Hydropower

Energy saving and renewable energy in vocational education

ENERSOL EU

Onderwijs en cultuur

Leonardo da Vinci Nederland

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Hydro power:

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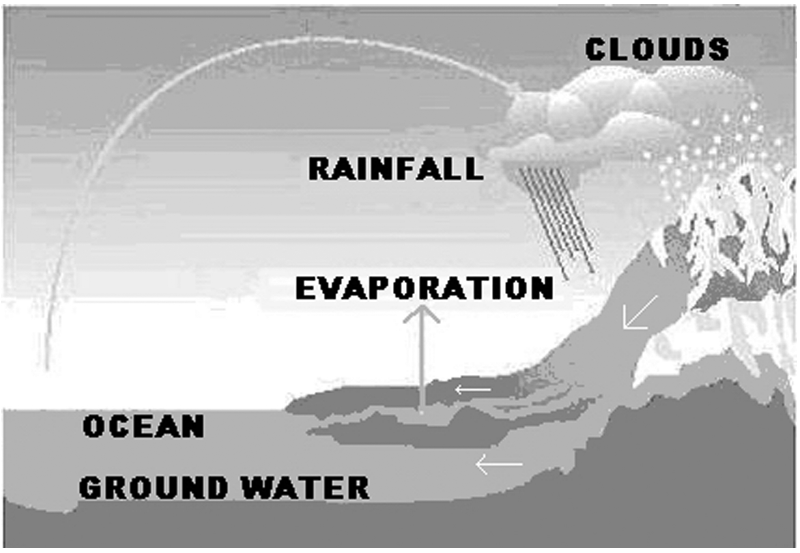
Content

1 Introduction to Hydropower

1.1 Hydropower utilization in the past

The hydrologic cycle in nature accompanies mankind during the entire development of civilization.



The above picture shows you how water can renew and that is why we can call it renewable.

Many years ago hydropower actuated some ingenious mechanical devices. The archaeological founds inform us of using water wheels as early as in 2nd century before Christ. The wheels for actuating millstone had a vertical shaft and were used in the west of the Balkan Peninsula. Later the merit of the way of using water has risen up, i.e. vertical placement of the wheel to horizontal placement, utilisation of tide energy, invention of a water engine working on the reaction principle called Segner's Wheel. In the 19th century we meet the first water turbines (1827 Benoit Fourneyon –the reaction turbine with an output of 40 kW).

We have been using water for the production of electric energy since the 19th century. First there were mostly small hydropower plants with inconsiderable power, which only insured the public lighting in towns and later some technological processes. In that time the contention between hydropower and steam engine power began.

In the late of the 19th century there had been 22 hydropower plants in Slovakia with total performance upwards of 1.5 MW. Most of these stations were used for producing electricity for towns. Mostly direct current was produced because the first electric rotary machines were one-way dynamos. Each city power plant worked independently, this means that they were isolated companies that provided electric energy.

Afterwards the development in this area brought that we could produce alternating current. This enabled the transformation of voltage and thus connection of all electricity. This allowed us to build bigger power plants not only on national but also international level.

1.2 Contemporary hydropower utilization, hydropower as renewable source of energy

The next table shows common exploitation of all primary energy sources in the world:

Primary source	Coal	Water	Nuclear power	Gas	Oil
% of usage	42.8%	18.5%	18.5%	10.5%	9.7%
Renew-able energy source	NO	**YES**	NO	NO	NO

The table tells us that from all primary sources only hydro energy can be considered as renewable energy source. Its contribution to the whole production of energy is 18.5%. It is clear that we can not upgrade this rate to 100% because the source is limited by the natural conditions.

In Slovakia we exploit approximately 58% of all available hydro energy. The hydropower plants are built mostly on big water courses. The share of hydropower utilization on the general electricity production in Slovakia is approximately 19%.

1.3 Reserves at exploiting of hydro energy

We will exhaust the reserves of fossil fuels in 150 to 200 years (coal, natural gas, petroleum assistance) and when using nuclear power we meet many problems with liquidation of radioactive waste.

This generation and the next have a big role in that they must reorient the production of electrical energy to ecological, and to renewable primary sources (besides hydro energy) as sun, wind, geothermal energy, biomass, and bio-fuels.

The primary source of renewable energy is sun power. But different regions do not have the same natural conditions for exploitation of energy from the sun. In Slovakia we have reserves mainly at the use of hydropower - building up mostly small hydropower plants.

2 Basic principles

2.1 Hydro energy potential, flash and decrease

Hydro energy proves itself by the movement effect which is dependant on the flow velocity and also on the pressurize effect of the height of the water column.

The mathematic formulas that can be used for calculation of hydropower energy are the following:

- Kinetic Energy
  $\mathbf{E_k = \frac{1}{2} . m. C^2}$, at which
  m = weight of water (kg)
  C = water speed ($m.s^{-1}$)

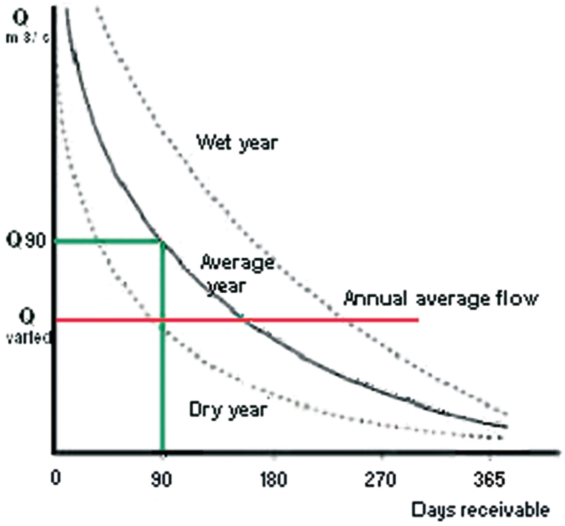
- Potential Energy
  $\mathbf{E_p = m. g. H}$, at which
  g = acceleration of free fall (g = 981 $m.s^{-2}$)
  H = height decrease (m)

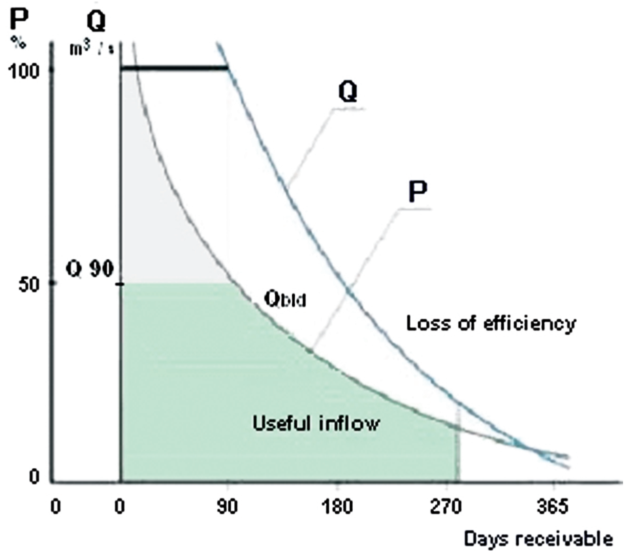
- Pressure Energy
  $\mathbf{E_t = p. m / \rho}$, at which
  ρ = water density ($kg.m^{-3}$)
  p = specific pressure (Pa)

As the law of energy conservation is applicable in nature; the total amount of energy which is given by the sum of kinetic, potential and pressure energy is constant. Only their proportions are changing. Near the stream source the potential energy is on maximum but the flash is low. Near the mouth flow to the sea the situation is contrary=; the overflow is maximum but the declivity is minimal.

