Hydroelectric Power Plants in the Czech Republic

Introduction to hydroelectric energy

History

Hydroelectric energy is made by moving water. Hydro comes from the Greek word for water. This energy, which is one of the renewable energy sources, has been in use for thousands of year. Hydro energy is one of the oldest methods of producing power. Ancient Romans built turbines, which are wheels turned by flowing water. Roman turbine weren't used for electricity production, but for grinding grains to make flour. Water mills, which were common until the Industrial Revolution, are large wheels usually located on the banks of moderately flowing rivers. The water mills generate energy that powers such diverse activities as mentioned grinding grain, cutting lumber, creating hot fires to steel production, etc. So people have used moving water to help them in their work throughout history and modern people make great use of moving water to the electricity producing. One of the first hydroelectric power plants was built on the Fox River in Appleton in Wisconsin (the U.S.) in 1882. This plant powered two paper mills and one home.

Principle of hydroelectric power plants

At facilities called hydroelectric power plants, hydro energy is generated. But how the hydroelectric power plants work (see Figure 1)? Actually, the hydroelectric and coal-fired power plants produce electricity in a similar way. In both cases a power source is used to turn a propeller-like piece called turbine, which then turns metal shaft in the electric generator, which is the motor that produces electricity. The coal-fired power plants use steam to turn the turbine, whereas the hydroelectric power plants use falling water to turn the turbine. The results are the same.

To generate electricity, water must be in a motion – this is kinetic energy. When flowing water turns blades in the turbine, the form is changed to mechanical energy. The turbine turns the generator rotor which then coverts this mechanical energy into another energy – electricity. There are three basic types of the water turbine – Kaplan, Francis and Pelton. The Kaplan turbine (see Figure 2) was invented by the Austrian engineer Viktor Kaplan. It is similar to propeller turbine, except that its blades are adjustable, their position can be set according to the available flow. This turbine is therefore suitable for certain run-of-river power plant, where the river flow varies considerably. The Francis turbine (see Figure 3) was named after James Bicheno Francis, the American engineer, who invented this apparatus in 1849. The water strikes the edge of the runner, pushes the blades and then flows toward the axis of the turbine. It escaped through the draft tube located under the turbine. The Pelton turbine (see Figure 4) was named, similar as all mentioned turbine, after its invertor – in this case Lester Pelton. The turbine uses spoon-shaped buckets to harness the energy of falling water.

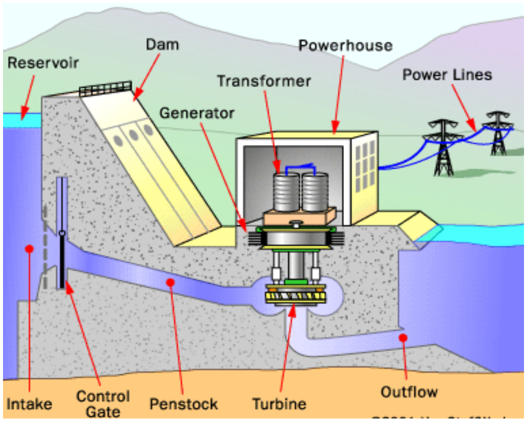

Figure 1 – Principle of hydroelectric power plant

Figure 2 – Kaplan turbine

Figure 3 – Francis turbine

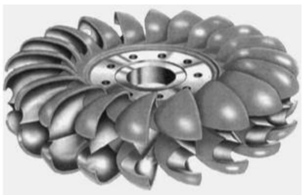

Figure 4 – Pelton turbine

Today world distribution of hydroelectric power

Hydropower is the most important and widely-used renewable energy source. Hydroelectric energy presents of 19 % total electricity production worldwide. The China is the largest producer of the hydroelectric energy, followed by Canada, Brazil and the U.S. Untapped hydro resources are still abundant e.g. in Latin America, Central Africa, India and China. Every day billions of people depend on hydroelectricity. It powers homes, offices, factories, hospitals and schools. Hydroelectric energy is usually one of the first methods a developing country uses to bring affordable electricity to rural areas.

