ČEZ’s Hydropower Fleet – past, present and future
Current utilisation and prospective new projects
Petr Maralík, Roman Mašíka and Václav Lagner

Kurzfassung
Die Wasserkraft bei ČEZ – Historie, Gegenwart und Zukunft

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ČEZ belongs to experienced energy companies with a deep tradition having a particular historical log in the year of 1878 when one Moravian textile company installed a first electrical generator connected after steam engine to get power for arc lamps to illuminate its production facility. Huge progress happened when Tomas Alva Edison installed his first power plant in order to provide illumination of Janacek’s Theater in Brno in 1881 and František Křižík succeed to light – on an electric arc illumination for Prague Municipal Hall in 1882. Many installations of those times used hydro energy by using water wheels driving electric generators at the beginning, then, later when commercialised invention of professor Viktor Kaplan and his wheel came into „routine use“ in power generation. Shortly after the year 1919 the share of hydro power reached 7.5% in the whole electricity production of the country. In the years after this initial period a fast growing electricity demand had helped to focus ideas and engineering inventions of scientists, technicians, politicians and local entrepreneurs to utilise energy of the Vltava (Moldau) river. The Vltava is delivering water from Sumava Mountains located on border with Germany and getting further enrichment from rivers Otava, Lužnice, Kocába, Sázava and their smaller inflows forms a major energy utilising river. The river that passes through the Prague Capitol and heading to a town Melnik where under Majestic Castle over a river junction contributes by its flow to River Labe (Elbe) which is continuing through Saxony to the North Sea in Hamburg, Germany (Figure 1).

Current company roots of ČEZ have been formed in 1946 when during couple of next years smaller generating companies have been integrated to a one big corporation dedicated to generate, distribute and transmit the electric power. Then in 1992 ČEZ company has got its name and structure at the new era.

The actual power mix of ČEZ consists of coal, hydro and nuclear generation, last years also brought renewables into energy production mix; next to it, the company provides energy distribution services, district heating, has its lignite mining company and provides further energy related services.

The company has an installed power capacity 21,856 MW, where 49% is generated from coal (mainly lignite) and hydro including pump storage has 10% of total number with an equal share (Figure 2).
dropower installation. In 1960, on an opposing nature combined with a big hydro power plant. The choice for Kaplan runners in that time was influenced by a fact that hydro power had more significant share in a country base load supply due to lower capacity installations of coal fired power plants (6 x 50 MWe or 2 x 110 MWe installations). The wider output power control ability of Kaplan installation was a main favour in opposite to the Francis runner technology, that can be applied in more steady operation. But skills of designers, metallurgists, workers and engineers of those times showed and still show the art of technology and skills.

In the late 1960ies, the Government of former Czechoslovakia decided to join a movement to nuclear power installations. In Slovakia started the construction of the Mochovce nuclear power plant after a successful pilot project at Slovakia’s Jaslovské Bohunice nuclear power plant. In Czechia the construction of the Dukovany nuclear power plant started. In those times energy (and energy safety) planners defined a definition that each big installation (nuclear power plant) needs its secure back-up to prevent a possible black-out of the grid. In the early 1970ies the decision was taken to build the pumped storage power plant in Dalešice at the river Jihlava. The design documents included a capacity of 4 x 120 MW reversible (Francis) machines delivering its output to the country’s transmission grid with the location proximity of the Dukovany nuclear power plant as a strategic advantage. This installation opened a new chapter in energy outlook of the Czech Republic (Czechoslovakia in that time). Technological abilities of local producers and local engineering teams gained an appetite of energy installation planners, also prospects of predicted industry and population growth established a demand to build a new big nuclear power plant installation in Temelin with a high capacity. On parallel to the previously mentioned definition of the

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The company owns also hydro installations in Poland, Romania, and Turkey with a total installed capacity of more than 314 MW. Small hydro power plants in the portfolio are owned by the specific company SPV and do not belong to the fleet of ČEZ Hydro. ČEZ’s domestic hydro power plant (HPP) installations are dominantly located as previously mentioned at the Vltava River, pumped storage power plants (PSPP) installations are built in South Moravia – Dalešice PSPP and in North West Silesia – Dlouhé Stránek PSPP (Figure 3).