The overflow Q ($m^3.s^{-1}$) is changing depending on the place of the stream and the season. If the river is very wide the influence of the amount of rain on the overflow is very low. In Slovakia the rate of maximum and minimum overflow is big and depends on the changing of the weather during the whole year. For example on the river Vah near the town Zilina this rate is 118:1 and on the Slovak sector of the river Danube it is 19:1.

For determining the exploitation benefits of a hydropower plant also the outfall curve is important. This curve represents the time of outfall of the specific amount of water on a specific place on the river. The more these outfall rates are balanced the more advantageous the exploitation of hydro energy is.





The value of the power output, which is possible to reach by the exploitation of the water course, is the water-energetic potential P (MW). The rough water-energetic potential is defined by the altitude of location and the average overflow. Its value is informative only, because we are not able to exploit it entirely. So there is a new term called theoretical hydro-energetic potential. Its size is determined by the exploitation of the decline of the area without any losses. The formula is:

P = ρ.g. Q.H (MW)

In reality, the hydro energy potential used technically is smaller than the theoretical potential because the water course can not be used without the rest. It is because of reasons such as protection of nature and environmental aspects and also the fact that the efficiency of producing electric energy is less then 100%.

In our conditions the value of the real used potential is about 50% of the theoretical potential. Mathematically it is expressed as:

P = k. ρ. G.Q.H (MW)

At which:

k = coefficient of turbine, gearing, generator and transfer way efficiency

H = net head (the difference between water level in front of and behind the turbine) (m)

Q = average overflow ($m^3.s^{-1}$)

ρ = water weight

g = acceleration of gravity

Yearly production of electricity is:

E = P. t (MWh), at which

t = estimated number of operation hours. Usually it is estimated at 5000 hours.

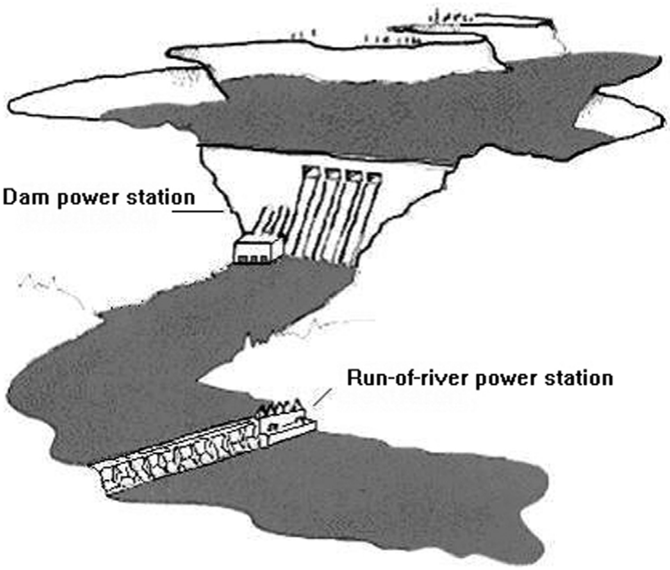
2.2 Categorization of hydropower plants

The hydropower plant is composed of many buildings and ground shaping which complete the plant. Except the for energy importance the hydropower plant has also an importance for flood safety and soil irrigation.

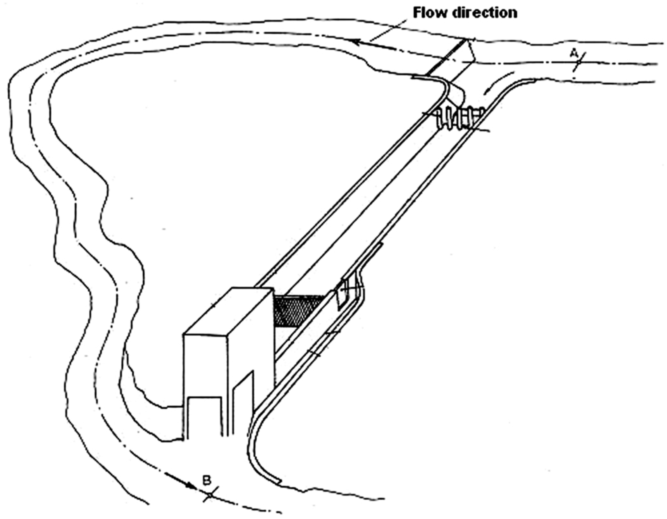
Experience shows us that hydropower plants that are too big have also an impact on climate and the wider environment. That is why at present small hydropower plants are preferred.

We can divide the types of hydropower plants as follows:

- Water-gate - head hydropower plants – their head is created by the water gate. They are built especially on flat lands with low decline. Their disadvantage is that the output depends on the water level and that is why at big water flow the water flows through the water gate unused. At small overflow the head / decline is inadequate. Nowadays because of these disadvantages this type of hydropower plant is not used very much.



- Derivative – flume hydropower plants – their head is created by made-up derivative channel or pressure supply. That is why they do not have the disadvantages of the water-gate - head hydropower plant.



- Pump through hydropower plants – are able to accumulate hydro energy by pumping through water from a lower reservoir to an upper reservoir. The hydropower plant works in two modes. When the electricity consumption is low, energy is spent on pumping water to the upper reservoir. When electricity consumption is high, water is sluiced from the upper reservoir and electricity is produced during this sluicing. The picture shows a typical pumping through hydropower plant in the Slovak Republic.

- Dam – accumulation hydropower plants –are built in valleys. A dam is built which collects most of the water during the year. Thus these power plants can be used at any time of the year.

- Hydropower plants using ocean energy – oceans are considered as a perspective source of energy already for some time. Water movements in oceans makes huge amount of energy at spring-tide. This form of energy can be utilized for the production of electricity.

2.3 Tidal hydropower plants

Tidal power is different from others sources of energy because it has the origin in the potential and kinetic energy which comes from the moon activity on the earth. The tide is a result of this activity and makes itself felt on all sea or ocean coasts.

Water level regularly changes twice a day (it rises and falls) and this lead to attempts to exploit this energy. All these efforts are based on flashing and draining the water from natural reservoirs. Spring-tide water can go through a turbine, placed in a dam, which produces electric energy. With this principle with higher tide there is also a bigger electricity production.

The world's potential hidden in tidal energy is estimated at 3000 GW (can be compared to 3000 bigger nuclear power plants). Some experts think that only about 2% of this potential could be technically available, which is 50 times less than the power of all hydropower plants.

Nowadays exploitation of the tide is economically possible on places where the height of waves is a minimum of 5 meters. On many places in the world we can see such tide, especially in bays which can make the tide more powerful. It is possible to make a dam in a bay and to put a turbine in it. The technology is very similar to those hydropower plants using low head of water.

The main difference to classical hydropower plants is that they must work with salt water and also with changing height declivity. Moreover, the electricity in those power plants is produced only for a few hours a day.

This means that finally the efficiency is low. Tidal power plants produce only one third of the electricity of comparable classical hydropower plants.

2.4 Coastal streams

Despite of the fact that the technology of using tidal energy is utilized from the beginning of the 90's the technicians are interested more in the exploitation of coastal streams for producing electricity. These streams arise in coastal waters as the result of forces of the see bottom, which pushes water to the narrow streams.

It is similar to strong wind arising in valleys or hills. As water density is more then 800 times bigger than air density, streams with speed of 16 km/h have the same energy as wind with a speed of 390 km/h. Unlike a strong wind, coastal streams can be forecasted because spring tide is changing every 12 hours.

We can use coastal tidal streams in tidal turbines. These turbines have a shape similar to wind turbines under water, but they are less unfolded. They work economically on places where the stream has a speed of 2-3 m/s. The disadvantage is that with bigger speed they are very shirt-sleeved and with lower speed they are not economical. A tidal turbine with a rotor-diameter of 20 m is able to produce the same amount of electricity as a wind turbine with a rotor-diameter of 60 m. An advantage of tidal turbines is that they are not visible and heard because the device is under water.