Advantages and disadvantages of hydroelectric energy

Producing electricity using hydroelectric power plants has some advantages and disadvantages over other power-producing methods. There are mentioned most important.
Advantages: Fuel is not burned so there is minimal pollution. Water to run the power plant is provided free by nature. Hydroelectric energy plays a major role in reducing greenhouse gas emissions. Relatively low operation and maintenance costs. The technology is reliable and proven over time. It is renewable – rainfall renews the water in the reservoir, so the fuel is almost always there.
Disadvantages: Investment cost is high. The power plants are hydrology dependent. In some cases, there is inundation of land and wildlife habitat, and loss or modification of fish habitat, and changes in reservoir and stream water quality.

Hydroelectric energy in the Czech Republic

The Czech Republic has a unique position in terms of the energy and environmental sectors. We are one of the very few European countries that are able to export electricity. We are situated in the heart of Europe and our energy grids (electricity and, to some extent, gas pipelines) have excellent connections to the neighboring countries, which enables our energy market to function efficiently. We have a long history in the power industry and there are thousands of companies that are active in the field of power engineering, power generation and energy trading, among other areas.
The power industry in the Czech Republic primarily comprises production and distribution of all forms of energy, include mining and the use of energy sources, such as coal, natural gas, solar energy, wind energy, etc. It is the production and the distribution of electric energy that plays principal role in the Czech power industry. Although the our natural sources aren't ideal for building large-scale hydro power projects, hydro power plants are the country's principal renewable energy source. As our rivers and streams don't have the necessary declivity or sufficient flow rates, hydro share in overall power generation is relatively low. An important role played by hydro power plants in the Czech Republic is to act as complementary source of electricity generation, mainly utilizing their ability to quickly ramp up to full output, which is advantage when immediate power is needed to maintain the balance between electricity production and consumption in the Czech power system.

