (kW)	Reactive power (kVAR)	Load curve
2	44.1	44.99	1
3	70.1	71.44	1
4	40	142.82	2
5	44.1	44.99	1
9	70	71.44	1
10	44.1	44.99	2
6	140	142.82	3
7	140	142.82	1
8	70	71.44	1
11	140	142.82	2
12	70	71.44	3
13	44.1	44.99	1
14	70	71.44	2
15	140	142.82	3
-	-	-	-
-	-	-	-
-	-	-	-

Initial data: load profile 1



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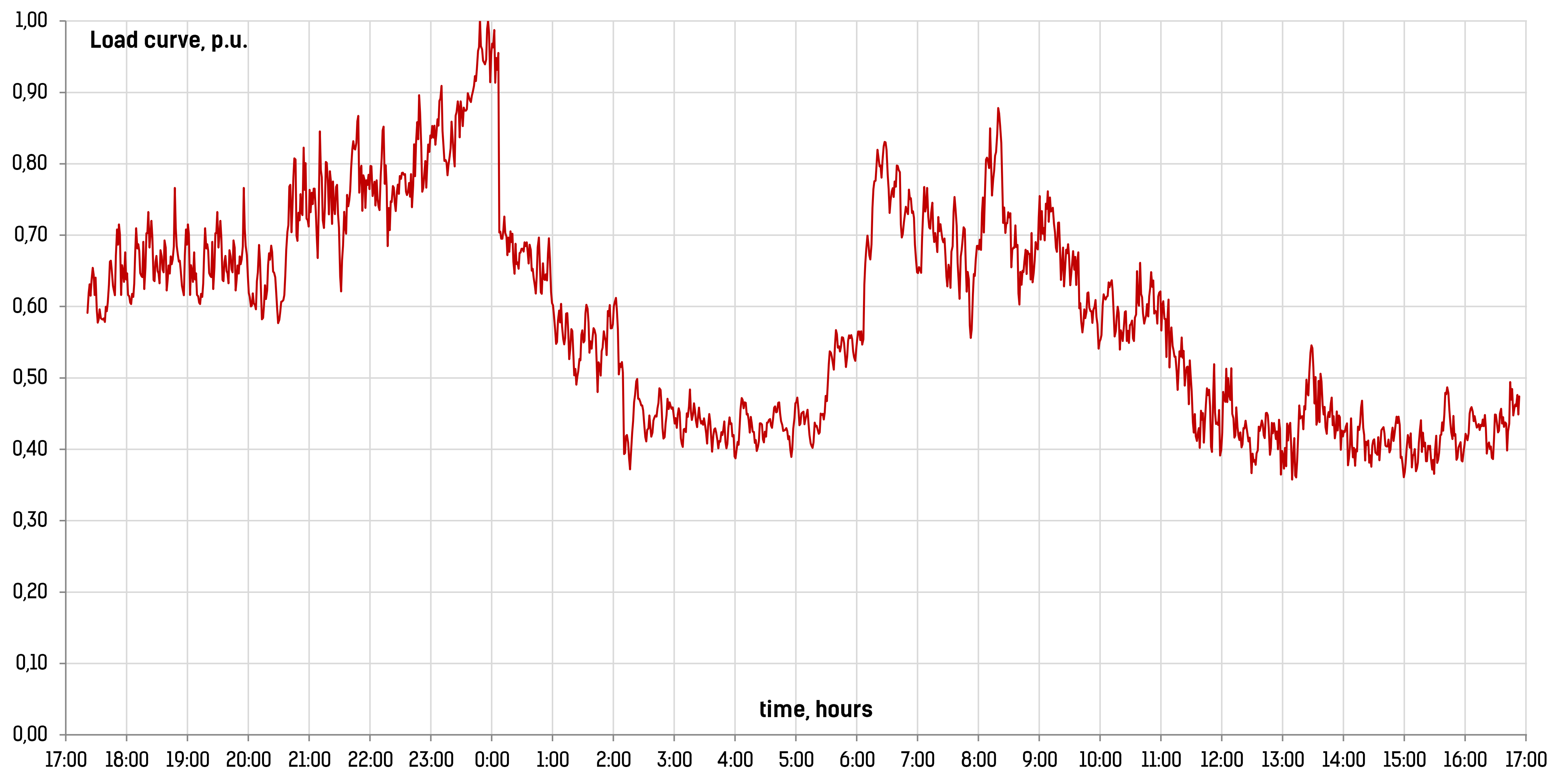