There are many suitable places in the world for placing tidal turbines and some experts estimate the potential of this energy source to more than 330 thousands MW. Southeast Asian coasts have especially suitable places.

The ideal spot for placing of a tidal turbine is at a depth of about 30 m where these turbines are able to produce 10 MW of electricity from each km2. There were 106 places convenient for placing the turbines identified in the European Union - 42 of which are in Great Britain's waters.

The first tidal turbines should be placed for the southwest coast of England and for the coast of Portugal. The turbine in England should have a rotor diameter 12-15 meters and a performance 300 KW which is sufficient to produce electricity for a small village. The expecting price of the produced energy is about 0.10 USD/KWh. This is more than the price of energy from a classical power plant but much less than people on a small island must pay, that is why technology can be used on these islands.

2.5 Wave energy

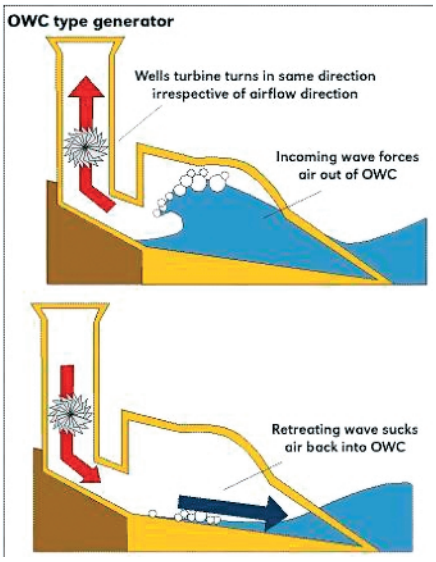
A big part of all energy that is coming down on the earth from the sun is changing to wind which consequently gives power to sea waves. The energy of sea waves is huge and about 70 MW/km of the plane wave front. Such waves move many kilometres without loosing their power.

These waves are produced by storms in the middle of the Atlantic Ocean. Normally they migrate to the coasts without loss of power. All energy is concentrated close to the water level and only a small part of the energy is migrating in the depth of 50 meters under water level. This means that it is a very concentrated source of energy that varies much less during a day in comparison to other renewable sources (sun, wind). The technology making use of the wave energy is based on capturing waves to the closed space and changing kinetic into electrical energy.

These power plants exploit the energy of **oscillating water columns (OWC)** when the atmospheric pressure is emerging through the air turbine. The atmospheric pressure reel the turbine which is connected to the electricity generator.

The biggest potential for exploitation of wave energy in Europe is near Great Britain. The price shouldn't be higher than 0.10 USD/kWh what makes this energy source competitive on the electricity market.

Till now the most efficient device named Salter Duck produces electricity for a price lower than 0.05 USD/kWh. Salter Duck is the first device of this kind and was constructed already in 1970 by Professor Stephen Salter on the university in Scottish Edinburgh.



As Slovakia is a country without access to the sea, there are four types of hydropower plants used here - Water-gate - head power plants, Re-pumping hydropower plants, Dam – accumulation power plants and Derivative – flume power plants.

The structure of hydropower plants in Slovakia makes conditions for using them as high level stations producing electricity at a time when the consumption of electricity is high or in times of a sudden increase of consumption. This is based on good adjustability and high speed of starting and shunting production. The electricity produced in hydropower plants relatively cheap because the price of the primary energy source does not have to be counted in.

According to the size of declivity we can classify power plants as follows:

- Low-pressure plants – head from 15 to 20 m
- Medium-pressure plants – head from 20 to 100 m
- High-pressure plants – head from 100 m

The size of the declivity also has influence on the arrangement and shoulder of the machine room of the power plant.

According to the size and the electric power of hydropower plants, they are dividing in two groups:

- Big hydropower plants – their installed power is bigger than 10 MW – in Slovakia these are derivative, accumulation and re-pumping hydropower plants.
- Small hydropower plants - their installed power is less than 10 MW.

2.6 Locations suitable for building, basic of the proposal and the economic efficiency of the investments in construction hydropower plants

If we want to use hydropower effectively in certain location, we must take care of head and overflow on that place. The production of the electricity must be profitable and must not invade the ecosystem.

The amount of energy produced is influenced by the declivity and the water course. Law-pressure plants have a declivity boundary value of 1.5 m or, in special cases, 0.8 m. High-pressure plants have minimum available overflow; approximately 10 $l.s^{-1}$. For example when the head is 1.5 m and the overflow is 1 $m^3.s^{-1}$ we can expect an output of 7 KW, when the declivity is 50 m and the overflow 0.01 $m^3.s^{-1}$ the estimated output is 3 KW. If there is a public supply network at the location, the electric power of 2 KW produced in small hydropower plants is usually more expensive than energy from the public supply network.

Electric power produced in small hydropower plants can be supplied to the public network, to other purchaser or it can be consumed at the same place. Electric power supply is the subject of the law of energy industry, law of energy business enterprises and others. Building, reconstruction and enlargement are also subject to the law. If there is an intention to supply the produced electric power to the public network conditions for supplying must be stated as early as during the preparation documentation in an agreement between the supplier and the distribution company.

It is advisable to use economic calculation for verifying the sense of the project and the return on investment before investing in construction. In most cases the project is being paid with a bank loan. If this is the case we must consider the annual payments and interest for paying back the loan in the desired time horizon. It is necessary for the economic durability (time of depreciation) to be shorter than the real physical durability of the power plants.

A higher regulation quality is better for good reaction of the power plants to operational changes. This results in a bigger amount of produced electrical power and also in higher profitability. Big power plants supply energy to the public network. Their design and building is expensive and only big energy companies are able to realize them. In these days we can hardly find any suitable locations for their construction in the whole of Europe.

3 Technical equipment of a hydropower plant

The main parts of a hydropower plant are:

- Intake object – Its purpose is to bring enough water from the reservoir to the feeder which leads it to the power plant.
- Conduit and sewage – We can divide it in 2 groups according to function: non-pressure (head race, channel, and road with free level) and pressure (conduit, road, and shaft). This takes for the biggest part of the construction costs. Therefore it is necessary to pay enough attention to its disposal design. Non-pressure conduits are commonly cheaper than pressure conduits and are preferred in most situations.
- Production objects – machine room, switch room and sometimes other items. All the technological equipment for the production of electrical power is placed in the machine room.
- The Electro-technical equipment and connection to the public supply network.

3.1 Intake structure, conduit and sewage

The water system of a hydropower plant (the intake structure, the conduit, and the sewage) depends on the flow rate of the water course and on the possibilities of ample decline.

To define the rates the outflow curve is needed. With the assistance of the flow curve we can specify the number of turbines, their input and the average number of annual working hours. The decline depends on the geographical situation of flow rate locality.

A small hydropower plant is expedient to build up on the spot of flow rate with a relatively big decline. The optimal situation is if the flow rate has a deep and narrow riverbed. If the locality has a gentle decline the water system increases the cost of construction.

During the construction of the sluice gate it is necessary to satisfy the following rules:
It is not allowed to whittle away the original profile of the riverbed. The weir has to be protected against the flood; it must not cause overflow of the riverbed. The water which streams in the turbine collects dirt; the intake structure therefore has to have a suitable configuration. Water which is not processed by the turbines falls through the sluice gate.

The main principle of the derivative small hydropower plant is best used there, where the shape of the watercourse creates a bend which enables to shorten the distance of the derivative channel.

