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Power Engineering Department

Distribuční sítě s rozptýleným zdroji

Distribution systems with renewable sources

Bachelor’s Thesis

Study program: Electrotechnika, energetika a management

Specialization: Applied Electrical Engineering

Supervisor: Ing. František Vybíralík, CSc.

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Czech Technical University in Prague
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BACHELOR PROJECT ASSIGNMENT

Student: **Tigran Avakyan**

Study programme: Electrical Engineering, Power Engineering and Management
Specialisation: Applied Electrical Engineering

Title of Bachelor Project: **Distribution systems with renewable sources**

Guidelines:

1. General information on distributed energy sources, types of power plants, specifically photovoltaic power plants.
2. Describe the rules for connecting dispersed energy sources to the distribution system.
3. A case study for the selected part of the medium voltage distribution system.

Bibliography/Sources:

[1] Distribution network codes
[2] eVlivy application manual
[3] SCHLABBACH, J, D BLUME a T STEPHANBLOME. Voltage quality in electrical power systems. London: Institution of Electrical Engineers, c2001, x, 241 p. IEE power and energy series, 36. ISBN 978-085-2969-755.

Bachelor Project Supervisor: Ing. František Vybíralík, CSc.

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Prague, April 18, 2016

Declaration

I hereby declare that this thesis is the result of my own work and all the sources I used are in the list of references, in accordance with Methodological Instructions of Ethical Principle in the Preparation of University Thesis.

In Prague, 10.01.2017 Signature.............................

Acknowledgement

I would like to thank everyone that were involved in the development of this thesis, especially my supervisor Ing. František Vybíralík, CSc. and Ing. Jan Kyncl, Ph.D. for their continuous guidance and support, also E-Vlivy for the experience and knowledge it has given me on Distribution Power Systems.

Abstract

This thesis is about the general information on distributed energy sources, types of power plants, specifically photovoltaic power plants (constraints, laws, standards and requirements), the rules for connecting dispersed energy sources to the distribution system, voltage characteristics before and after connection to a consumption network.

Key Words

Distribution system, generation, power plants, solar cells, renewables, power quality.

Abstrakt

Tato práce pojednává o obecné informace o distribuovaných energetických zdrojů, typů elektráren, zejména fotovoltaických elektráren (jeho omezení, zákonů, norem a požadavků), pravidla pro připojení rozptýlených zdrojů energie k distribuční soustavě, charakteristika napětí před a po připojení k spotřeba síť.

Klíčová slova

Distribuční soustava, generace, elektrárny, solární články, obnovitelné zdroje, kvalita elektrické energie.

Table of Contents

1 Introduction [1]

1.1 Distributed power generation

In our generation, electricity is one of the most important and necessities in everyday life. It is undeniable that the usage of renewable energy will have a very progressive future since it is environmental friendly. Distributed power (DP) refers to the process and concepts in which small to medium (a few kW up to 10 MW or more) power generation facilities, energy storage facilities (thermal, flywheel, hydro, flow, and regular batteries). DP technologies installed near customers' loads operate as grid-connected or islanded resources at the distribution or sub-transmission level and are geographically scattered throughout the service area. DP generation harnesses renewable and nonrenewable energy sources, such as solar insolation, wind, biomass, tides, hydro, waves, geothermal, biogas, natural gas, hydrogen, and diesel, in a distributed manner. DP also includes several nonutility sources of electricity, including facilities for self-generation, energy storage, and combined heat and power (CHP) or cogeneration systems. DP is ideally suited to power sensitive loads, small remote loads located far from the grid, and integrated renewable energy sources into the grid.

1.2 General features. Motivation

DP will have one or more of the following features: Small to medium size, geographically distributed. Intermittent input resource, e.g., wind and insolation power. Stand-alone or interface at the distribution or sub-transmission level. Utilize site-specific energy sources. Located near the loads. Integration of energy storage and control with power generation.

Some of the main motivations for the use of DP are:

- Low incremental capital investments.
- Long lead-times to site DP plants.
- Likely to result in improved reliability, availability, and power quality.
- Location near load centers lowers the energy transport losses and decreases transmission and distribution costs. Better utilization of distribution network

infrastructure. Integration of control and protection with energy flow stream. Preferred technology for digital society, requiring high-reliability figures.

1.3 DP technologies

A listing of some of the DP technologies is given below:

- Photovoltaic.
- Wind energy conversion systems.
- Mini and micro hydro.
- Geothermal plants.
- Tidal and wave energy conversion.
- Fuel cell.
- Solar-thermal-electric conversion.
- Biomass utilization.
- Thermoelectric and thermionic.
- Micro and mini turbines as cogeneration plants, powered by natural gas and supplying electricity and heat.
- Energy storage technologies, including flow and regular batteries, pump-storage hydro, flywheels, and thermal energy storage concepts.
- Small-scale nuclear reactors are also in the development phase as pebble-bed modular nuclear reactors (PBMR).

1.4 Defining terms

Biomass: General term used for wood, wood wastes, sewage, cultivated herbaceous and other energy crops, and animal wastes.

Distributed generation (DG): Medium to small power plants at or near loads and scattered throughout the service area.

Distributed power (DP): System concepts in which distributed generation facilities, energy storage facilities, control, and protection strategies are located near loads and scattered throughout the service area.

Photovoltaic: Conversion of insolation into dc power by means of solid-state pn-junction diodes. Solar-thermal-electric conversion: Collection of solar energy in thermal form using flat-plate or concentrating collectors and its conversion to electrical form.

Wind energy conversion: The generation of electrical energy using electromechanical energy converters driven by wind turbines.

Hydropower: Conversion of potential energy of water into electricity using generators coupled to impulse or reaction water turbines.

Fuel cell: Device that converts the chemical energy in a fuel directly and isothermally into electrical energy.

Geothermal energy: Thermal energy in the form of hot water and steam in the Earth’s crust.

Hydropower: Conversion of potential energy of water into electricity using generators coupled to impulse or reaction water turbines.

Insolation: Incident solar radiation.

Thermoelectric: Direct conversion of thermal energy into electrical energy using the thermoelectric effects in materials, typically semiconductors.

Fuel cell: Device that converts the chemical energy in a fuel directly and isothermally into electrical energy.

Tidal energy: The energy contained in the varying water level in oceans and estuaries, originated by lunar gravitational force.

Wind energy conversion: The generation of electrical energy using electromechanical energy converters driven by wind turbines.

2 Photovoltaic (PV) power generation [2]

2.1 What is a solar cell?

Nowadays, it is a quickly growing and progressively important renewable alternative to conventional fossil fuel electricity generation, but compared to other electricity generating technologies, it is a relatively new. PV refers to the direct conversion of insolation (incident solar radiation) to electricity. A PV cell (also known as a solar cell) is simply a large-area semiconductor p-n junction diode, with the junction positioned very close to the top surface as it is shown in *Figure 2.1*. Typically, a metallic grid structure on the top and a sheet structure in the bottom collect the minority carriers crossing the junction and serve as terminals. The minority carriers are generated by the incident photons with energies greater than or equal to the energy gap of the semiconductor material. Single-crystal silicon is still the dominant technology for fabricating PV devices. Polycrystalline, semi-crystalline, and amorphous silicon technologies are developing rapidly to challenge this. Highly innovative technologies such as spherical cells are being introduced to reduce costs.

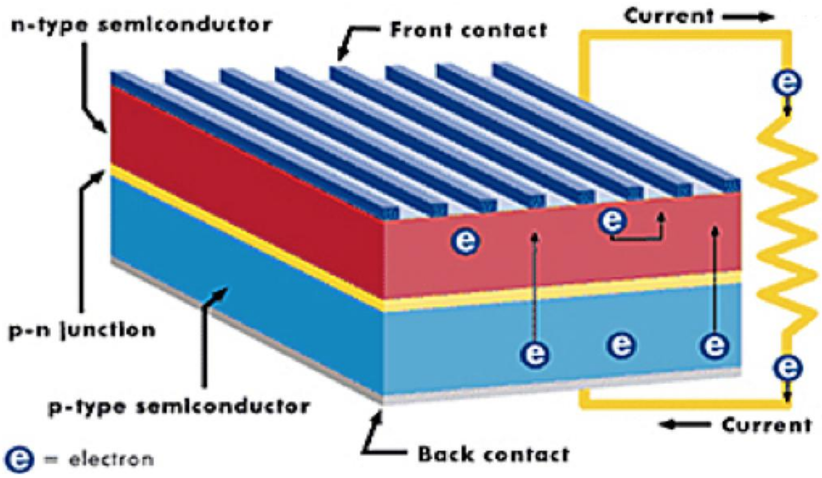


Figure 2.1 - Basic structure of a solar cell

The output of a PV system is dc, and inversion is required for supplying ac loads or for utility-interactive operation. The input to a PV system is determined by external factors, such as cloud cover, time of day, season of the year, geographic location, orientation, and geometry of the collector. Therefore, PV systems are operated, as far as possible, at or near their maximum outputs. In addition, PV plants have no energy storage capabilities, and their power output is subject to rapid changes due to moving clouds. The *Figure 2.2* represents the map of the Czech Republic with the annual amount of solar radiation. It is very clear that the solar radiation is more captured in the southeast and decreases towards the north.