Hydro power plants located at the Vltava River are formed as a cascade. They have been constructed during a 56 years lasting period when Vrané HPP (currently 2 x 6.9 MW) has been put into operation in 1936 as a first installation, then in 1947 HPP Stechovice started its full commercial operation. Hydro power plant Štěchovice consists of 2 Kaplan units delivering 22.6 MWe of capacity and an additional pumped storage power plant installation which has been redesigned and refurbished in 1996. This pumped storage power plant provides 45 MWe with an reversible Francis installation. Shortly after II. World War construction period of the Slapy hydro power plant started. The Sloppy rock massive in the location near literally known Svatý Jan Poutník (St. John Streams) musically popularised in Bedřich Smetana Symphonical Poem Má Vlast (My Home Country) - Part Vltava forms an impressive background for 3 Kaplan installations of 48 MW each. Self supply and distribution substations are located inside a dam body, what helps to keep a nice scene of surrounding nature combined with a big hydropower installation. In 1960, on an opposite end of the river, a new lake has been constructed to form an upper reservoir for a dual Francis installation in Lipno hydro power plant. The machine hall is located in an artificially made cavern in 153 m depth of the right bank rock massive. The arrangement forms a huge head that provides a double 65 MWe capacity. During the years of Lipno and Slapy hydro power plan construction, teams of planners and designers dealt with a project of two adjacent hydro power plants to use a portion in the middle of Vltava River. The Orlik hydro power plant near the town of Solenice is a state of the art installation with a unique construction of its dam utilising four turbines with Kaplan Runners and a capacity of 91 MW each. This hydro power plant forms a unique example of technology-edge application of this runner technology. Down the river the hydro power plant Kamýk is located. It forms with its dam a lower reservoir of the Orlik hydro power plant. The Kamýk hydro power plant itself utilises a four Kaplan runner based installation, by the size almost similar to those in the Orlik hydro power plant, but with a much lower head it provides an output of 10 MW from each turbine. The choice for Kaplan runners in that time was influenced by a fact that hydro power had more significant share in a country base load supply due to lower capacity installations of coal fired power plants (6 x 50 MWe or 2 x 110 MWe installations). The wider output power control ability of Kaplan installation was a main favour in opposite to the Francis runner technology, that can be applied in more steady operation. But skills of designers, metallurgists, workers and engineers of those times showed and still show the art of technology and skills.

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Fig. 2. ČEZ company hydropower fleet in Czech’s power energy mix. The company owns also hydro installations in Poland, Romania, and Turkey with a total installed capacity of more than 314 MW. Small hydro power plants in the portfolio are owned by the specific company SPV and do not belong to the fleet of ČEZ Hydro. ČEZ’s domestic hydro power plant (HPP) installations are dominantly located as previously mentioned at the Vltava River, pumped storage power plants (PSPP) installations are built in South Moravia – Dalešice PSPP and in North West Silesia – Dlouhé Stránek PSPP (Figure 3).

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Fig. 3. ČEZ group hydropower fleet.
In 1996 the installation of a couple of challenging projects abroad. Internationally approved skills on several specialists where majority of them enjoyed in fully fledged multi-profession teams of specialists. Czech EPC companies have in that time fully fledged multi-profession teams of specialists where majority of them enjoyed internationally approved skills on several challenging projects abroad.

In 1996 the installation of a couple of reversible Francis turbines with 325 MWe (each) have been inaugurated and provided firm message that also the Temelin nuclear power plant will start operation soon. As a raw water source for the Temelin plant the Hněvkovice hydro power plant (2 x 4.8 MWe) and the Kofensko hydro power plant (2 x 1.9 MWe) at the Vltava River and as the final installation of Vltava River cascade were build (Figure 4).