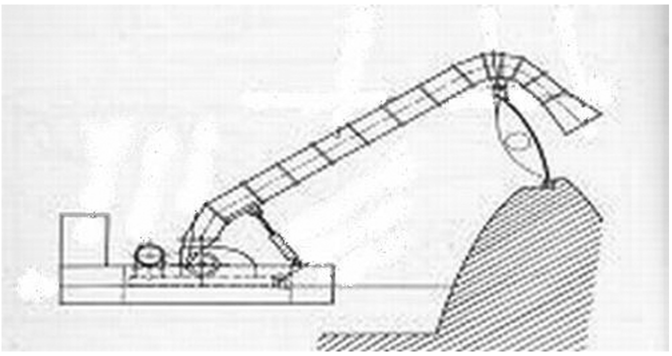
At the increasing of the flow rate, the intake of the water is regulated to the channel and to the original riverbed by the help of the weir. Through the structure of the weir the minimal-sanitary flow rate through the original riverbed has to be reached.

Barriers at the beginning of the channel receive rough dirt. The fine barriers and the increased thresholds receive small dirt. The barriers are placed in front of the intake to the turbine station.

Currently it is possible to build the conduit and the sewage as structural pre-fabricated element. That means that the building is simplified. On the market unit assembly systems for drops of 1.5 m to 10 m, and a performance of 30 to 450 kW, are available.

Another reduction of the construction costs, and also a simplification of the operation in the power plant, appears when the power plant is created as floating. The load-bearing structure of the power plant in this case floats.

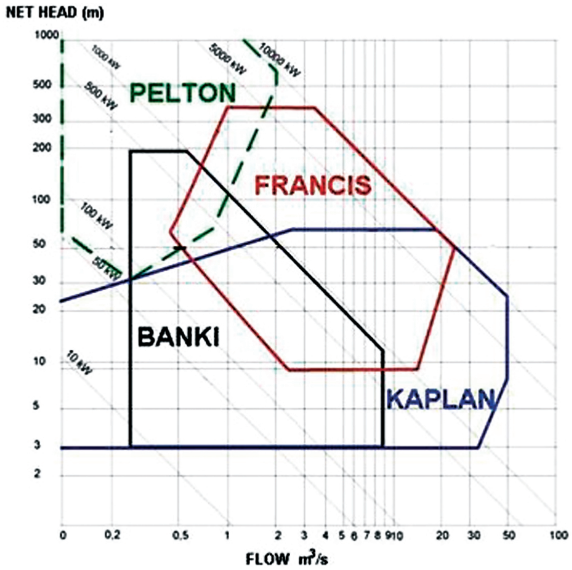
Besides the savings of capital expenses, another merit is the possibility of producing electricity even though the surface of the water is unstable. There is no special need to protect against overflow of water. A floating power plant can be moved according to requirements and can be installed at a majority of locations suitable for construction of a small hydropower plant.



Constructing a dam and a pumped storage power plant is very expensive. The recoverability of investments of a small hydropower plant is long.

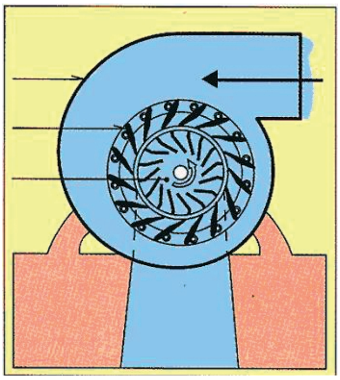
3.2 Processing objects – turbine

Another important and financial costly part is the construction of processing objects and their shoulder by plant instrumentation. The organization of the machine room at big hydropower plants is usually vertical. This means that the turbine is set on vertical axis below the generator. During the construction of a small hydropower plant it is not usual that the configuration is horizontal. The choice of which kind of turbine to use depends on declivity and the flow rate of the watercourse, as wells as from the installed power capacity of the power plant.

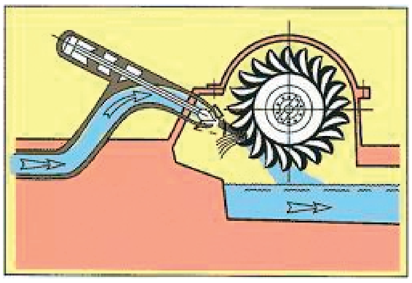


3.3 Most used turbines at present

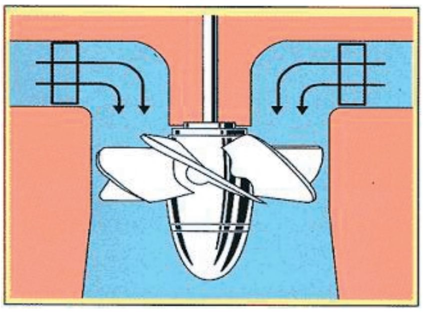
- **Francis' turbine** - It was developed in the year 1849 by J.B. Francis. Later it was supplemented with the regulation of the line and rate of flow by the installation of rotate stationary blades. Nowadays it is utilized in a broad range of declines and flows.



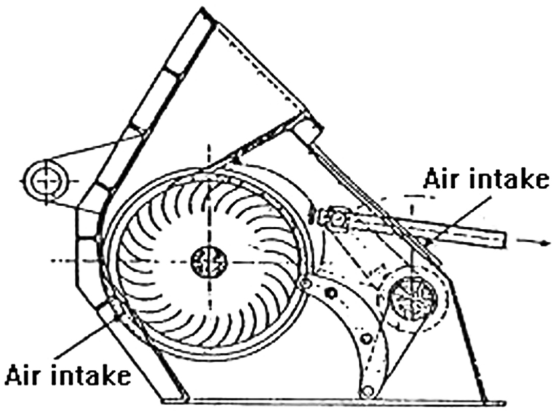
- **Pelton's wheel** – It was constructed in the year 1880 by L. Pelton, who worked out the shape of the paddle moving wheel and injection jet with regulations. At present it is used for bigger declines and at the same time for small rate of flows.



- **Kaplan’s turbine** – This was constructed in the year 1913 by V. Kaplan, who used the hydro energy potential on rivers with small declivity and big flow rate. Kaplan's turbine has been improved meanwhile but this type of turbine still is not able to run at the same high speed as a Francis’ turbine. Its advantage is particularly the adjustable paddle wheels of the runner, which stretched the angle of the setting to the flow. Its effect is the advantageous course of the turbine’s efficiency. Particularly it is used at the situation where there is low decline and high range of flows.



- **Other turbines** - Other turbines suitable for constructing small hydropower plants are – a vertical propeller turbine, Banki's turbine, Girard's turbine, possibly a classical water wheel. Their merit is serviceability at low installed capacity and at low declivity.



From the view of preponderated direction of the stream of water turbines can be divided as follows:

- **Axial flow turbine** - Water races parallel with the turbine's axis. (Kaplan's turbine)
- **Radial flow turbine** - Water races perpendicularly to the turbine's axis. If water flows from the shaft, the turbine has an internal intake - centrifugal. If water flows to the shaft the turbine has an external intake – centripetal.
- **Radial - axial turbines** - Water flows by the runner wheel rotary, than changes direction which is approximately parallel to the axis. (Francis’ turbine)
- **Diagonal turbines** – Water races by the runner obliquely to the shaft.

- **Tangential turbines** - Water flows to the paddle wheel of the runner at the direction tangent to the circle of the paddle wheel. (Pelton's turbine)
- **Double flow rate** - water enters centripetally and gets out centrifugally. (Banki's turbine)

All the types of turbines can have a vertical, a horizontal or an oblique shaft. If water flows around the turbine by the whole perimeter of the runner, the turbine has full splash and if not the turbine is fractional – it has partial splash.

According to the energy transfer to the runner, water turbines are divided as follows:

- If the whole hydro energy is turned into kinetic energy (already at guide wheel) we talk about an impulse turbine. (Pelton's, Banki's, Girard's turbine).
- If only part of the hydro energy is turned into kinetic energy (even at the runner), we talk about a reaction turbine (Franci's and Kaplan's turbine).