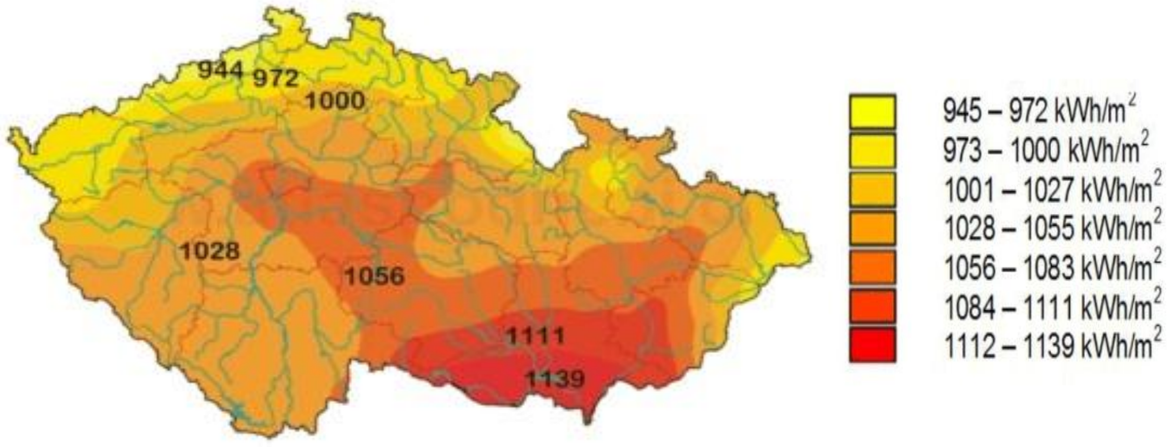


Figure 2.2- Solar radiation in the Czech Republic

2.2 Basic operational principles

Solar cells, which substantially are made from crystalline silicon, nowadays work on the principle that is called photovoltaic effect. Basically, the photovoltaic effect means the generation of a potential difference of two materials at the junction between them in response to the radiation. There are two crystalline structures that solar cells based on, such as silicon in its purest form so called Intrinsic Silicon and the second is Extrinsic Silicon, which is doped with some dopant impurities in order to get desired characteristic either p-type or n-type. The basic steps in the operation along with photovoltaic effect are:

- The generation of light-generated carriers due to absorption of solar radiation (photons);
- The separation and then collection of light-generated carriers at terminals of a junction to generate a current;
- The generation of a voltage throughout a solar cell;
- The dissipation of the power in the load and parasitic resistances. (PV website)

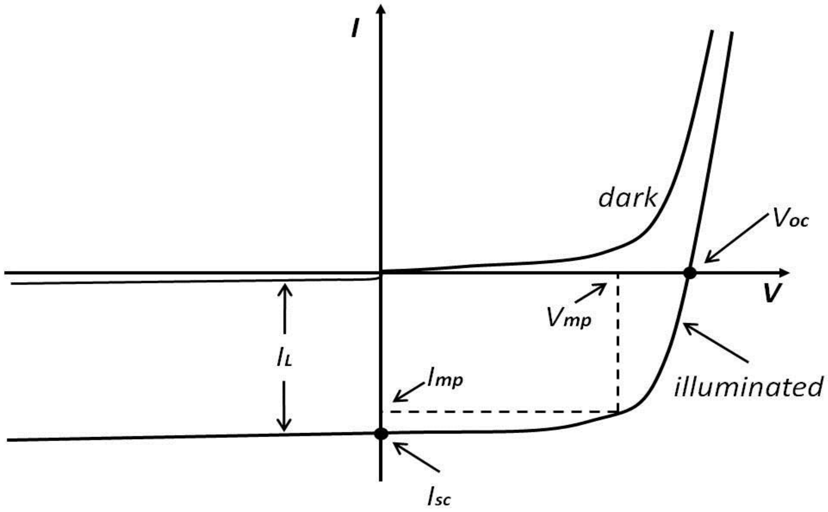


Figure 2.1- The current-voltage (IV) characteristics of the illuminated and dark p-n junction

Semiconductor’s regions, which are doped with donor impurities at normal temperatures, have an increased number of electrons in the conduction band and are known as n-type junction (material). Those regions, which are doped with acceptors, are known as p-type material.

When an ideal diode is in the dark, the supplied energy comes from the outside of a cell through applied voltage and under illumination the energy supply occurs inside the cell. Electrons and holes are forced in opposite directions due to the internal electrical field, caused by the space charged region. It creates a current, called “photocurrent”, because it is driven by the light. A function of the incident light spectrum and the material properties of the diode is the photocurrent. When it is not an illuminated cell, the current running through a p-n junction diode can be calculated with the ideal diode equation:

$$I = I_0 \left(e^{\frac{qV}{kT}} - 1\right)$$

(2.1)

Where:

I = the net current flowing through a diode

I_0 = dark saturation current, in the absence of light

V = applied voltage across the terminals of the diode
Q = absolute value of electron charge
K = Boltzmann’s constant
T = absolute temperature

Module with a series-parallel arrangement of cells, the IV characteristic will be similar, except that the current scale should be multiplied by the number of parallel branches and the voltage scale by the number of cells in series in the module.

Cells in parallel

Parallel wiring:

For practical use it is necessary to have cells in series connection to obtain a source of a higher voltage. All cells have same voltage, currents sum up. (*Shown in Figure 2.2*).

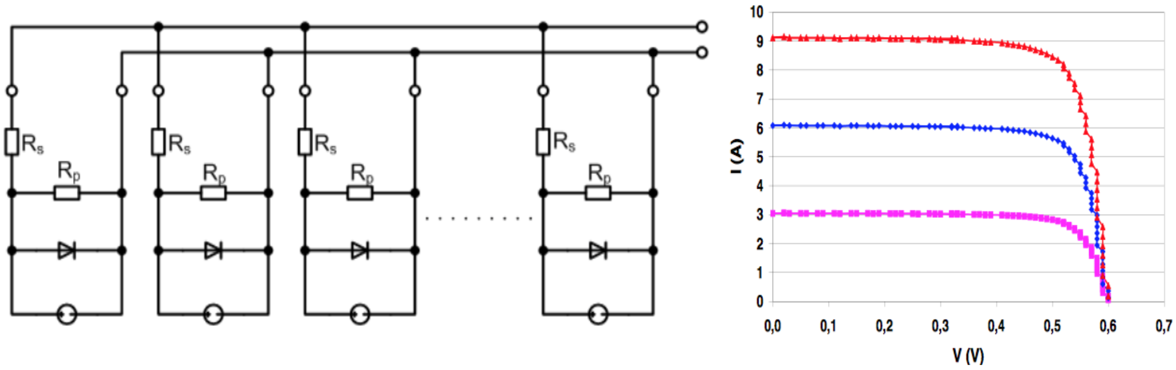


Figure 2.2 - cells in parallel → I-V curves stack on each other

Cells in series

Series wiring:

Parallel connection increases the output of a current (amperes) whereas keeping voltage the same. All cells have same voltage, currents sum up. (*Figure 2.3*).