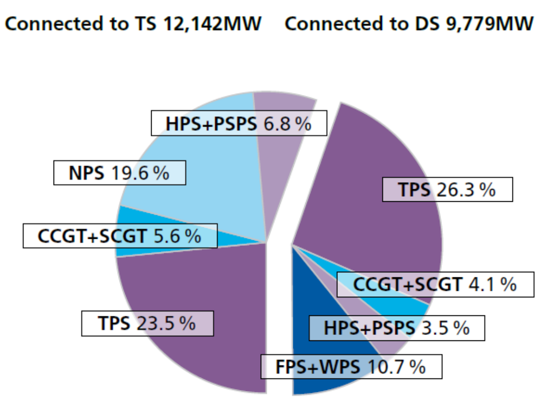

Figure 5 – Structure of the power plant units in the CZR

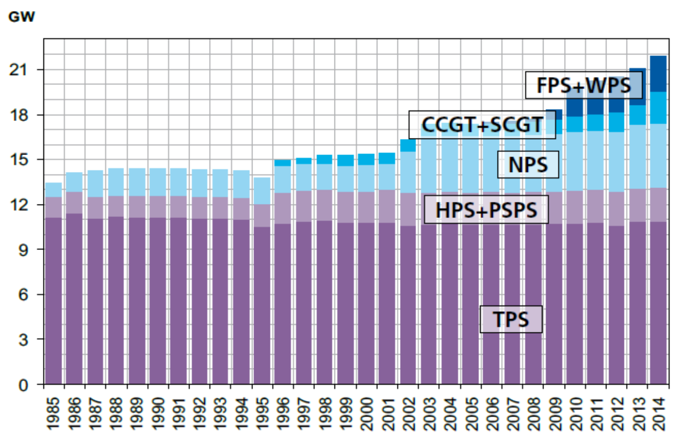

Figure 6 – Installed power capacity, trend since 1985

	2014 (GWh)	2013 (GWh)	2014/2013 (%)
Gross production			
NPS	30,325	30,745	-1.37
TPS	44,525	44,737	-0.47
CCGT	2,205	5,272	8.10
SCGT	3,494		
HPS+PSPS	1,953	2,735	-28.59
PSPS	1,052	1,027	2.39
WPS	477	478	-0.31
FPS	2,122	2,070	2.50
Total	**86,152**	**87,064**	**-1.05**
Export	26,339	27,458	-4.08
Import	9,965	10,571	-5.73
Balance	**-16,373**	**-16,887**	**-3.04**
Pumping	**1,362**	**1,217**	**11.91**
Gross consumption	**68,416**	**68,960**	**-0.79**
Auxiliary consumption	**6,107**	**6,206**	**-1.60**
National consumption	**62,309**	**62,754**	**-0.71**
National consumption per capita/year (2014)			**5,969kWh**

Abbreviations:
TS - Transmission System
DS - Distribution Systems
TPS - Thermal Power Stations (coal only)
CCGT - Combine Cycle Gas Turbine
SCGT - Simple Cycle Gas Turbine
NPS - Nuclear Power Station
HPS - Hydro Power Station (without PSPS)
PSPS - Pumping Storage Power Station (hydro)
FPS - Fotovoltaic Power Station
WPS - Wind Power Station

Table 1 – Balance of electrical energy in the CZR in 2013 and 2014

All large hydroelectric power plants in the Czech Republic (i.e. plants with installed power capacity more than 10 MW), with the exception of Dalešice and Dlouhé Stráně, are located on the longest Czech River Vltava (430 km long), where form a cascade-like system called the Vltava River Cascade. The largest hydropower plants are Orlík (364 MW), Slapy (144 MW), Lipno I (120 MW), Kamýk (40 MW) and Štěchovice I (22.5 MW). Their operation is automated and controlled from central dispatch situated in Štěchovice. The small plants (installed power capacity between 1 kW do 10 MW) are located all over the Czech Republic. At the end 2015 there work more than 1600 small hydroelectric power plant. The total installed power capacity of all Czech power plants is 21 921 MW (situation as of 31. 12. 2014). The installed capacity of the hydroelectric power plants is 6.8 %, i.e. 1 491 MW. Structure of the power stations units in the Czech Republic you can see on the Figure 5. On the Figure 6 there is installed power capacity – trend since 1985. The Table 1 shows balance of the electrical energy in the Czech Republic in 2013 and 2014.

Types of hydroelectric power plants used in the CZR

There are 3 basic types of the hydroelectric power plants in the Czech Republic – impoundment, diversion and pumped storage. The power plants are located on rivers, streams and canals, but for a reliable water supply, the dams are needed. But some plant use dams and some don't. The most common type of hydroelectric power plant is an impoundment facility. An impoundment facility, typically a large hydropower system, uses a dam to store river water in some reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level. A diversion, sometimes called run-of-river, facility channels a portion of a river through a canal or a penstock. It may not require the use of a dam. Another type of plants called pumped storage works like a battery, storing the electricity generated by other power sources like solar, wind and nuclear for later use. It stores energy by pumping water uphill to a reservoir at higher elevation from a second reservoir at a lower elevation. When the demand of electricity is low, a pumped storage facility stores energy by pumping water from lower reservoir to upper reservoir. During periods of the high electrical demand, the water is released back to the lower reservoir and turns the turbine generating electricity.