All these parameters of a turbine determine the draft of the feeder and the waste of the power plant. Nowadays there are also modern, untraditional arrangements of building of small hydropower plants, without big interventions as accumulation of water and flooding safety.
Power plants like these are designed as floating or anchored. Special types of water engines are often used for their shoulder. For example: Zeus' turbine, Savoniu's turbine or Teslo's turbine, Schneider hydrodynamic unit component.

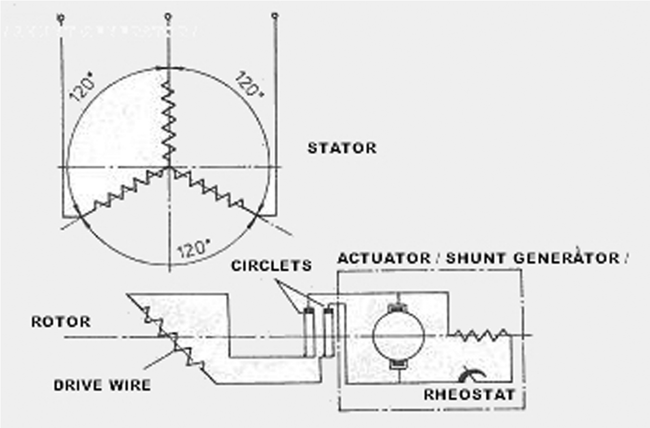
3.4 Energy unit

At many cases the turbine is set on the shaft together with a generator, sometimes connected through the connector or the transmission. The type of energy unit, its letting down and regulation depend on the power capacity. Also it is important if the source is connected to the public distribution network or works as independent unit.

Hydropower plants with a high power capacity are often fixed by a hydro-alternator and connected to the public distribution network. The hydropower plant can be fixed with a synchronous or asynchronous generator. That point depends on if they are connection to the network or work independently.

The synchronous hydro alternator is a multiple slow-running synchronous machine.
In the grooves of the magnetic circuit of the stator a three-phase winding is placed, which is connected to the star or triangle.

On the terminal extensions of the rotor, a one-way field winding which is, through the circles and brushes, connected to the source of the one-way current is placed. As source is used the exciter (derivational dynamo), which is placed on the shaft with the alternator. The electric scheme of the machine can be seen at the following picture:

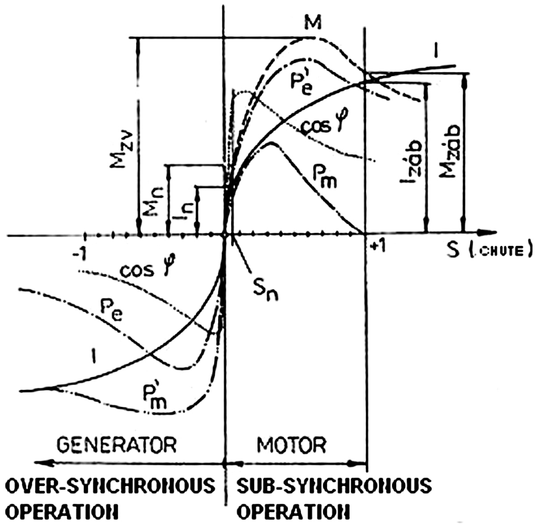


The advantage of a synchronous alternator is that it has an ideal ballast characteristic and high overload. If power is added to the electric system, phase problems have to be solved. If the condition of phase (identical train of phases, the value of voltage, the value of frequency, and nominal value of voltage net and alternator) are in order, then, during the operation, frequency and voltage are kept at the values in the network. By this way all big hydropower plants are developed.

If the power plant works in isolation the regulation of the water turbine has to be solved according to the loading alternator. This regulation is named as performance (the regulation of turbine performance), or speed regulation (preservation of the constant revelations of the alternator together with the frequency at load change). The regulation is needed for preservation of constant voltage and frequency on the load.

The regulation of the turbine is run manually or more often automatically, in which case the mechanical or hydraulic regulator adapts the output of the turbine to the load of the alternator. On the opposite case it could decrease the float at the location of a small hydroelectric power plant. After that the effect will be loss of the power.

The asynchronous generator is in essence a three-phase asynchronous motor which, at over-synchronous revelations, gets down to generator state. The nominal value of time lag (slowing of the revelations of the rotor against the turning of the magnetic field of the stator) at the motor is approximately 5 % and at the generator approx. - 5 %, which answers the value of rated output.



The structure of its stator is identical to that of the synchronous alternator. In the mortises of the rotor, a rotor cage (with the anchor as short) or a winding is placed, which is lead out through three circles on the rotor clip (the looped machine).
The application for asynchronous generators is mainly in small hydropower plants connected to the public distribution network. The advantages are evident; simple construction, mainly machines with anchor as short, easy manipulator, lower price, simplicity of the connection, higher effectiveness, the exciter is not needed here and also there is no problem with the phase.

The generator supplies to the network just active output, its delivery is conditioned by the voltage network. At the delivery of the output the value of the voltage and frequency is kept on constant value by the automatic network values.

When there is a power failure in the network, the generator ends the delivery of the output and the revelations of the turbines begin an uncontrolled raise. That is why the turbine has to be secured to the amount of revelations.

An asynchronous generator can not be installed in a power plant with high power, because the electric system acts as an instable element. At higher power and overloading of the net fragmentation of the power system could be caused. The choice between a synchronous and an asynchronous generator depends on the requirements of the keeper of the power plant and of the runner of the distribution chain to which the power plant is connected.

3.5 Distribution of the output to the power system

For distribution of the output from the power plant the terminals from the generator are connected to the switch room of the generator terminals, which can be the constituent of the technological equipment of the machine room.

The switch room of the generator terminals is connected to the blocked transformer, which arranges the level of the produced voltage to the network voltage where the power plant is connected to.

4 Description of some implemented projects

Many years ago in Slovakia invested much in the progress of water energetic. In the late 19th century and in the early 20th century lots of hydropower plants were built. Many of them were not kept till today.

When electric systems began their development, promotion to build up all hydropower plants on bigger water courses with bigger installed performance started.

4.1 Hydroelectric dams

In Slovakia all types of hydropower plants, except for ocean hydropower plants, exist. A typical example can be found on the river Vah. Through the construction of 25 power plants the trim stream of the rivers Vah and Orava was reached. So a flood protection was established. Inside the power plants there are 73 mechanisms. An installed power capacity of approximately 2200 MW significantly contributes to the production of electrical energy.

The first hydroelectric dam was introduced in the year 1936 – this power plant is called Ladce and has an installed performance of 13.8 MW. In the year 1946 a power plant with output of 15 MW was started in Ilava. In 1949 in Dubnica nad Vahom a power plant with an output of 16.5 MW has been introduced.

These hydropower plants were developed to float on the river Vah and for that reason lock chambers were included. Another issue of substance was the construction of the hydroelectric dams in Orava (21.75 MW) in 1954 and in Liptovska Mara (198 MW) in1976, the re-pumped hydro energy power system in Cierny Vah (735.2 MW) in 1982 and the hydroelectric dam in Gabcikovo (720 MW) in 1995.
The last part of the cascade is the hydroelectric dam in Zilina (85 MW), which was finished in 1998.

A control of all workings at the Vah cascade is implemented from the work place in Trencin. The main task of the dispatching is to program and operatively control the working in all hydropower plants. The dispatching works during peak operation and also during the collision service, when the powerhouse can produce electricity to increase the power of the system in 2 to 5 min. to the level of the power asked for.

Typically interesting are the hydroelectric dams of Gabcikovo, Liptovska Mara and Cierny Vah.

Hydroelectric dam of Gabcikovo

The construction of the hydroelectric dam began on the basis of an interstate agreement with the Hungarian Republic in the year 1977. Unilaterally resignation by the Hungarian Republic resulted in a new variant just for the Slovak territory.