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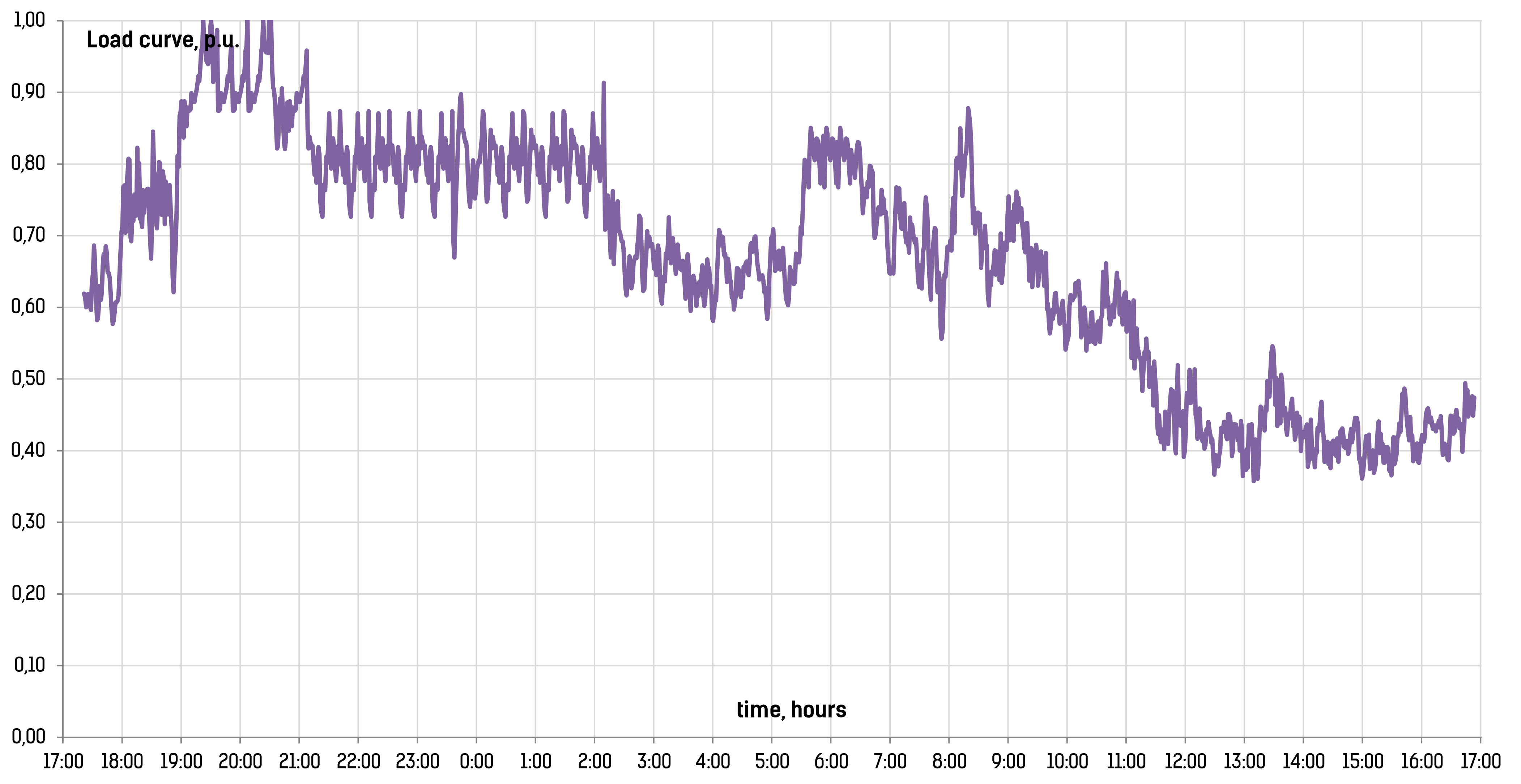

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GOOD LUCK WITH THE CASE