The most important and interesting hydroelectric power plants in the CZR

The Orlík Hydroelectric Power Plant

The Orlík Power Plant forms a fundamental part of the mentioned Vltava River Cascade. The water reservoir, holding 730 million m^2 of water, is the largest retention reservoir in the Czech Republic, and, together with the Lipno reservoir, it is crucial for the long-term water flow regulation of the Vltava River and the lower course of the Labe River. Its water surface covers an area of 27.3 km^2 and the deepest point is at 74 m. The Orlík Dam was built between 1954 and 1961 and it is 450 m long and 91 m high. The body of the dam has three 15 x 8 m spillways with the capacity of 2.2 m^3/s (so-called hundred-year water) and two bottom outlets (4000 mm in diameter). Additionally, the water reservoir offers opportunities for summer recreation, water sports and fish-farming. It joins the dam with the Orlík Chateau and with the Zvíkov Castle, which stands above the confluence of the Vltava and Otava River at the head of reservoir. The Orlík Hydroelectric Power Plant began operations between 1960 and 1961 and was equipped with four fully automatic sets of Kaplan turbines for

70.5 head. It was new turbines with ten blades, which was exhibited at EXPO 58 in Brussels and won the gold medal. The plant is located in the left part of the river at the heel of the concrete dam. This plant participates significantly in regulating the power engineering system, and in generating inexpensive, environmentally clean peak-load electricity. This is possible due to its 364 MW capacity, its ability to reach full load in 128 seconds, and its remote controlling from the control center located at Štěchovice, as was mentioned. The median annual production of electrical energy is 398.1 GWh. The water is brought to turbine sets by four steel pipelines, 6250 mm in diameter and embedded in the concrete of the dam. The intake is equipped with quick-operating closing valves and emergency stop logs. The generated 15 kV electric energy is transformed to 220 kV in six single-phase transformer units.

Figure 7 – Aerial view of the Orlík reservoir

Figure 8 – Generators in the Orlík Hydroelectric Power Plant

The Lipno I and Lipno II Hydroelectric Power Plant

The Lipno I Hydroelectric Power Plant is the first, and located at the highest altitude, step of so-called the Vltava River Cascade. The Lipno water reservoir, covering an area of almost 50 km^2, forms the largest artificial lake in the CZR. The volume of reservoir is 306 millions m^3 water and it is used in a long-term runoff regulation to increase the minimum flow, limit flood peaks, and increase the generation at the other hydroelectric power plants along the Vltava Cascade. The dam, built during the years 1952 to 1957, is 296 m long, 25 m high and 130 m wide at its base and 10 m at its crown. The reservoir is set in the beautiful nature of the Šumava Mountains and is used for water sports, effective fish-farming and summer recreation.

This power plant represents the significant producer of inexpensive and environmentally clean electricity and the output regulating factor within Czech power engineering system. Its ability to very quickly increase its output to the maximum (120 MW) in 230 seconds. Its remote control from mentioned Power Station Control Centre at Štěchovice allows it to influence the output balance of the Czech power system at any given time. The power plant is equipped with two Francis turbines, into which water is fed via two vertical 160 m high shafts with a diameter of 4.5 m. The turbines are located in the underground cavern of area 60 x 22 x 38 m. Each of turbines is firmly connected with generator, which reaches during maximal flow 46 m^3s^{-1} of water through turbine output 60 MW. Water which hand over its energy in turbine, outlets through waste tunnel of diameter 7.5 m and longitude 3.5 km to balance reservoir Lipno II at Vyšší Brod. So aim of the Lipno II Hydroelectric Power Plant is to balance outlet from power plant Lipno I. It is flow hydro plant with Kaplan turbine with maximal hold 20 m^3s^{-1} and generator with output 1.5 MW. Water surface of reservoir Lipno II covers an area of 12.4 km^2, its long is 224 m and high 11.5 m.