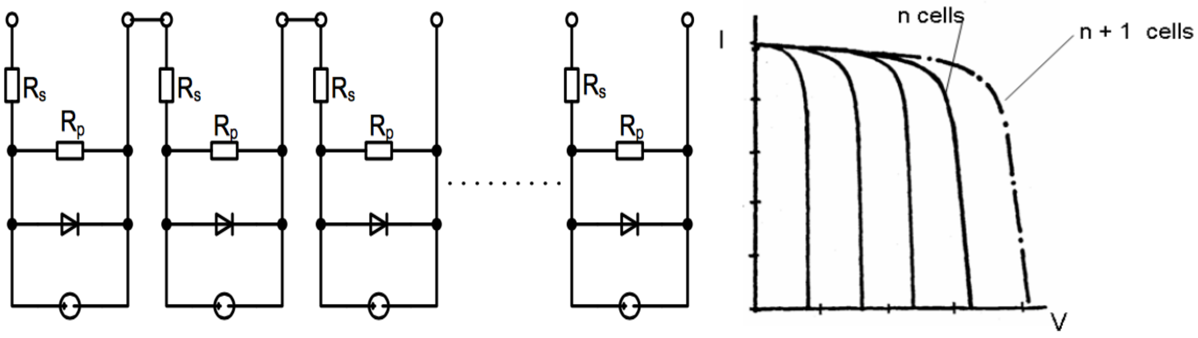


Figure 2.3 - cells in series

2.3 Important solar cell electrical parameters [3]

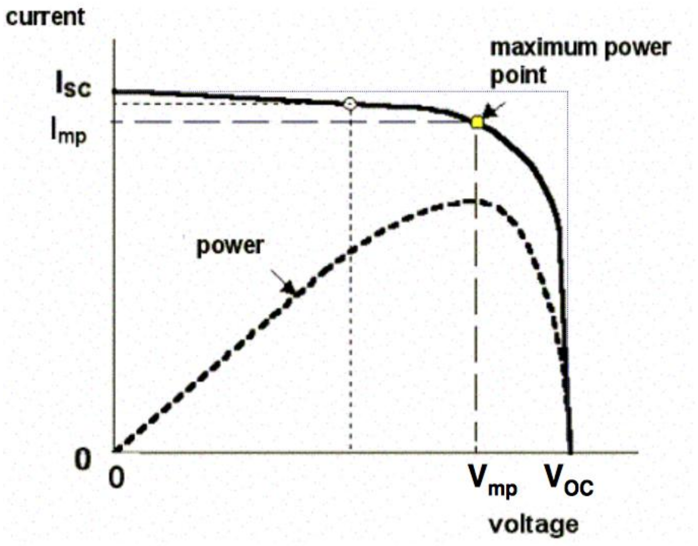


Figure 2.4 – maximum power point

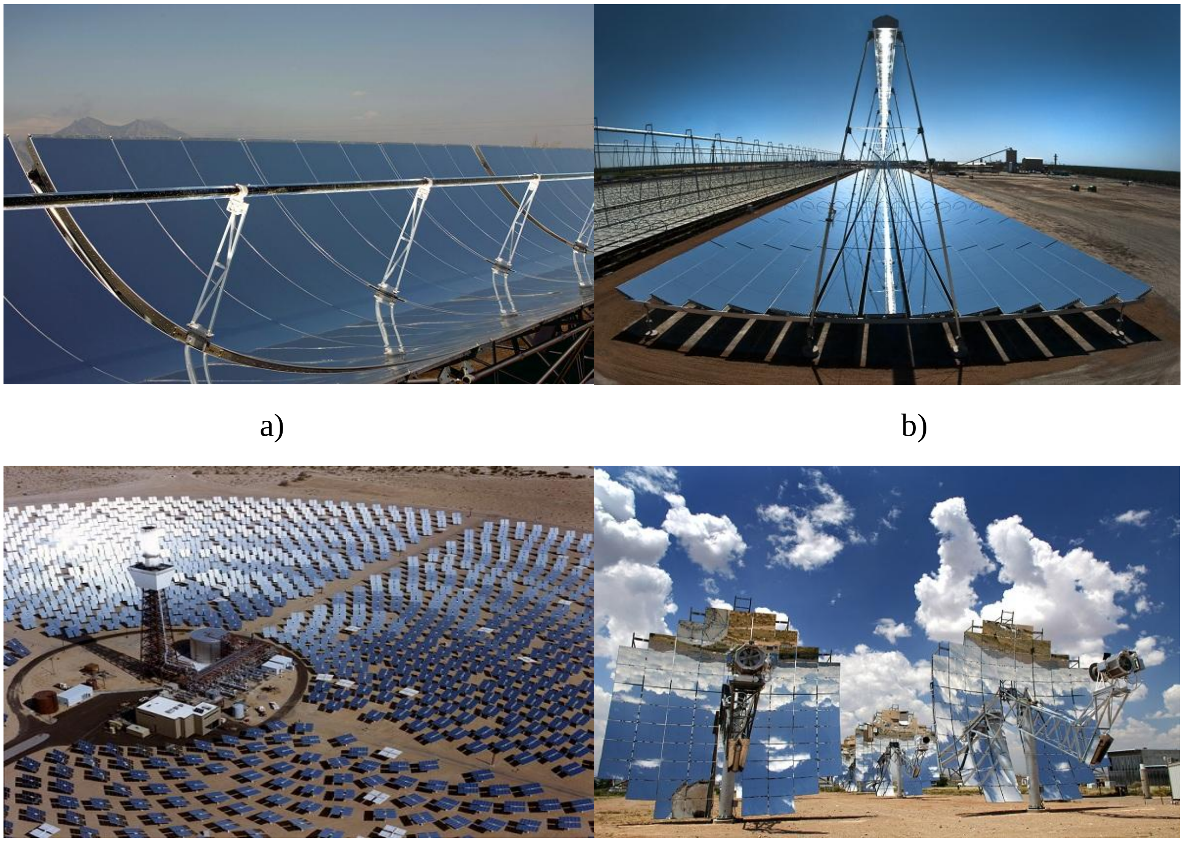
- Open circuit voltage V_{oc}
- Short circuit current I_{sc}
-
- aximum output power V_{mp}, I_{mp}
- Fill Factor $FF = \frac{VmpImp}{VocIsc}$
- Efficiency $\eta = \frac{VmpImp}{Pin} = \frac{VocIscFF}{Pin}$

Parameters V_{oc}, I_{sc}, FF and η are usually given for the standard conditions:

- Spectrum AM 1.5
- Radiation power 1000 W/m^2
- Cell temperature 25 ℃

2.4 Concentrated solar power (CSP)

CSP systems are utility-scale generators that use lenses or mirrors to concentrate (focus) the solar radiation onto a small area (receiver). By using this received heat that drives steam turbine, which then generates the electricity. Nowadays, there are many types of concentrated solar power technologies used. The four most common types are troughs, linear Fresnel reflectors, dishes, towers. All four types are depicted in *Figure 2.5*.



a) b)

c) d)

Figure 2.5 - The four most common types of concentrated solar power systems: a) Parabolic trough b) Compact linear Fresnel reflector c) Solar Tower d) Solar Dishes

- **Parabolic trough (PT)** systems are the most used and developed technologies use large parabolic (U) shaped reflectors (focusing mirrors or lenses) to concentrate sun's rays on heat receivers (i.e. steel tubes). The receiver tube is located exactly along the center (focal point) of a reflector as shown in *Figure 2.5.a)* and is filled up with fluid (e.g. synthetic oil, water or molten salt), something that holds heat well. The reflectors are inclined towards the sun and focus insolation on the tubes to heat the fluid up to the working point, which is around 150-350 °C. The hot fluid is used then to boil water, which creates steam to make conventional steam turbines system work and to generate electricity.
- **Compact Linear Fresnel reflector (CLFR)** systems are based on the similar principles to parabolic trough (PT) systems but the difference is that uses the principle of series of ground based, flat or slightly curved mirrors, which are placed at different angles to concentrate the sun's rays onto fixed receivers located several meters higher above the mirrors *(shown in Figure 2.5.b).* While the Fresnel reflector (FR) system's optical efficiency is lower than parabolic troughs (PT) system's efficiency, its main advantages are the lower cost of the mirrors and solar collectors.
- **Solar Tower (ST)** systems use a central receiver system and consist of many computer-mirrors (called heliostats), which allow to for greater operating temperatures and thus greater efficiencies. The heliostats track the sun individually along two axes and focus solar irradiation onto a receiver, which is mounted on top of a central tower *(shown in Figure 2.5.c).* The concentrated energy is used to heat the working fluid (e.g. synthetic oil, water or molten salt) up to 600 °C to produce steam for further electricity generation or storing for late use. Because of high concentration factors, the solar tower plants can produce higher temperatures then PT and FR plants.
- **Solar Dishes (SD) system** consists of a parabolic dish-shaped concentrator (look like satellite dish) that reflects irradiation onto a receiver and there are mirrors distributed over the dish. *(Shown in Figure 2.5.d).* Unlike other CSP technologies that use steam to create electricity, a solar dish system employs a working fluid such as hydrogen or helium gas. The receiver is placed at the focal point of the dish and can be represented in form of Sterling engine. The sun tracking system of solar

dishes is required to be two-axis and offer high concentration factors thus operating temperatures. The main advantages of solar dishes systems are high efficiency (i.e. up to 30%) and in contrast to other CSP features there is no need of cooling systems for heat exhaust therefore it is suitable for using in water constrained regions.

2.5 Application areas for solar cells. [4]

There are several different types of the sunlight conversion into electricity, which are playing an important role helping us to generate clean energy with the most common types of solar power plants such as using directly PV systems, or indirectly by using concentrated solar power (CSP).

- Photovoltaic power plant system employs solar cells or solar arrays to convert sun’s rays into direct current electricity. The original application areas were employed to power satellites and other spacecraft to provide power for transmission to earth with scientific data and for other power requirements on a board *(Figure 2.6).*

Figure 2.6 - Solar cell array mounted on the spacecraft

In practice, produced direct current can be used to power equipment or charge batteries. Simple photovoltaic systems provide power for small items such as watches and calculators.

Provision of solar energy to entire communities (households) is obviously a concept of great interest. The majority photovoltaic modules are used to grid connected power generation: ČEZ Group commissioned a complex of modern photovoltaic installations in Ralsko.

The group of photovoltaic installations known collectively as FVE Ralsko, which are located a few kilometers apart from each other is located in the territory of the Liberec Region between Mimoň and Mnichovo Hradiště, some 25 kilometers southeast of Česká Lípa. The average yearly sum of global radiation amounts to up to 3,800 MJ/m^2 here and the conditions are therefore suitable to generate electricity from solar radiation.

The photovoltaic installations have the following output: 14.269 MW, 12.869 MW, 6.614 MW, 4.517 MW and 17.494 MW. It is expected to generate an amount of electricity that would cover the consumption of some 15.000 households on the border of Central and Northern Bohemia.

Figure 2.7 - Three Photovoltaic power plants CEZ in Ralsko region

3 Wind energy [5]

3.1 What is conversion of wind energy?

Wind power is the conversion of wind energy (the kinetic energy) into useful form, such as electricity, using wind turbines. In windmills, wind energy is directly used to crush grain or to pump water. At the end of 2012-2016, worldwide capacity of wind-powered generators was 94.1 GW.

Wind power is produced in large-scale wind farms connected to electrical grids, as well as in individual turbines for providing electricity to isolated locations.

Wind energy is plentiful, renewable, widely distributed, clean, and reduces greenhouse gas emissions when it displaces fossil-fuel-derived electricity. The intermittency of wind seldom creates insurmountable problems when using wind power to supply a low proportion of total demand, but it presents extra costs when wind is to be used for a large fraction of demand.

3.2 Operational parameters of a wind turbine

Basically, a wind turbine works on a simple principle - the opposite of a fan. The fan uses electricity to make wind but wind turbines do vice versa. The wind energy turns usually two or three blades, which are placed around a rotor. The rotor is connected to a shaft that spins a generator to produce electricity. Typical operational parameters and components are represented by *Figure 3.1.*

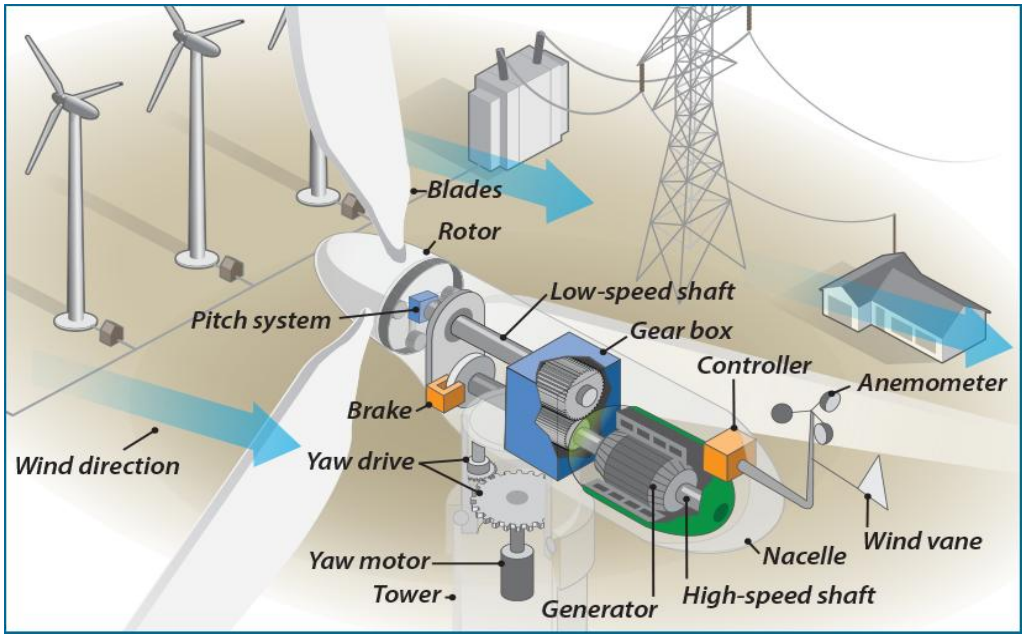


Figure 3.1 - Typical components of a wind turbine

- **Wind direction:** determines the design of the turbine. Up the wind turbines – like the one shown here – face into the wind while downwind turbines turn away.
- **Blades:** lifts and rotates when wind is blown over them, causing the rotor to spin; most turbines have either two or three blades.
- **Rotor:** blades and hub together from the rotor.
- **Pitch system:** turns blades out of the wind to control the rotor speed, and to keep the rotor from turning in winds that are too high or too low to produce electricity.
- **Brake:** stops the rotor, mechanically, electrically, or hydraulically in emergencies.
- **Low-speed shaft:** turns the low-speed shaft at about 30-60 rotations per minute (rpm).
- **High-speed shaft:** drives the generator.
- **Gear box:** connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 30 – 60 rotations per minute (rpm), to about 1000 – 1800 rpm; this is the rotational speed required by most generators to create electricity. The gear box is a costly, heavy part of the wind turbine and engineers are exploring “direct-drive” generators that operate at lower rotational speeds and do need gear boxes.