The hydroelectric dam carries out the following functions:

- Protection of the surroundings against flooding
- Construction a year-round accessible international channel all the way to Austria
- Work out problems with the surface of ground water in a given section of the Danube
- Energy use-application

Nowadays the hydroelectric dam consists of:

- Unit delay element with a fascine with an accumulative reservoir in Cunovo, which comprises along the channel
- Impoundment Danube by Cunovo, which keeps the level of surface in the reservoir and at the same time leaks water to the original riverbed
- Supply channel which leads water from the unit delay element to the stage of Gabcikovo. At the same time it is used as a channel.
- Stage of Gabcikovo, which consists of a hydroelectric power plant and a lock

- Waste sewer which takes water from the power plant and the lock chambers back to the Danube and at the same time comprises the channel

In the hydropower plant eight synchronously alternators powered by Kaplan's turbines with a diameter 9300 mm are installed.

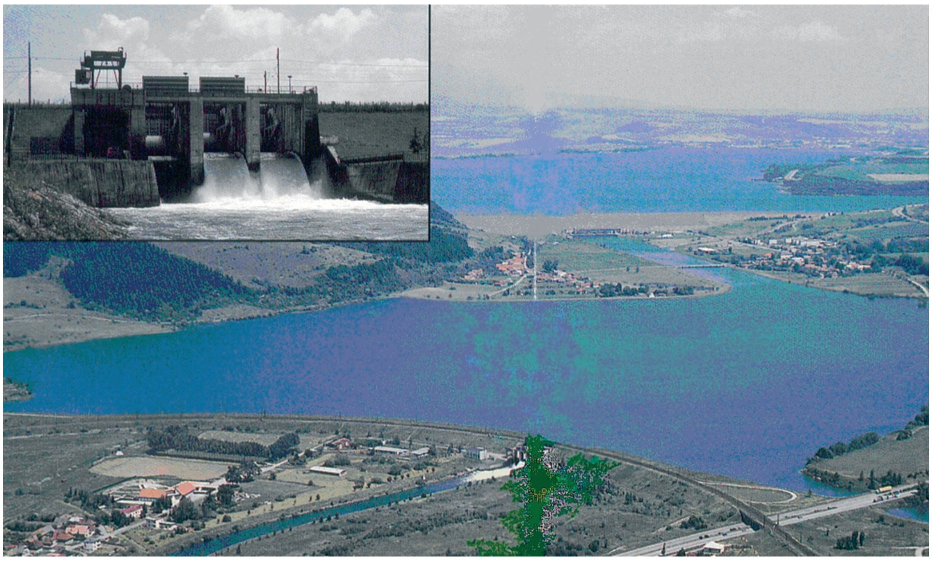
The power capacity of one alternator is 90 MW (all together 720 MW). A particular solution is to run out the power capacity through a cased switching station of 400 kV, isolated by a gas SF_6 to the Slovak and Hungarian side and through the switching station of 110 kV to the Slovak side.

Hydroelectric dam of Liptovska Mara

The hydroelectric dam Liptovska Mara together with the stage Besenova has its main function in balancing the flows of the river Vah. This means it should supply enough water for other hydropower plants of the Vah – cascade placed under the hydroelectric dam.

The main purpose of the hydroelectric dams of Liptovska Mara and Besenova is:

- Protection against floods
- Improvement of the flow on the river Vah and supplying drinking-water
- Production of electric power from the flow of the ricer Vah and from pump-over
- Production of electricity in other hydropower plants and creation of conditions for recreation and sports and breeding fishes in the Tatra region.



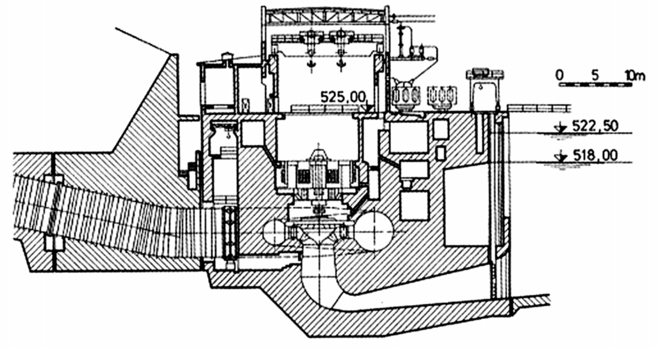
In the picture the situation of the hydroelectric dams is portrayed, at the background the Liptovska Mara reservoir with an area of 2134.4 ha and water level can be seen which is located at a height of approximately 564.9 m above sea level. The holding space of the reservoir catches secular flood water and flattens top-flows of 550 $m^3.s^{-1}$ to 240$m^3.s^{-1}$. At the background the Besenova reservoir can be seen.

The dam of the reservoir, has a length of crown of 1225 m, and a height of 43 m above the valley. A tower-like building is protuberant in front of the dam, which with the assistance of four supply pipes, leads the water to four turbines.

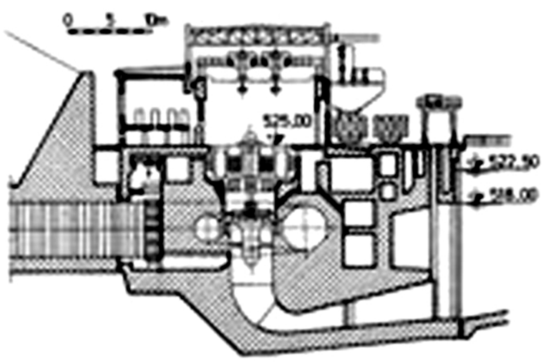
Two of them are Kaplan's turbines – vertical with a diameter of the moving wheel of 4600 mm and with 6 blades each. The flow of each is 140 $m^3.s^{-1}$ (TG2 and TG4). Another two turbines are diagonally reversible with a diameter of the moving wheel of 5000 mm and 8 blades and with a flow in the turbine of 130 $m^3.s^{-1}$ and in the pump of 105 $m^3.s^{-1}$ (TG1 and TG3).

The reversible turbines enable operation of the hydroelectric dam. Besenova serves as lower reservoir in the process. The dam further includes a bottom outlet and a safety overflow as a protection against overflow of flood water. The building of the power plant is forwarded in front of the slope of the dam. During the top-operation all four turbines are able to work.

A synchronous hydro alternator with total installed capacity of 198 MW (2 times 50 MW + 2 times 49 MW) is installed. The capacity is lead out through transformers 10.5/110 kV to the switching station of 400 kV in Liptovska Mara. The planned annual production in a year with average amount of water is 77 GWh from the flow and 122 GWh from re-pumping.



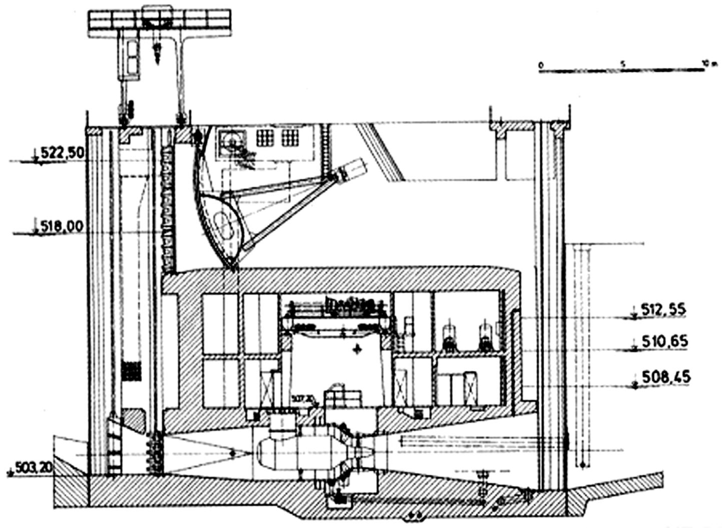
The cut of mechanism TG1 and TG3 of water power plant Liptovska Mara



The cut of mechanism TG2 and TG4 of water power plant Liptovska Mara

The water tank of Besenova is spaced on 193 ha; the altitude of the surface is 522.1 m above sea level. It serves as a tail water pond of the top hydroelectric power plant of Liptovska Mara. It collects the top flow rates and evenly leaks them to the riverbed of Vah. The minimal flux is 10 $m^3.s^{-1}$. At the same time it serves as the storage tank for the reversible turbines of the power plant of Liptovska Mara. The dam is 1109.4 m long.