The portfolio described forms the power fleet of ČEZ Hydro.

Current role of ČEZ’s hydro division is described below:

- Fast backup in case of other company’s power plants failure
- ČEZ hydropower fleet provides important grid support services (grid ancillary services – ENTSO-E) for national grid operator (ČEPS) beside providing regular “base load” electricity supply.

The portfolio of available grid services covers:

- Minute backup (QS5) – (PSPPs, Vltava river cascade) – ability to be initiated within 5 minutes from command receive as power demand and be kept in duration of 4 hours.
- Island operation (OP) – ability of hydro power plants to operate in isolated grids
- Secondary frequency control (SR) – (Vltava river cascade) – not currently in use
- Black start – in case of a black-out, the ability to start without external sources of power from the grid
- Power source back-up for Czech nuclear power plants
- For Temelin nuclear power plants – provided from Lipno, Orlík, and Hněvkovice hydro power plants

A growing demand grow for a flexible pumped storage power plant services is shown in Figure 5, further utilisation of renewable power installations will keep necessity to have such massive and fast operation sources of peak power in order to keep national grid stable.

Main Areas of technical development

Maintenance activities of ČEZ’s hydro power plant fleet are organised in periodical annual outages with a duration from 1 up to 3 weeks. Maintenance work focuses to correct minor negative observations on technical means and also to define necessary information for maintenance activities and specific procedures to be planned and carried out (financially and technically) in further years. Maintenance activities are mostly considered as corrective, minor part of that can be found as preventive.

All those activities are focused to achieve prolongation of the parts lifetime (water intake, turbine parts, outlets, bearings, hydraulic control system, generator, I&C system).

Overhaul periods are planned for each 25 to 30 years with a duration of several months. A general idea of overhauls is not only to replace matured components, but also to improve energy efficiency improvements (+3% to +4%).

One further significant focus of ČEZ and its employees is dedicated to the topic of reduction of environmental impacts resulting
from hydro power plant operation. A decrease of oil use, electrical consumption of hydraulic control systems have been achieved by a switch from low/mid pressure to high-pressure hydraulic regulation. Activities in the past years are shown below:

- Slapy hydro power plant (2011) control oil volume decreased from 3,000 l to 830 l
- Lipno hydro power plant (2013-2017) control oil volume decreased from 2 x 6,600 l to 2 x 500 l
- Kamýk hydro power plant (2008) control oil volume decreased from 6,500 l to 450 l
- Vrané hydro power plant (2007-2009) control oil volume decreased 2 x 3,000 l to 2 x 450 l

Note: Original operating pressure ca. 20-50 bar changed to cca 150 to 200 bar

In total, these improvements resulted in saving of ca. 25,000 l of oil at the 4 main hydro power plants and easier (as well less expensive) hydraulic control system maintenance shows the way for the future.

ČEZ Hydro’s management and its team of employees has identified advantages of highest achievable level of process automation very early after 1990. Since that year a massive implementation of highly unified solution of hydro power plant and pumped storage power plant automation supports maximum income from the installed operation base, decreases time of outages, improves safety of operation, widens overall know-how that is shared among the operation staff, and builds up own hydro power and pumped storage power plant control system knowledge management including the establishment of cyber-safety measures and procedures.

**New PSPP projects**

There are two examples of ČEZ’s future activities. The first requires a relatively modest budget, the second one is an example for a really challenging but strategical issue.