- **Generator:** produces 50 – cycle AC electricity; it is usually an off-the-shelf induction generator.
- **Controller:** stars up the machine at wind speeds of about 13 to 26 kilometers per hour (km/h) and shuts off the machine at about 88 km/h. Turbines do not operate at wind speeds above 88 km/h because they may be damaged by the high winds.
- **Anemometer:** measures the wind speed and transmits wind speed to the controller.
- **Wind vane:** measures wind direction and communicate with the yaw drive to orient the turbine properly with respect to the wind.
- **Nacelle:** sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for helicopter to land on.
- **Yaw motor:** powers the yaw drive
- **Yaw drive:** orients upwind turbines to keep them facing the wind when the direction changes. Downwind turbines do not require a yaw drive because the wind manually blows the rotor away from it.
- **Tower:** made from tubular steel, concrete or steel lattice; supports the structure of the turbine. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. Typically from 25 to 75 meters in height.

3.3 Types of wind turbines

Nowadays, contemporary wind turbines can be divided into two basic groups, the horizontal-axis and vertical-axis wind turbines. Most modern large wind turbines rotate around horizontal-axis.

- Horizontal axis wind turbine *(HAWT shown in Figure 3.2 a)*

Horizontal axis wind turbines, also called HAWTs, are the most common types and they are similar to windmill. The HAWT turbines have blades like airplane propellers and usually it is used three blades. At the top of the tower is placed the main rotor shaft and electrical generator and can be pointed either up-wind or down-wind. The pointing of small turbines is run by a wind vane whereas big turbines are pointed by a wind sensor connected with servomotor. Great majority wind turbines are equipped with a gearbox, which accelerates slow rotation of a rotor into faster rotation and that is more suitable for a generator. The main advantages of the horizontal axis wind turbines from the efficiency point of view are that tall tower basement allows getting stronger wind thus be more efficient and also since the blades rotate at right angle to the wind, receiving power throughout the whole rotation.

a) b)

Figure 3.2 – a) Horizontal axis wind turbine, b) Vertical axis wind turbine

- Vertical axis wind turbine *(VAWT shown in Figure 3.2b)*

Vertical axis wind turbines, which are also called VAWTs, have different arrangement of the main rotor shaft regarding HAWTs and it is vertically. The blades of a vertical rotor are attached to the top and the bottom. Based on this arrangement, there is an inherent advantage that the turbines do not need to be pointed into the wind for effectiveness, so there is no need for steering into the wind direction. Because of less steering need and independence of wind direction, making the turbines particularly suit to urban areas and can be integrated in many different locations – roofs, along highways and so on. Moreover, such heavy components as generator, gearbox can be installed at ground level. However, vertical axis wind turbines are less efficient than the horizontal axis wind turbines they are might be cheaper to build and easier to maintain.

3.4 How to calculate wind power

Three most important factors that affect the amount of energy a turbine can yield from the wind: wind speed, density of air and swept area of a turbine.

$$P = \frac{1}{2}\rho A V^3$$

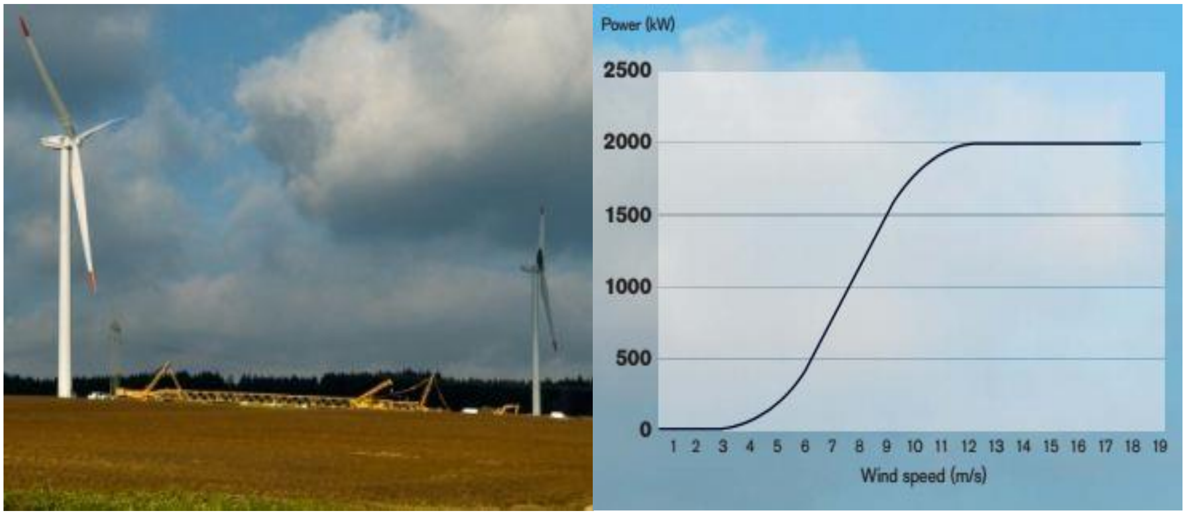
(3.1)

- Wind speed [V] – the amount of energy in the wind is changeable with the cube of its speed. There is eight times more energy in the wind if there is a double of wind speed. Thus, small changes in the wind speed have great in influence on the available amount of power in the wind.
- Density of air [ρ] – the denser the air, the more energy gets turbine. Temperature and elevation have large impact on air density. Air is denser at sea level than at higher levels and cold air is denser than warm air.
- Swept area of the turbine [A] – also called “capture area”, the output power of the wind turbine is directly associated to area covered by its blades. The larger the capture area, the more wind energy the turbine can extract from the wind.

3.5 Technologies and Applications [6]

In general a wind plant is called a power generating object, which consists of several numbers of wind turbines. The typical elements of an onshore wind plant are wind turbines, transmission lines, monitoring facilities and substations. If the wind plant is offshore then we also need port facilities for maintenance. Today, offshore wind plants are gaining higher attention because of supportive ideas that offshore wind plants are faster and more stabilized than onshore ones. There are noticeable differences between offshore and onshore wind plants, which are onshore wind power plants are installed on the lands, more often alongside the coast while offshore plants have to be cabled, operated, installed and maintained in bodies of deep water (50-60 meters). One of the important reasons for installation at water is because of greater capacity utilization as a result of higher wind speeds and the expected energy income that outreaches limitations up to 100 per cent.

- As an example of the onshore wind power plant in the Czech Republic is a modern wind power plants near Věžnice in the territory of the Vysočina region went into operation at the end of 2009 *(represented in Figure 3.3a).*



a) b)

Figure 3.3 – a) Onshore wind power plant in Věžnice, b) The power plant performance

The plant covers the demand of three thousand households around the region and it is operated by ČEZ. Control of wind power plants during normal operation is done remotely through the web interface and the operation is virtually automatic. The plant is equipped with generator operation on 690 V with variable rotation and a converter. This allows the range of available revolutions ±40% of nominal. Therefore maximal system effectiveness is achieved along with rotation controlled by setting the rotor blade's pitch. Thus, the power plant can be operated with almost a constant power output. The output voltage of generator is transformed to 22 kV. Regulation of the revolution speed and power is automatic, individually from speed of wind and of the current strength. Output parameters – nominal electrical power (PN) is 2050 kW, power factor ~ 1, nominal voltage (UN) – 690

V, nominal frequency (fN) – 50 Hz, nominal current (IN) – 1715 A, nominal generator revolutions – 1800 rpm.

4 Hydropower plant

4.1 Introduction to hydropower

Hydropower is a mature and one of the most promising renewable energy technologies. In the context of DP, small (less than 10 MW), mini (less than 1 MW), and micro (less than 100 kW) hydroelectric plant of interest. The source of hydropower is the hydrologic cycle driven by the energy from the sun. Most of the sites for DP hydro are either low head (2 to 20 m) or medium-head (20 to 150 m).

Both impulse and reaction turbines have been employed for small-scale hydro for DP. Several standardized units are available in the market. Most of the units are operated at constant speed with governor control and are coupled to synchronous machines to generate ac power. If the water source is highly variable, it may be necessary to employ variable-speed generation. Similarly to variable wind generation, variable-speed hydro generation utilizes back-to-back power electronic converters to convert the variable generator output to constant-frequency ac power. In a very small system of a few, it may be required to install energy storage on the dc link of the power electronic converter.

- *Figure 4.1* shows the most common type of hydroelectric power plant, that is an Impoundment (Conventional) and its main parts.

4.2 Operational principles of an impoundment hydropower plant

Basically it is hydropower system that uses a dam to keep water as potential energy in it subsequently water driving a turbine and generator. Water released from the reservoir flows through a turbine, which then activates a generator to produce electricity.