On top of the dam a railway is placed. In the body of the dam 3 over-flows fields of weir in conjugated objects are placed. Underneath the object there is a small hydroelectric power plant with two mechanisms with flow rounds generators. Their power capacity is 2 times 2.4 MW. The power output is lead out through the transformations and the switching station of 22 kV. The power plant has been projected for an annual operation of 8760 hours and a production of 20 GWh.



The cross-section of water power plant Besenova

The operation of the hydropower plants of Liptovska Mara and Besen-ova is fully automated and unattended, with surface regulation and possibility of control from the power plant of Liptovska Mara or the dispatching in Trencin.

The hydro energy application of the hydroelectric dam Liptovska Mara is, that of each 1m_ of water 0.68 kWh of electric energy is produced. This equals a yearly amount of about 160 thousand tones of coal used in traditional power plants.

Hydroelectric dam of Cierny Vah

The re-pumping hydropower plant of Cierny Vah meets the require-ments with a daily accumulation - production of energy from re-pum-ping - , spare power capacity and daily regulation.

Dynamic functions are mainly the regulation of speed changes, changes of loading by the instant cover and regulation of the frequency and outputs to the electric system.

Before the independence, static functions were paid more attention to by the Slovak electric system (the epoch Czech-Slovak federation), whereas nowadays dynamic functions get more attention.

After The Slovak Republic enters the EU and connects the electric system to the European association UCPTE the main functions of re-pumping hydropower plant will be:

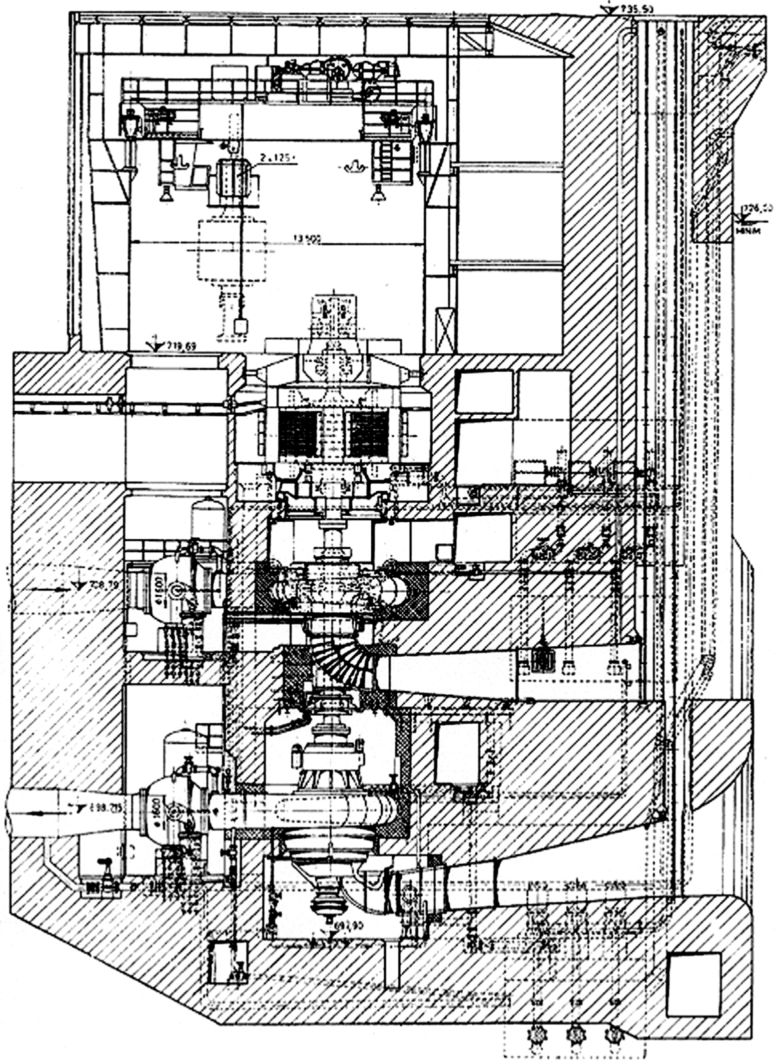
- Impact pressure service for the electric system
- Dispatch reserve for power failure of the biggest block electric system
- Observance of agreed balance of foreign co-operation
- Cover of peak capacity and cover of urgent decrease of capacity of the electric system

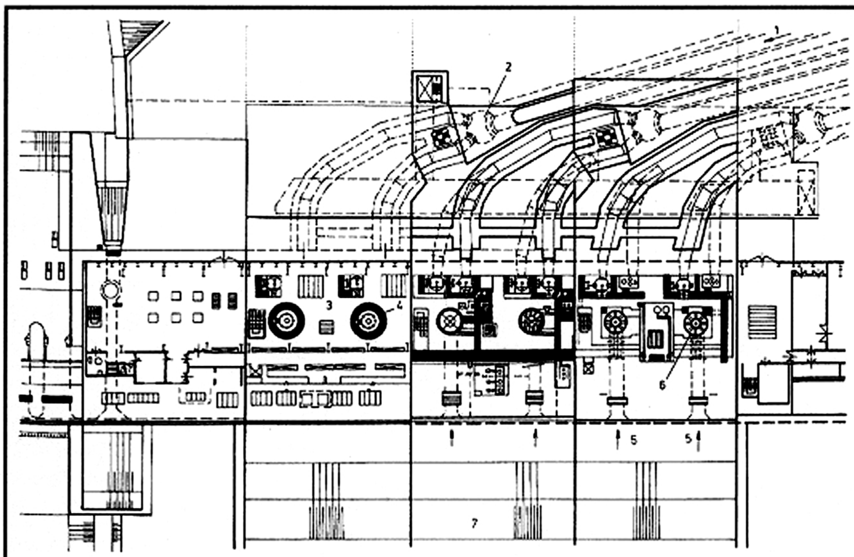
The power plant was built in the national park Nizke Tatry and that is why at the construction and usage the conditions of the state administration and nature protection had to be used.