**A: Dlouhé Stráně PSPP Storage Capacity Increase Project**

Year to year higher utilisation of the Dlouhé Stráně pumped storage power plant is the trigger for the project to increase the Dlouhé Stráně pumped power plant storage capacity. The idea is to achieve it without huge civil works by larger utilisation of
current basins with minimal investment costs. Main reason are:
- Increasing of basins capacity by 150,000 m³ with the advantage of further
  23 minutes of operation (+189 MWh).
- Main activities:
  a) Upper basin
    - Decreasing of minimum operational wa-
      ter level about ca. 0.5 m (to 1325.8 masl.)
    - Increasing of maximum operational wa-
      ter level about ca. 0.7 m (to 1348.7 masl.)
  b) Lower basin
    - Decreasing of minimum operational wa-
      ter level about ca. 0.3 m (to 800.5 masl.)
    - Increasing of maximum operational wa-
      ter level about ca. 0.3 m (to 822.7 masl.)
    - Excavations of sediments and material
      (ca. 40,000 – 70,000 m³)

B: PSPP Orlik – REVAMP project of HPP
Orlik, change of runner technology

A strategical discussion among ČEZ’s planners and strategist comes into venue near a
life-time period end of main hydro technol-
ygy at Orlik hydro power plant. Higher uti-
lication of the company’s pumped storage power plant fleet during last year is also an
idea behind.

What is current situation of Orlik hydro power plant (Figure 6)?
- 4 units – 4 x 91 MW – peak operation
- Kaplan – 8 runner blades (150 m²/s)
- 364 MW available in 128 seconds
- Runner diameter: 3,700 mm
- Maximum head: 75 m
- Commissioning: 1961 to 1962

There are 3 superlatives to notice about that location:
- It is the largest-capacity reservoir in the
  Czech Republic (720 mil. m³)
- It is the highest head for this type of tur-
bines and
- It is, last but not least, with 364 MW the
  most powerful power plant at the Vltava
  river cascade.

The Company plans for years after 2021 are to
replace two existing Kaplan turbine sets with
reversible Francis turbines. Such change will result in a new utilisation of the
Orlik and Kamýk basins. There are some
main reasons for this project. First is a ne-
necessity to prepare an overhaul of two units
in 2021 to 2024 (Orlik hydro power plant).
Business wise ideas related to overhaul are
influenced with a new movement in area of
grid support services for CEPS (national
grid operator) what is also complementary
to the optimisation of ČEZ Group energy
sources portfolio. It comes into account to
increase the pumped storage power plant
installed capacity of 1,145 MW by 2 x 90 MW
(Figure 7).

Set of expectations is as follows:
- Daily operation except failures and
  planned outages
- Annual availability 92%
- Time of turbine operation at maximum
  power of both units 4.5 hours
- Time of pump operation at maximum
  power of both units 5.6 hours
- Installed capacity of the turbine / pump
  90 MW / 89 MW
- The efficiency of the pumping cycle
  ≥ 79%
- Production per one cycle 761 MWh
- Consumption per one pump mode cycle
  964 MWh
- Estimated time of works 50 - 60 months
  (downtime is about 30 - 48 months)
- The project evaluation activities prior to
  a final decision to start the project covers
  a wide spectrum of topics and will be
  prolonged in coming months/year to
  identify known or still yet hidden risks
  and uncertainties.
- Before final statement of this article
  showing ČEZ’s past, present and future,
there are some rather philosophical as-
pects about the future of the pumped
storage power plant branch.
- The economy of ROI in pumped storage
  plants is influenced by the price volatility
  of electricity/possibly related to the de-
  mand for ancillary services
- Despite the increase in renewable ener-
gy price volatility declines in the last
5 years, the future development may be
influenced by many factors (continued
growth in the share of renewable energy
sources, conventional sources flexibility
– flexibility of demand, market coupling
with ancillary etc. ...)
- Economy of pumped-storage power
  plants is affected by a considerable un-
certainty.
- However, due to the expected needs of
  flexibility we consider it is appropriate to
  prepare projects having potential com-
  petitive advantage.
- The expected investment costs of the Or-
lík pumped storage power plant is ap-
proximately 400 €/kW.
- Planned and/or realised projects in
  neighbouring countries have an average
  investment cost of 1,200 €/kW.
- Another advantage of this project should
  be shorter construction time and easier
  permitting process.

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pumped storage hydro power plants is and
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