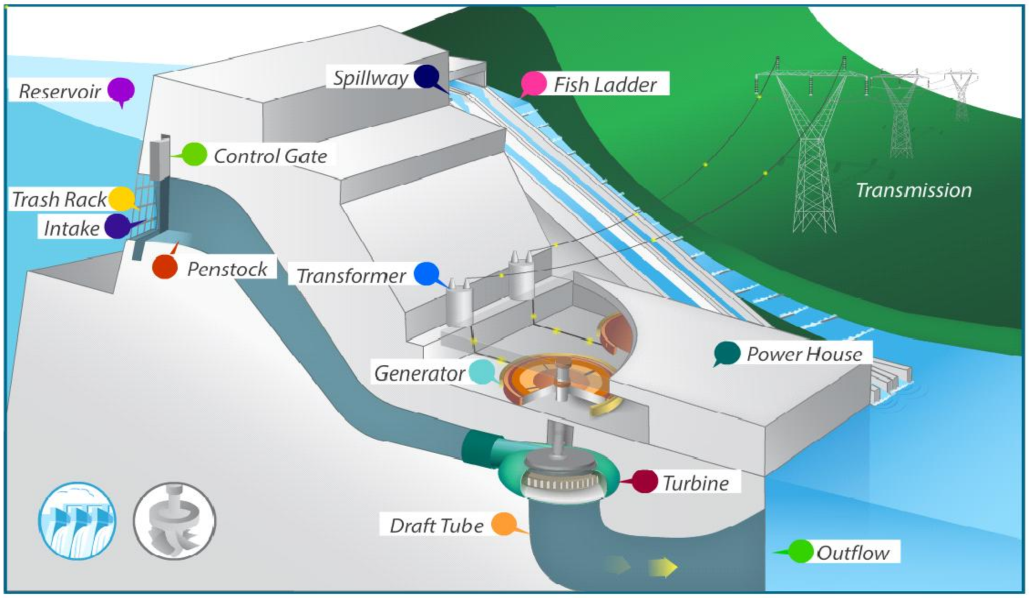


Figure 4.1 - Main parts of conventional hydropower plant

Reservoir: This is the body of water that builds up behind many dams. The stored energy that is contained in the reservoir is converted into kinetic energy once the control gate opens and the water flows through it.

Trash Rack: A screen typically comprised of metal or concrete bars that prevents debris from entering penstock.

Intake: The section of the reservoir immediately in front of the control gate where water is drawn into the penstock.

Penstock: Water travels into this channel from the intake, forcing it to run through the turbine.

Control Gate, Turbine: As water runs through the blades of the turbine, it forces them to spin, turning a shaft that is connected to the generator. Pictured is Francis, the most common type of hydropower turbine. Kaplan and Pelton are the other major hydropower turbine types.

Spillway: This structure allows water to be released in a controlled fashion from the dam downstream into the river, controlling flood situations – "a safety valve" for the facility.

Fish Ladder: This structure allows fish to migrate past a dam by providing them a series of steps to swim and leap up to reach the other side of the dam.

Transformer: Here the electricity produced is converted to a higher voltage to travel into the transmission grid.

Generator: As the turbine runner is moved by water the connected shaft spins he generator producing the electricity.

Power House: This section houses the generators, turbines, and the controls.

Draft Tube: After water exits the turbine the draft tube slows down the water to keep the turbine under a more constant pressure, which increases turbine efficiency.

Outflow: The measure of water released from the dam during a certain period, typically expressed as acre-feet per day or cubic feet per second.

Transmission: Here the electricity produced is converted to a higher voltage to travel into the transmission grid.

4.3 The Orlík hydro power station parameters [7]

Typical type of such a hydropower plant as an impoundment is represented in Figure 4.2, in the Czech Republic, so called the Orlík.

The fundamental part of Vltava Cascade is the Orlík hydroelectric power plant. The reservoir, holding 720 m^2 of water, it is the largest capacity storage reservoir in the Czech Republic and together with the Lipno reservoir, it is crucial for multi-annual water-flow regulation of Vltava River and the lower Elbe. The reservoir surface area is 26 km^2 and it raises Vltava River level for 70 km, the Otava level over 22 km and the Lužnice over 7 km upstream of the confluence with Vltava River. The concrete gravity dam is 91.5 m high and 450 m wide at the crest. The body of the dam has three 15 m x 8 m spillways with the capacity of 2184 m^3/s, and two bottom outlets, 4m in diameter. The 20 m high and 17 m x 127.5 m hydroelectric power station is situated in the left part of the river at the heel of the concrete dam. The water is delivered to turbine units by four steel pipelines, 6250 mm in diameter. The plant is equipped with four fully automatic Kaplan turbines and with 70.5 m head, each rated at 91MW. The generation of a 15 kV electric energy is transformed to 220 kV in six phase transformer sets.

Figure 4.2 - hydroelectric power station Orlík in the Czech Republic

4.4 Main turbine components

The Stator *(Figure 4.3)*, often made of a series of magnets, is the stationary part of a rotary generator system. The water moves runner, which spins the shaft and the conductive rotor inside the stationary magnetic stator producing an alternating electric current.

The Rotor *(Figure 4.3)*, often made of copper wire or other conductive material, is the spinning part of a rotary generator system.

The Shaft *(Figure 4.3)*, connects the turbine with generator.

The Blades of Turbine *(Figure 4.3)*, are known as the runner, and their shape determines the flow of water and amount of energy extracted.

The Wicket Gate *(Figure 4.3)*, is used to focus the flow of water directly onto the turbine blades, which are also called the runner.

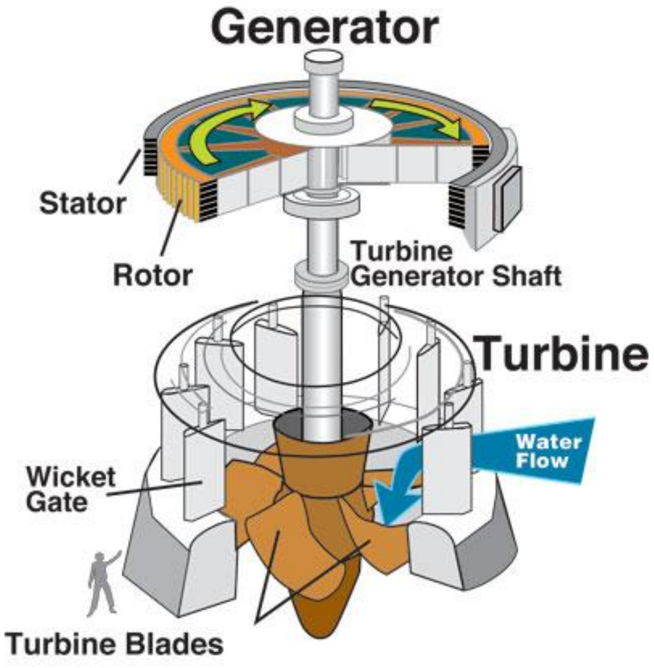


Figure 4.3 - Main Turbine Components

4.5 Calculating the hydroelectric power

The power available from falling water can be calculated from the flow rate and density of water, the height of fall, and the local acceleration due to gravity. In SI units, the power is:

$$P = \eta \rho Q g h$$

P is power in watts

η is the dimensionless efficiency of the turbine

ρ is the density of water in kilograms per cubic meter

Q is the flow in cubic meters per second

g is the acceleration due to gravity

h is the height difference between inlet and outlet in meters

4.6 Pumped-Storage plant

Another type of electric power system so called pumped storage, which works like accumulator, it stores the generated electricity by other power sources. This method is based on producing electricity at high peak demands by pumping water from lower elevation reservoir to higher elevation. When the demand for electricity is low, the excess generation capacity is used to store energy at higher elevation by pumping water from lower reservoir to higher one. Diagram of pumped-storage facility is represented in *Figure 4.4.*

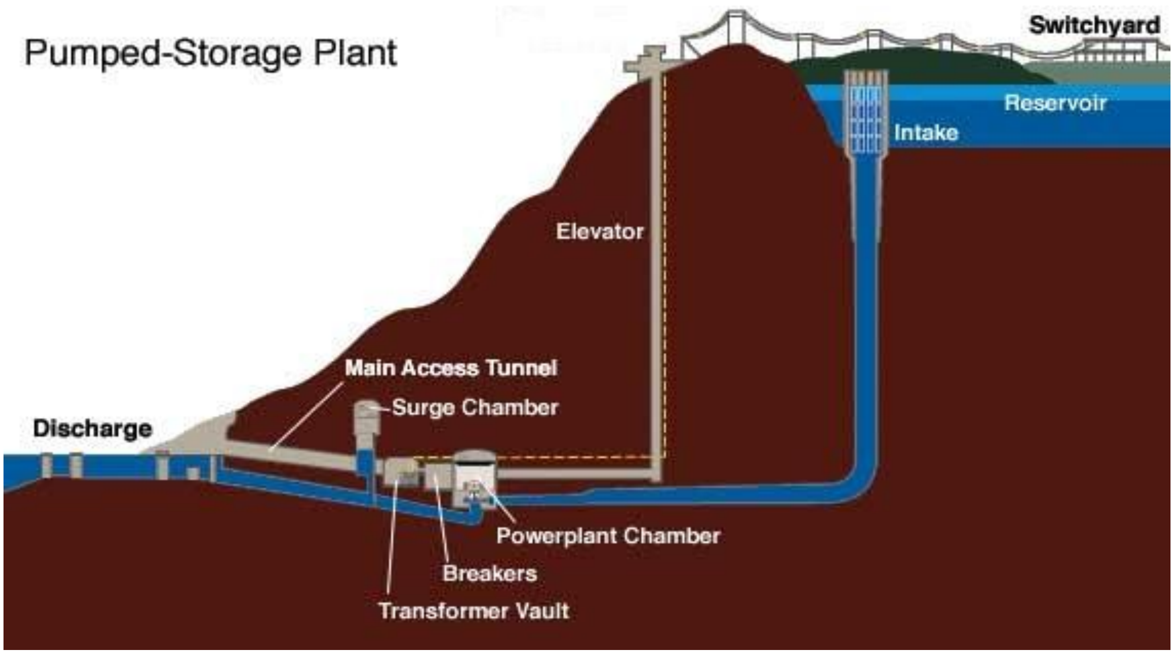


Figure 4.4 - Diagram of pumped-storage facility

One of the Great examples of pumped-storage plant in the Czech Republic is the Dlouhé Stráně hydro power station (represented in Figure 1.8). The power station is located on the Desná River, which is in Moravia, near Loučná nad Desnou in the district of Šumperk.

4.6.1 Basic operational principles

The power plant fulfills three considerable functions in the electric power system, such as static, dynamic and compensation. All these functions are very beneficial and advantageous. The static function means the converting of excess energy to peak-load energy – at the time of surplus electricity in the network (specifically at night) the water is pumped from the lower reservoir to the upper one and during the peak periods, when there is a time of power shortage, the turbines are used to generate electricity. The dynamic function of the pumped-storage hydroelectric power plant means functioning as a power reserve in the system to generate regulating output and energy, and participating in the frequency regulation of the system. The compensation function is for voltage regulation in the power system.