Figure 9 – Aerial view of the Lipno Hydroelectric Power Plant

Figure 10 – Dam of the Lipno Hydroelectric Power Plant

The Dlouhé Stráně Hydroelectric Power Plant

This pumped storage power plant is situated in Moravia, near Loučná nad Desnou in district of Šumperk. It prides itself with three superlatives – it has the largest reversing Francis turbine in Europe, it has the largest head of all hydroelectric power stations in the Czech Republic (510.7 m) and it has the largest installed capacity of all hydroelectric power plant in the Czech Republic (2 x 325 MW). The construction of this power plant was started in May 1978, in the 1980's the building was converted into reduction program, in 1985 the project was modernized and after 1989 it was decided to complete the project. The power plant fulfils static, dynamic and compensatory functions within the power system. The static function lies in converting the surplus energy in the system into peak-load energy – at periods of surplus electricity in the system, namely at night, water is pumped from the lower reservoir to the elevated storage reservoir, and during the on-peak periods, when there is a shortage of electricity, the turbines generate electricity. The other function – dynamic function – means functioning as the system's output reserve, generating the regulating output and energy, and participating in the frequency regulation of the system.

Figure 11 – Aerial view of the upper reservoir

Figure 12 – Lower reservoir

The power plant was designed as underground, i. e. two reversing turbines (output 312 MW in the storage pumping operation and up to 325 MW in the turbine operation) are located under the ground, in 87.5 x 22.5 x 50 m cavern. Next to the turbine chamber, there is located 115 x 16 x 21.7 m transformer chamber included two unit three-phase transformers, 22 kV switching rooms and other necessary equipment. The administration building and the control room are situated on the surface, along with the outgoing lines with the 400 kV encased switching station, workshops and warehouses, garages, a sewage treatment station and a water treatment station. The elevated reservoir is connected with the underground power plant by two penstock (1547 and 1499 m long), each feeding one turbine set. This reservoir is situated on top of the Dlouhé Stráně Mountain, 1.350 m above sea level. Its total capacity is 2.72 million m^3. Two discharge tunnels (5.2 m in diameter, 354 and 390 m long) connect the power plant with the lower reservoir. It is on the Divoká Desná River, it has total capacity is 3.4 million m^3 of water and 56 m high dam.

The Černé jezero Hydroelectric Power Plant (so called Black Lake Power Plant)

In the 20's of the 20th century, the largest glacial lake in the Czech Republic (18.4 ha) – Černé jezero – inspired the chief chancellor for technology from the State Office in Prague to build the first pumped-storage hydroelectric power plant in Czechoslovakia then. The project investor was West Bohemian Energy Company and the technology was designed and supplied by Škoda Factory in Plzeň. The construction work was completed and the plant put into operation in 1930. There is the Pelton turbine with the installed capacity of 1500 kW. The lower reservoir on the Úhlava River with the volume of 25 000 m^3 is closed by a dam. Since 1960, the pumping mode has been restricted. The equipment for processing the water outflow from the equalizer reservoir was produced by Strojírny Brno Company. In 2004, the new 40 kW turbo generator with horizontal Kaplan turbine was installed in the detached building. In 2005, another turbo generator with the output of 370 kW with a Pelton turbine was installed in the generator room of the original power plant. The dam of the reservoir, which dammed Černý Potok (Black Stream) running from the Černé Jezero, is 7 m high and 64 m long. The reservoir contains 23 000 m^3 of water. The dam can be found on the field path, which turns-off right from the road from the village Špičák to the town Nýrsko (ca 3 km).

Figure 13 – The Black Lake

Figure 14 – Engine room of the Černé jezero Hydroelectric Power Plant

The Čeňkova Pila Hydroelectric Power Plant (so called Cenek's Saw Mill)

Čeňkova pila, which means in English Cenek's Saw Mill, was built by the Prague tradesman Čeněk Bubeníček near the junction of the Otava and Křemelná Rivers after the forest disasters of 1863 and 1870. In 1908 the saw mill was modernized and three water wheels were installed here. Two wheels ran two types of frame saws for processing various types of timber, the third was used for running wood-working machinery. In 1912 the facility was rebuilt into the small hydroelectric power plant, which is still in service today and still uses its original machinery, such as generator with output of 96 kW, the automatic voltage control and the overvoltage protection. The generator unit consisted of the Francis horizontal turbine constructed by J. M. Voight AG Company. It is located in the brick container with a tower next to the engine room. The order for the project and supply of the power-related machinery was placed with Brown-Boweri Wien Company. The initial annual production was 500 MWh (enough to supply the town Kašperské Hory with electricity).