4.6.2 The Dlouhé Stráně hydropower station characteristics [8]

The upper storage reservoir is connected to the underground power station with two penstocks, each has one turbine. The penstocks are 1547 m and 1499 m long. Two discharge tunnels, 5.2 m in diameter that are connected between the power plant and lower storage reservoir. The length of the tunnels is 354 m and 390 m. The lower reservoir is on the Divoká Desná River and its total capacity is 3.4 million m^3. The upper reservoir is located top of the Dlouhé Stráně mountain at1350 m above sea level. Its total capacity is 2.72 million m^3.

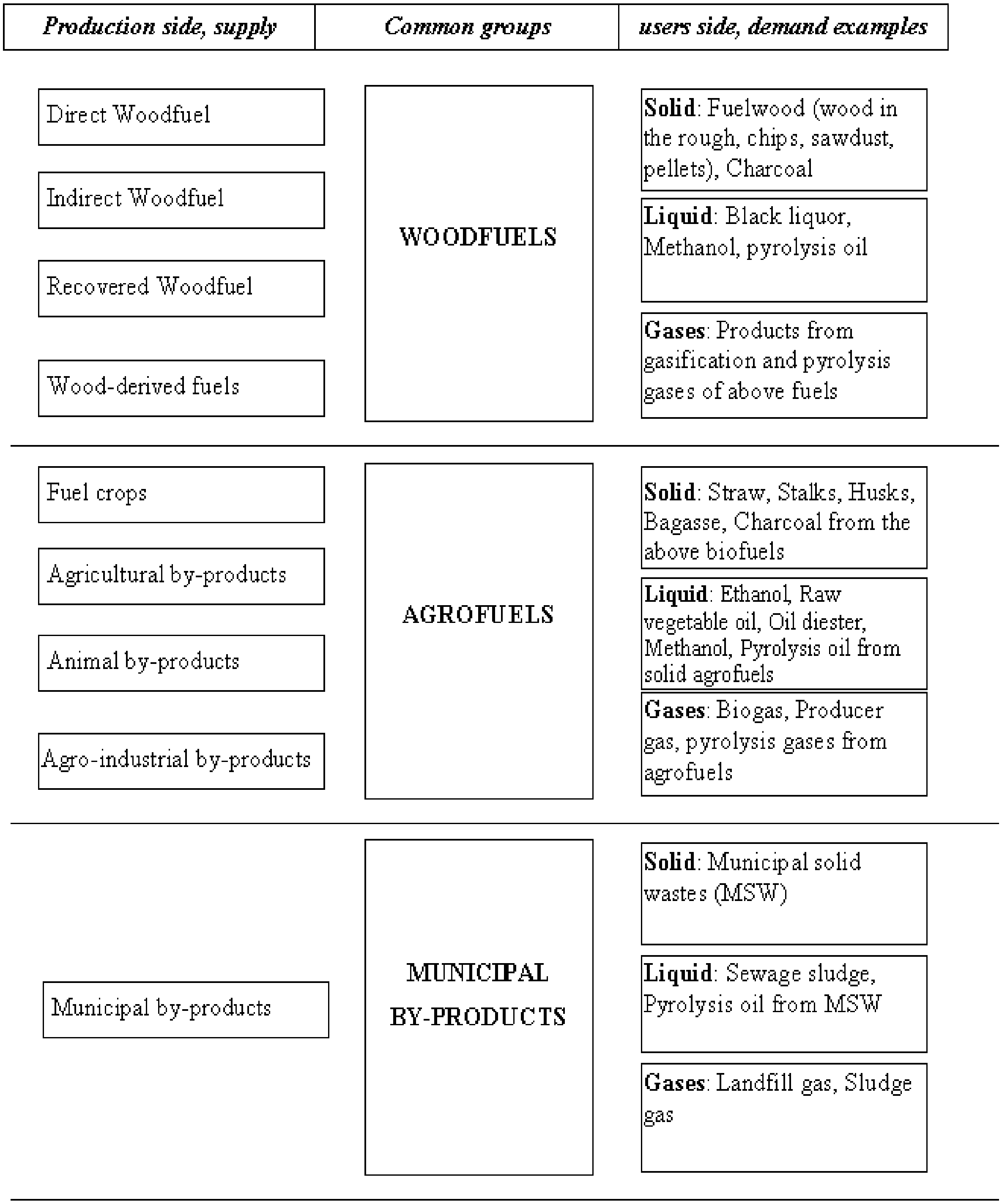
The station is provided by two reversing turbines each with a nominal power 325 MW. The turbine types, Reversing Francis turbine FR 100. The output power of the reversing turbine in the pumping mode is 312 MW whereas in the turbine mode is up to 325 MW.

The Dlouhé Stráně hydro power plant is shown in *Figure 4.5.* It has three hard advantages: the largest turbine unit with reversing turbine in Europe (325MW), it has the largest water head of all power plants in Europe (510.7m) and it is the biggest installed capacity in the Czech Republic (650MW).

Figure 4.5 - The Dlouhé stráně hydropower station

5 Biomass Energy. Biofuel classification

Biomass is organic matter derived from plants or plant based materials, residues from forestry and agriculture, and the organic constituent element of industrial and urban wastes. For thousands of years mankind has been used wood to provide heat for many purposes. Biological sources provide a wide array of materials that have been and continue to be used as energy sources. *Table 5.1* represents the biofuel classification.



Production side, supply	***Common groups***	***users side, demand examples***
Direct Woodfuel Indirect Woodfuel Recovered Woodfuel Wood-derived fuels	**WOODFUELS**	**Solid**: Fuelwood (wood in the rough, chips, sawdust, pellets), Charcoal **Liquid**: Black liquor, Methanol, pyrolysis oil **Gases**: Products from gasification and pyrolysis gases of above fuels
Fuel crops Agricultural by-products Animal by-products Agro-industrial by-products	**AGROFUELS**	**Solid**: Straw, Stalks, Husks, Bagasse, Charcoal from the above biofuels **Liquid**: Ethanol, Raw vegetable oil, Oil diester, Methanol, Pyrolysis oil from solid agrofuels **Gases**: Biogas, Producer gas, pyrolysis gases from agrofuels
Municipal by-products	**MUNICIPAL BY-PRODUCTS**	**Solid**: Municipal solid wastes (MSW) **Liquid**: Sewage sludge, Pyrolysis oil from MSW **Gases**: Landfill gas, Sludge gas

Table 5.1 – biofuel classification scheme

5.1 Conversion Technologies

The most compelling argument for the use of biomass technologies is the inherent recycling of the carbon by photosynthesis and amount of energy extracted from biomass can compete with other non-renewable energy sources (primary energy sources – particularly coal). In addition to the obvious method of burning biomass, conversion to liquid and gaseous fuels is possible, thus expanding the application possibilities.

In the context of electric power generation, the role of biomass is expected to be for repowering old units and for use in small (2 to 5 MW) new plants. Biomass technologies decompose organic matter in order to release the stored energy of the sun. The using process depends on the type of biomass and also on intended end use. Several new high-efficiency conversion technologies are either already available or under development for the utilization of biomass.

There are several high-efficiency options of conversion technologies currently developed for the utilization of a wide range of biomass types as renewable power sources. Conversion technologies can be used to release energy either directly, in the form of electricity or heat, or may be converted into other forms, for instance – combustible biogas or as liquid biofuel. Whilst for several types of biomass recourses there may be different utilization options, for others there may be only one corresponding technology. The technologies and their overall conversion efficiencies are listed in the next chapter.

5.2 Thermal Conversion

Thermal conversion term implies the involving of heat utilization as the primary mechanism for converting the biomass into another chemical form. The main technologies of thermal biomass conversion are conventional combustion, fluidized-bed combustion, co-firing, co-generation and pyrolysis.

Conventional combustion

Conventional combustion is the burning of flammable biomass materials in the presence of oxygen. Typically to create steam in order to use for driving turbines and producing electricity or in district/cooling systems are furnaces and boilers. In a furnace, there is combustion chamber where biomass is burned and converted into heat. Afterwards, the heat is distributed either in the form of water or hot air. In a boiler, the heat is converted into high-pressure steam, where the steam is introduced into a steam turbine, as result the turbine rotates and produces electricity, mechanical energy or cooling and heating.

FBC (fluidized-bed combustor)

FBC is also the combustion technology, which is used about 36 to 38% in the Czech Republic. Its basic form represents suspended solid fuels in a bubbling fluidity bed of ash and other particular materials such as sand, limestone etc. In order to provide the required oxygen for combustion or gasification, jets of air are blown through the materials. This technology burns biomass fuels at combustion temperatures of 500 to 900 °C. The obtained rapid and intimate mixing of solids and gas provides fast transfer of heat and chemical reactions in the bed. Fluidized-bed combustor offers burning of many low-grade solid/feedstock fuels at high efficiency and without the need for expensive preparation. There are two reasons why the FBC technology is rapidly increasing. The first, generally it is not depending on choice of fuels and (First, the liberty of choice in respect of fuels in general, not only the possibility of using fuels which are difficult to burn using other technologies, is an important advantage of fluidized bed combustion.) The second advantage is that during combustion there is possibility to achieve low emissions of nitric oxides and it reduces the amount of emitted sulfur in the form of SO_x emissions.

Co-firing

Co-firing implies the combustion of two dissimilar types of materials such as natural gas or coal with a biomass feedstock in the same time and same system. The co-firing plants have several advantages such as if conversion facility/unit is located beside an agro-industrial or forestry product processing plant, big amounts of low-cost biomass residues are obtainable for burning with fossil-fuel feedstock and when the output of the plant is electricity especially. Nowadays it is normal that fossil-fuel plants are generally highly polluting from the point of view CO_2 and greenhouse gases. Use of existing equipment, with modifications, to co-fire biomass may be a cost-effective that means for meeting more stringent emissions targets. Biomass fuel's comparatively low sulfur content allows biomass to potentially offset the higher sulfur content of fossil fuel

Cogeneration (Combined heat and power)

Advanced technologies like cogeneration can be described as the simultaneous production of thermal energy and electricity through a combined heat and power (CHP). Most beneficially and efficiently biomass fuels are typically used when generating heat and power through the cogeneration system. A typical combined heat and power system provides:

- Distributed generation of electrical and/or mechanical power.
- Waste-heat recovery for heating, cooling, or process applications.
- Seamless system integration for a variety of technologies, thermal applications, and fuel types into existing building infrastructure.

The supply of high-temperature heat drives first a gas or steam generator and the resulting low-temperature waste heat is after used for water or space heating.

6 Geothermal, Tidal energy, Fuel cells, Solar-Thermal electric conversion

Geothermal

Geothermal plants exploit the heat stored in the form of hot water and steam in the Earth's crust at depths of 800 to 2000 m. By nature, these resources are extremely site-specific and slowly run down (depletable) over a period of years. For electric power generation, the resource should be at least around 200–C. Depending on the temperature and makeup, dry steam, flash steam, or binary technology can be employed. Of these, dry natural steam is the best, since it eliminates the need for a boiler.

The three basic components of a geothermal plant are: (1) a production well to bring the resource to the surface, (2) a turbine generator system for energy conversion, and (3) an injection well to recycle the spent geothermal fluids back into the reservoir.

The typical size of backpressure plants ranges from 1 to 10 MW. Indirect and binary cycle plants are usually in the 10 to 60 MW range, while condensing units are on the order of 15 to 110 MW. The variable size and nature of geothermal generation plants has the advantage of enabling units to be installed in modules.

Tidal energy

The origin of tidal energy is the upward-acting gravitational force of the moon, which results in a cyclic variation in the potential energy of water at a point on the Earth's surface. Topographical features, such as the shape and size of estuaries, amplify these variations. The ratio between maximum spring tide and minimum at neap can be as much as three to one. In estuaries, the tidal range can be as large as 10 to 15 m.

Power can be generated from a tidal estuary in two basic ways. A single basin can be used with a barrage at a strategic point along the estuary. By installing turbines at this point, electricity can be generated either when the tide is ebbing or flooding. In the two-basin scheme, generation can be time-shifted to coincide with hours of peak demand by using the basins alternately.

This is the only form of energy, which comes from the motion of the Earth-Moon system, though some of it comes from the solar tides as well. Tidal energy is generated by the relative motion of the Earth, Sun and the Moon, which interact via gravitational forces. Due to these gravitational forces, water levels follow periodic highs and lows. Associated with these water level changes, there are tidal currents. The specific tidal motion produced at a certain location is the result of the changing positions of the Moon and Sun relative to the Earth, the effects of Earth rotation, and the local shape of the sea floor.

The tidal energy generator uses this phenomenon to generate energy. The stronger the tide, either in water level height or tidal current velocities, the more promising it is to harness tidal energy.

Fuel cells

A fuel cell is an electrochemical energy conversion device. It produces electricity from various external quantities of fuel (on the anode side) and oxidant (on the cathode side). These react in the presence of an electrolyte. Generally, the reactants flow in and reaction products flow out while the electrolyte remains in the cell. Fuel cells can operate virtually continuously as long as the necessary flows are maintained.

Fuel cells are different from batteries in that they consume reactant, which must be replenished, while batteries store electrical energy chemically in a closed system. Additionally, while the electrodes within a battery react and change as a battery is charged or discharged, a fuel cell's electrodes are catalytic and relatively stable.

Many combinations of fuel and oxidant are possible. A hydrogen cell uses hydrogen as fuel and oxygen as oxidant. Other fuels include hydrocarbons and alcohols. Other oxidants include air, chlorine and chlorine dioxide.

Solar-Thermal electric conversion

Solar thermal energy is a technology for harnessing solar_energy for heat. This is very different from solar photovoltaic, which convert solar energy directly into electricity. Solar thermal collectors are characterized by the US Energy Information Agency as low, medium, or high temperature collectors. Low temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for creating hot water for residential and commercial use. High temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production.

7 The rules for connecting dispersed energy sources to the distribution system

While renewable energy systems are capable of powering houses and small businesses without any connection to the electricity grid, many people prefer the advantages that grid-connection offers.

A grid-connected system allows you to power your home or small business with renewable energy during those periods (daily as well as seasonally) when the sun is shining, the water is running, or the wind is blowing. Any excess electricity you produce is fed back into the grid. When renewable resources are unavailable, electricity from the grid supplies your needs, eliminating the expense of electricity storage devices like batteries.

In addition, power providers (i.e., electric utilities) in most states allow net metering, an arrangement where the excess electricity generated by grid-connected renewable energy systems "turns back" your electricity meter as it is fed back into the grid. If you use more electricity than your system feeds into the grid during a given month, you pay your power provider only for the difference between what you used and what you produced.

Connection conditions [9],[10]

Connection of small power plant (distributed sources) to the distribution network may be at low voltage level (0.4 kV) and at medium level (22, 35 kV), depending on the total power of the power plant, the nominal power of the generator, the circumstances of the distribution network , the power plants operation mode and other factors.

Connection to a low-voltage network:

- A power plant up to 50 kW - at the low voltage line or low voltage buses of 22 / 0.4 kV substation,
- A power plant up to 100 kW - at the medium-voltage network (22, 35 kV):
- A power plant up to 1000 kW - at the medium voltage line,
- A power plant over 1000 kW - at the medium or high voltage line, input-output system.

A possible way of connecting the power plant to the distribution network is determined by a detailed techno-economic analysis to define the optimal solution in terms of connection costs and the impact of production facilities on the distribution system. The final evaluation of the capabilities and mode of connection of distributed sources to the distribution network has been adopted with regard to the state and expected development of the distribution network, and after calculation of voltage drops, load flow, short circuit current and total harmonic voltage distortion. Defining the conditions for connection to the distribution network ensures reliability of the electric power system and user facility, and avoids at the same time unacceptable detrimental effects between them. Technical requirements for connection of generating units to the distribution network are delivered by the distribution system operator. The Grid System Rules define the basic features at the connection point to the distribution network and general requirements for the connection of system users to the distribution system, as well as special conditions to be met by all generating units connected to the distribution system under normal operating conditions. The distribution system operator defines the basic technical information relevant to the design of manufacturing plants:

- Available capacity
- Data for insulation coordination
- Concept of protection (fault clearance time in the user's facility with the primary and backup protection)
- Maximum and minimum short circuit power
- Terms of parallel operating with electric power systems
- The share of higher harmonics and flickers towards the principles for determining the effect on the system
- Breaking capacity for the corresponding nominal voltage of the transmission network
- Way of earthing,
- Maximum and minimum continuous operating voltage, the duration and level of short-term overdraft,
- Typical load profiles,

- Nature and extent of reactive power exchange, and installed reactive power reserve into the user's facility, for the production and delivery of energy, power plant must generate a sufficient quantity of reactive power. Production of reactive power should be in the range of cos φ = 0.85 inductively to cos φ = 1, except for solar power plants, where such a claim does not arise, and wind farms with asynchronous generators for which it is expressed in additional terms of Grid System Rules,
- Stake in the plan of the defense system (under frequency load shedding, under voltage shedding, manual and automatic control)
- Share in securing ancillary services,
- Behavior in large-scale disturbances (the ability to pass through a state of failure)
- The method of measurement and calculation
- Integration into the remote control system
- Integration into the telecommunication system

7.1 Criteria for connecting electricity generating plants to the distribution network ČEZ supplier.

Way to connect electricity generating plants to the distribution network determines the network operator. When connecting to evaluate the effects of backward production plant to the distribution system of low or high voltage. They will cover the following feedback effects:

- Change Voltages when operating an electricity generating plant
- Change Stress during switching
- long term flicker
- Current harmonics
- Influence to device ripple control (HDO)
- Influence to short-circuit conditions

For photovoltaic plants are judged mainly voltage changes in the operation of the electricity generating plant, issued by harmonic currents and the effect on ripple control devices.

Voltage changes in the operation of the electricity generating plant.

PPC variations in voltage caused by connecting or disconnecting the electricity generating plant must not be at the medium voltage level (22 kV) exceed. Voltage change in the distribution of medium voltage by connecting electricity generating plant at the connection point (PCC) must not exceed 2%.

Variation in voltage distribution system low voltage by connecting electricity generating plant at the connection point (PCC) must not exceed 3%. Voltage changes when switching electricity generating plant 3%.

PPC variations in voltage caused by connecting or disconnecting the electricity generating plant must not be connected to low voltage (0.4 kV) exceed 2%.

These limits apply only to the case where switching is more frequent as once every 1.5 min., Which is at most plants using RES respected.

Most mass-produced dispersion of resources should have in their technical dossier factor information flicker. The amount of this quality parameter depends on the uniformity of the equipment operation. Generally, machines with great energy of rotating masses have little flicker factor and therefore not a source of flicker, for example: turbo generators and hydro generators. Problematic are the production of electricity from renewable sources, where it reaches a factor of flicker to 40. The highest values achieved without wind power converters and a small number sheets. Photovoltaic plants are generally deemed to be devices with very low duty flicker.

From the perspective of long-term rates flicker at each connection point to observe the following limits:

Term flicker effect can be determined by short-circuit power networks and rated apparent power of the connected source.

When flicker factor is declared by the equipment manufacturer.

7.2 Power Quality. Parameters [11]

Power quality is a characteristic of electricity at a certain point of the power system and it is usually considered as continuity of supply (availability of electricity) and voltage quality. Ideally, the best electrical supply would be a constant magnitude and frequency sinusoidal voltage waveform. However, because of the non-zero impedance of the supply system, of the large variety of loads that may be encountered and of other phenomena such as transients and outages, the reality is often different. The Power Quality of a system expresses to which degree a practical supply system resembles the ideal supply system.

- If the Power Quality of the network is good, then any loads connected to it will run satisfactory and efficiently. Installation running costs and carbon footprint will be minimal.
- If the Power Quality of the network is bad, then loads connected to it will fail or will have a reduced lifetime, and the efficiency of the electrical installation will reduce. Installation running costs and carbon footprint will be high and/or operation may not be possible at all.