Figure 15 – Old building of the Čeňkova pila Hydroelectric Power Plant

Figure 16 – New building of the Čeňkova pila Hydroelectric Power Plant

The entire power plant, where water is steered through an open diversion channel changing into a water-conduit bridge 50 m before building, is register as the listed building by the Ministry of Culture of the Czech Republic. Any alterations to the channel upstream water-way, the building or the technological equipment must be approved by the authorities for the care of historical monuments. Almost original plant is still in operation – energy produced is transmitted to near Vydra hydroelectric power plant, which is mentioned below. The Vydra power plant, built between 1937 and 1944, uses water from the Vchynice-Tetov Transport Channel, which was designed by the engineer Josef Rosenauer and built between 1799 and 1800. It connected the Vydra and Křemelná Rivers and the whole system enabled wood from the high mountains to be transported via the Otava River and taken further inland.

The small hydroelectric power plants in the CZR

The Czech Republic is eight largest producer of electricity from small hydropower installation (<10 MWe) in the EU. Nevertheless, systematic growth in installed capacity of 2.5 MW/year was observed in the last 10 year. The total installed capacity is more than 370 MW and this power plants generate 1100 MWh per year, i. e. 1 % all electricity generated in the CZR. One of the main obstacles to development of small hydropower in the CZR is the costs of operation and maintenance. The small hydroelectric power plant is considered as a complementary source of energy as priority is given to solid fuels and nuclear energy. The use of renewable energy sources is ecological therefore its future and financial support depends on the preferences of the political parties in the Government.

The brief description of selected small hydroelectric power plants in the west Bohemian

Bukovec (see Figure 17) – This small power plant is situated at the end of the restored diversion channel of the Berounka River. It is run-of-rive plant, which uses the hydrostatic drive of the river generated by solid weir on border of the Pilsen's suburb Bukovec and Bolevec. The inlet into the diversion channel is ca 700 m before the power plant and is mounted with coarse racks and sluice gates. To the left of them there is an inlet into the fish pass with the arch-like channel bed emptying into an under weir. There are fine racks in both turbines intakes, where two cleaning machines sweep silt out into and conduit emptying into the collecting container. Two horizontal fully regulated Kaplan turbines have the installed capacity of 630 kW. The design average yearly electricity generation is 2700 MWh.

Figure 17 – Bukovec Hydroelectric Power Plant

Figure 18 – Kalikovský mlýn Hydroelectric Power Plant

Čeňkova Pila – this power plant is mentioned above.

Kalikovský mlýn (see Figure 18) – The hydroelectric small power plant Kalikovský mlýn (so called Kalikov Mill) was built near of the center of Plzeň in the place, where located mill for grinding grains to make flour, in 1932. In this time the people can see technical equipment of the power plant, e.g. Kaplan turbine with installed capacity 80 kW, through the glass wall from the restaurant, which is immediately adjacent to the power plant.

Vydra – This power plant is located near the junction of the Vydra and Křemelná River in the Sušice district. The upper Vydra River has the high fall and, for the most of the year, plenty of water. The power plant construction started in 1937. In 1939 it started to operate as run-of-river power plant and the full operation only after the storage reservoir was finished in 1942. Water is conveyed from the historical Vchynice-Tetov Transport Channel in the underground supply canal into the storage reservoir with capacity of 67000 m^2. The generator room has two turbo-generating sets consisting of the Francis horizontal turbine with the capacity of 3.2 MW and three-phase generator. During years 2005 and 2006, turbines were modernized, two new pumping aggregates of the regulation and new control system of the power plant were installed. In January 2007, the operation was changed from the run-of-river to peak mode. During off-peak periods, the power plant supplies electricity to the grid only in the case of sufficient water inflow into storage reservoir.

The brief overview of other hydroelectric power plants

The Table 2 summarize basic information about other hydroelectric power plant in the CZR. You can know about type of turbine, installed capacity, etc.

name of power plant	place	year of put into operation	turbine	total installed capacity
Dalešice (Figure 19)	Dalešice	1978	reversing Francis	480 MW
Hněvkovice	Hněvkovice (Vltava Cascade)	1992	Kaplan	9.6 MW
Hracholusky (Fig. 20)	Hracholusky	1964	vertical Kaplan	2.55 MW
Hučák	Hradec Králové	1911	Francis	0.27 MW
Kamýk (Fig. 21)	Kamýk (Vltava Cascade)	1961	Kaplan	40 MW
Kníničky	Brno	1941	vertical Kaplan	3.1 MW
Kořensko	Kořensko (Vltava Cascade)	1992	horizontal Kaplan	3.8 MW
Mělník	Mělník	2010	horizontal Kaplan	0.59 MW
Pardubice	Pardubice	1978	Kaplan	1.96 MW

Slapy (Fig. 22)	Slapy (Vltava Cascade)	1956	Kaplan	148 MW
Štěchovice	Štěchovice (Vltava Cascade)	1944	Kaplan	22.5 MW
Štěchovice II (Fig. 23)	Štěchovice (Vltava Cascade)	1947	reversing Francis	45 MW
Vrané (Fig. 24)	Vrané nad Vltavou (Vltava Cascade)	1936	Kaplan	13.9 MW

Table 2 – Information about other hydroelectric power plant

The power plant Hněvkovice is reservoir of water for nuclear power plant Temelín.

Figure 19 – Dalešice Hydroelectric Power Plant

Figure 20 – Hracholusky Hydroelectric Power Plant

Figure 21 – Kamýk Hydroelectric Power Plant

Figure 22 – Slapy Hydroelectric Power Plant

Figure 23 – Štěchovice II Hydroelectric Power Plant

Figure 24 – Vrané Hydroelectric Power Plant

At the end – future of the hydro energy

The European hydro power (Czech too) is currently well-developed. Although European hydroelectric power generation will increase in absolute terms, its share of total generation will decrease slightly. The capacity of hydro power to store energy and act as balancing power will be increasingly important as renewable but intermittent types of energy, such as solar and wind, gain significance.
The small hydroelectric power plants have a great potential. Like large hydroelectric power plant, electricity generation in small power plants is renewable and inexpensive. However, these plants have an impact on the surrounding natural environment. The disadvantage of small plants as compared to large plants is that they don’t offer the same level of security of supply, since they often lack regulation or storage capabilities and therefore cannot be used as balancing power. At this time, however, several regulatory obstacles must be resolved before a more comprehensive expansion of small hydro power plants can be achieved.
The pumped-storage hydroelectric power plant fill an important role in the energy system as a way of storing energy and equalizing electricity supply and demand. When electricity generation is high and consumption is low (for example at night or during the summer months) the surplus is used to pump water into a higher reservoir. When electricity demand is higher than generation (for example during the day or in winter) the water is released from the higher reservoir and electricity is produced as in conventional hydro power plant.
Although new technologies utilizing hydro power, such as wave, tidal and osmotic power have great potential, they are still under development. Their significance in future energy systems is hard to predict.

Questions

1) What is the total installed capacity of the hydroelectric power plants in the Czech Republic?

2) Where are the largest reversing Francis turbine in Europe installed?

3) What is the Vltava River Cascade? What other hydroelectric power plants in the Czech Republic do you know?
4) How many the hydroelectric power plant generate electric energy in the Czech Republic?
5) What are the most common water turbine in the Czech Republic?