The following main contributors to Low Voltage poor Power Quality can be defined:

- Reactive power, as it loads up the supply system unnecessary
- Harmonic pollution, as it causes extra stress on the networks and makes installations run less efficiently
- Load imbalance, especially in office building applications, as the unbalanced loads may result in excessive voltage imbalance causing stress on other loads connected to the same network, and leading to an increase of neutral current and neutral to earth voltage build-up
- Fast voltage variations leading to flicker

7.2.1 Parameters and Terminology of PQ

Reactive power and power factor (cos φ)

In an AC supply, the current is often phase-shifted from the supply voltage. This leads to different power definitions (Figure 7.1):

- The active power P [kW], which is responsible of the useful work, is associated with the portion of the current which is in phase with the voltage.
- The reactive power Q [kvar], which sustains the electromagnetic field used to make e.g. a motor operate is an energy exchange (per unit of time) between reactive components of the electrical system (capacitors and reactors). It is associated with the portion of the current which is phase shifted by 90° with the voltage.
- The apparent power S [kVA], which gives a geometrical combination of the active and of the reactive powers, can be seen as the total power drawn from the network.

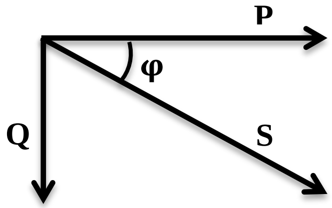


Figure 7.1 – Basic Power in AC systems

The ratio between the active power and the apparent power if often referred to as the displacement power factor or cos(φ), and gives a measure of how efficient the utilization of the electrical energy is. A cos(φ) that equals to 1 refers to the most efficient transfer of useful energy. A cos(φ) that equals to 0 refers to the most inefficient way of transferring useful energy.

Harmonic Distortion

The harmonic pollution is often characterized by the Total Harmonic Distortion or THD which is by definition equal to the ratio of the RMS harmonic content to the fundamental:

$$\mathrm{THDV} = \frac{\sqrt{\mathrm{V}_{\mathrm{RMS}}^2 - \mathrm{V}_1^2}}{\mathrm{V}_1} = \frac{\sqrt{\sum_{\mathrm{k}=2} V_k^2}}{V_1},$$

(7.1)

where V_k is the k-th harmonic component of the signal V.

This quantity, expressed in %, is very useful when the fundamental value component is implicitly given or known. Consequently, the THD is particularly relevant information for the voltage (as the rated voltage is known). In order to be able to gauge THD of the current, it is imperative that a fundamental frequency current reference be defined.

Voltage unbalance

A normal three phase supply has the three phases of same magnitude but with a phase shifted by 120°. Any deviation (magnitude or phase) of one of the three signals will result in a negative phase sequence component and/or a zero phase sequence component. The definition of voltage unbalance is usually expressed as the ratio between the negative phase sequence component and the positive phase sequence component. This parameter is expressed in %.

Flicker

According to the International Electrotechnical Vocabulary (IEV) of the International Electrotechnical Committee (IEC), flicker is defined *as 'Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time'*. From a more practical point of view one can say that voltage fluctuations on the supply network cause change of the luminance of lamps, which in turn can create the visual phenomenon called flicker. While a small flicker level may be acceptable, above a certain threshold it becomes annoying to people present in a room where the flicker exists. The degree of annoyance grows very rapidly with the amplitude of the fluctuation. Further on, at certain repetition rates of the voltage fluctuation, even small fluctuation amplitudes can be annoying. The influence of the flicker phenomenon on people is complex to analyze given that it depends not only on technical aspects like the lamp characteristics to which the fluctuating voltage is applied but also on the appreciation of the phenomenon by the eye/brain of each individual.

8 A case study for the selected part of the medium voltage distribution system. [12]

Distribution network characteristics:

Distribution line 22 kV.

Main source for calculation is distribution network of 110 kV that feeds to one transformer to 110/22 kV, the transformer has apparent capacity 25 MVA and it supply 22 kV network.

We make the calculation for maximum load and maximum power generation in PVPP.

Outline of the line.

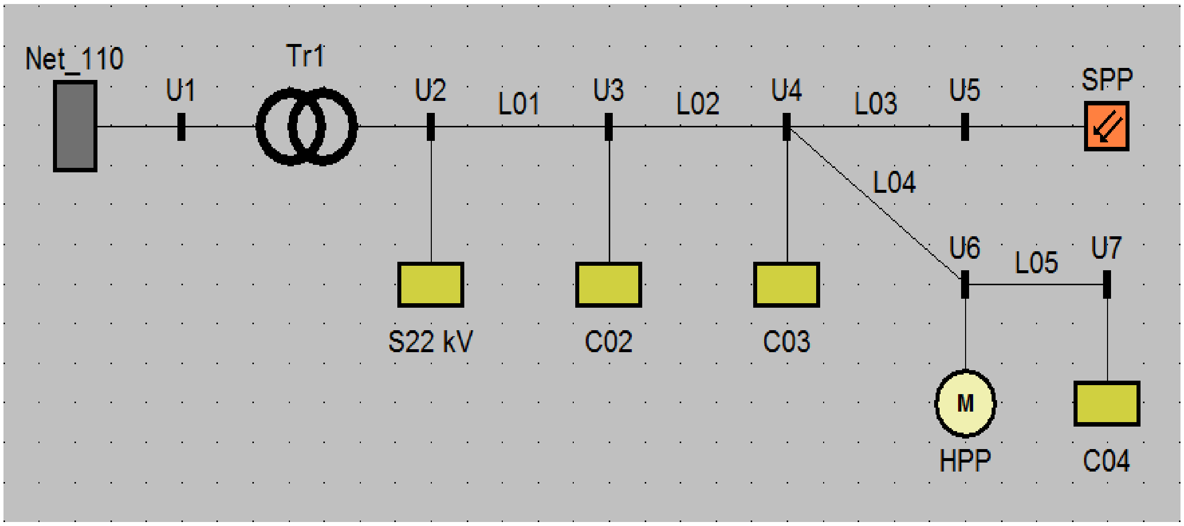


Figure 8.1 – Network topology

Input parameters:

Overhead lines

Name of line	Begin of line	End of line	Distance [km]
L01	U2	U3	5
L02	U3	U4	5
L03	U4	U5	5
L04	U4	U6	5
L05	U6	U7	5

Table 8.1

Parameters of overhead lines

Name of line	Type	R (Ω/km)	X (Ω/km)	B (µS/km)	I_{max} (A)
L01 – L05	95AlFe6	0.301	0.374	1.448	289

Table 8.2

Transformer parameters

Manufacturer	Type	U_{n1} (kV)	U_{n2} (kV)	S (MVA)	Pk (kW)
Škoda	8 ERH 31 M-O	110	23	25	140

Table 8.3

Consumption

Name of consumption	**Number of Node**	**Installed Power (kVA)**	**Maximum load (kVA)**
S22 kV	**U2**	**20000**	**12000**
C02	**U3**	**630**	**400**
C03	**U4**	**630**	**500**
C04	**U7**	**400**	**300**

Table 8.4

Calculation results:

Voltage difference before and after connection to the Photovoltaic Power Plant (PVPP).

	dU before [%]	**dU after [%]**	**Difference**
U1	-4.456	-4.491	-0.037
U2	-8.969	-9.047	-0.119
U3	-8.458	-9.101	-0.660
U4	-8.099	-9.308	-1.225
U5	-8.100	-9.872	-1.792
U6	-7.931	-9.141	-1.226
U7	-7.816	-9.028	-1.227

Table 8.5

Commentary:

Difference of voltage before and after connection PVPP with capacity 2100kV to distribution line 22 kV is 1.792 % and it does not exceed the limit, which is 2% by Czech standards.

Voltage difference before and after connection the Hydropower plant.

	dU before [%]	dU after [%]	Difference
U1	-4.494	-4.491	0.003
U2	-9.053	-9.047	0.011
U3	-9.161	-9.101	0.061
U4	-9.421	-9.308	0.115
U5	-9.985	-9.872	0.115
U6	-9.309	-9.141	0.170
U7	-9.196	-9.028	0.170

Table 8.6

Commentary:

Voltage difference in connection point induced with hydropower plant before and after connection with capacity 2100kV to distribution line 22 kV is 0.17% and it is in limit 2% by Czech standards.

8.1 Conclusion of the case study

I accomplished in detailed calculations of voltage changes within the distribution network of 22 kV. Voltage changes were within the Czech standards. Due to not having the harmonics' data from manufacturers, I supposed that the values of harmonics in the solar power plant and hydro power plant are relevant to the Czech standards. In case of PVPP connection to the distribution network there is 1.792% voltage difference from the nominal voltage before connection, and in case of hydro power plant connection to the system there is a 0.17% voltage difference from the nominal. Although the percentage voltage difference are in the range of 2% of the Czech norms, it is possible to conclude – according to the case study presented/calculated – that a connection of a hydro power plant is more feasible to a distribution system due to small voltage differences from the voltage before the connection, which means that it is better for the distributor, since there are less voltage losses and consequentially less financial losses in terms of electrical distribution.

9 Bibliography/References

- [1] Distribution network codes
- [2] https://moodle.fel.cvut.cz/pluginfile.php/41743/mod_resource/content/1/SVS-A-02%20Holovsky%202016-02-28.pdf
- [3] https://moodle.fel.cvut.cz/pluginfile.php/41743/mod_resource/content/1/SVS-A-02%20Holovsky%202016-02-28.pdf
- [4] https://www.cez.cz/en/power-plants-and-environment/solar-power-plants/ralsko.html
- [5] https://www.energy.gov/eere/wind/how-do-wind-turbines-work
- [6] https://www.cez.cz/en/power-plants-and-environment/wind-power-plant/veznice.html
- [7] https://www.cez.cz/en/power-plants-and-environment/hydraulic-power-plants/orlik.html
- [8] https://www.cez.cz/en/power-plants-and-environment/hydraulic-power-plants/dlouhe-strane.html

- [9] H. Chandler, Empowering Variable Renewables, Options for Flexible Electricity Systems, International Energy Agency, 2008, http://www.iea.org/g8/2008/ Empowering_Variable_Renewables.pdf (July 2011)
- [10] SCHLABBACH, J, D BLUME a T STEPHANBLOME. Voltage quality in electrical power systems. London: Institution of Electrical Engineers, c2001, x, 241 p. IEE power and energy series, 36. ISBN 978-085-2969-755
- [11] IEC 868, 'Flickermeter: Functional and design specifications', International Standard, IEC publication, 1986
- [12] e-Vlivy application manual