The building dam has the following elements:

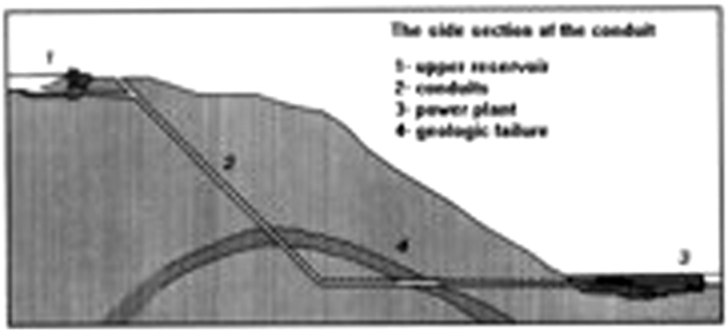
- **Upper reservoir** – The upper reservoir is artificial, without natural tributary, built in an altitude of approx. 1150 m above sea level. In the toe of the reservoir the road for checking of infiltration is built around the whole circuit. The swing of the water level is 25 m. The intake object for three feeders and embouchure of the communication channel are integrated into the dam. Driveway connection is built at the upper reservoir.
- **Underground feeders and communication tunnel** – The three feeders have a diameter of 3.8 m each. Before the power plant each is ended by the junction box. The feeder is ramifying for two turbines and two pumps. Before the turbine and pump are ball stoppers placed. Next to the feeders is a self-reliant communication tunnel with a skew lift situated.
- **Bottom reservoir** – the dam itself is made of concrete with free parts for greenery. The altitude of the dam is approx. 730 m above sea level. The water level can differ 7.45 m. Also part of the construction was the remaking of the road connection.
- **Power plant** – The power plant itself is part of the bottom reservoir. Inside 6 vertical re-pumped devices are placed in three machine systems: motor-generator, - turbine-pump. The first two machines are connected with the pump hydraulically. In the pump operation the turbine is airless. The turbines are Francis with a diameter of the wheel of 2.6 m, and an installed output of 6 x 122.4 MW. The real flow of the river Cierny Vah is used with Kaplan's turbine with an installed output of 0.768 MW.

THE CROSS SECTION THROUGH THE PUMP SET





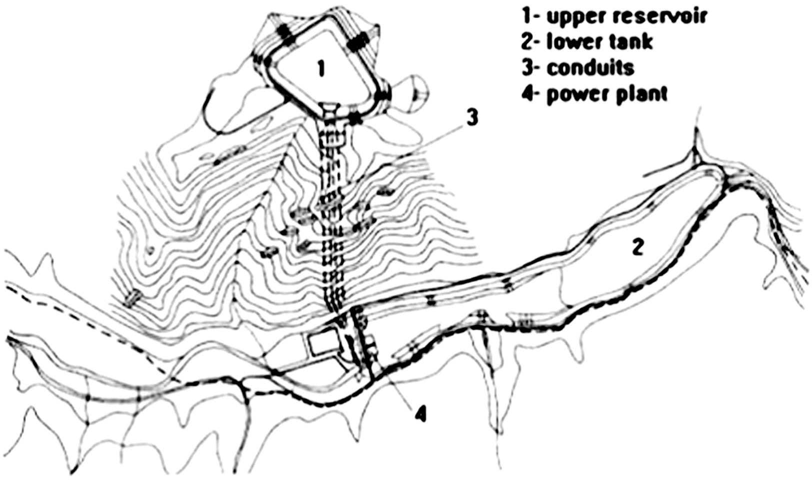
THE GROUND PLAN OF THE ENGINE ROOM



The power capacity of the power plant is lead out through the blocked transformations to the 400 kV switching room of Liptovska Mara. Its own usage is secured by the flow assembly and the 22 kV line. The flows above 8 $m^3.s^{-1}$ are let into the riverbed out as idled to secure water economy of the river. It is not possible to use the water rate for recreational purposes because it is not safe, as the pumping comes to an unexpected swinging of the water surface.

The performance of assembly is fully automated, directly controlled by the Slovak energy dispatching in Zilina. The run up from un-worked turbine takes 70 seconds, to pumping operation it takes 3 minutes. The annually production is 314 GWh of electric energy, of this about 312 GWh is realised with pumping; whereas the consumption at pumping is about 418 GWh. The aggregates are each year started approximately 4500 times at turbines, pumping and compensative operation.

The situation of pumping through of power plant Cierny Vah



Small hydropower plants

Since realized small power plants projects are very mixed in Slovakia, referring to type, flow rates, decline and installation by production units and power capacity, it is difficult to case a sample project.

Another problem is that many of them are projected, built and operated by a private person. Their project documentation is not free for the public. Because of that we have just brief information on most of these projects.

The specification of hydropower plants according to the installed power capacity:

Region	Locality	Installed power capacity in kWh
The west of Slovakia	Tura	2168.0
	Velke Blahovo	1200.0
	Nova Dedinka	1120.0
	Male Palenisko	1080.0
	Preselany	800.0
	Bosany	440.0
	Drahovce	375.0
	Horne Oresany	70.0
	Podluzany	55.0
	Kunov	41.0
The middle of Slovakia	Uhorska Ves	992.0
	Trnovec na Vahu	800.0
	Okolicne	800.0
	Krpelany	500.0
	Jasenie	495.0
	Nosice	400.0
	Lubochna	400.0
	Brezno-Bujakovo	340.0
	Hrinova I	320.0
	Dubrava	257.0
The east of Slovakia	RIMY Sulin	900.0
	ROTOR Vysne Opatske	630.0
	Vojany	500.0
	Huncovce SES	500.0
	Tahanovce	400.0
	Druzstevna nad Hornadom	400.0
	Liptovska Teplicka	360.0
	Stakcin	360.0
	Betlianska Masa	250.0
	Krasna nad Hornadom	150.0

In the table, just the biggest hydropower plants in each region, which deliver energy to the public network and do not belong to an energy company are indicated (source: SE a.s., The Energy Consulting in Bratislava, 31.12.2000).

According to the shoulder of the turbine it is possible to divide small hydropower plants as follows:

Locality	Type	Quantity	Output per unit	Head /m	Rev at min__
Small Francis' turbine					
Liptovska Teplicka	Horizontal	1	370.0	66.0	1000
Gabcikovo	Horizontal	2	585.0	17.2	360
Predajna	Horizontal	1+1	160.0+80.0	8.0	270/352
Dobsina	Horizontal	1	2058.0	53.0	600
Turcek	Horizontal	1	172.0	41.5	760
Small Peltons turbine					
Liptovska Dubrava	Horizontal	1	257.0	133.0	930/1500
Malinec	Horizontal	1	47.0	45.0	500/750
Turcek	Horizontal	1	63.0	52.0	580/1000
Small Kaplan turbine					
Brezno-Bujakova	Vertical	2	170.0	7.0	600
Moson	Horizontal	2	636.0	7.0	300/750

At the table are power plants attached by the turbines from the Czech producer - CKD Blansko (source: official home page CKD, ref about the small hydropower plants).

5 Safety precautions

In Slovakia the keeper of a power plant has the responsibility for safety during operation and working on electric devices according to technical norms. In Slovakia these are the STN, which are in accordance with normalization of the European Union (EN).

As an example on how many regulations are necessary to keep during the operation of a hydropower plant, the Slovak general valid norms are the following:

- STN IEC 61 140 – protection against injury of electric current. Collective point of view for installation and devices
- STN 33 2000-4-41 –protection against injury of electric current
- STN 33 2000-5-54 - selection and built of electric device. Earth system and protective conductors
- Another STN concerns the initiate problems STN 34 1390, STN 33 2000-6-61,
- STN 33 0050-826, STN 33 0050-195, STN 33 2000-1 and STN 33 2000-3
- A notice 74/1996 Z.z – (statute-book) - to secure a safety and protection of health while working, the safety of technical equipments / pressure device, lift device, electric device, gas device/ and professional qualification
- Laws concerning initiate problems, for example 95/2000 Z.z. about inspection at work 330/1996 Z.z. together with changes and amendments about safety and protection of health at work
- Rules of government of the Slovak Republic concerning the initiative to built a power plant

The keeper of a power plant also has to respect the rules which are published by the energy company and the customer of electric energy which is produced on hydropower plants. The rules include all valid norms and requirements of the distribution company.

5.1 Security protection to avoid injury of electric current

Security protection in the hydropower plant to avoid injury of electric current should meet all the terms of STN 33 2000-4-41- STN include all basic requirements, which is needful to respect to secure the safety.

The norm is in accordance with the internationally norm IEC 60364-4-41. The norm terms are given for secure protection of people and farm animal against the danger and damage which can arise at the normal use of electric device.

The main rule of security against injury of electric current in the meaning of the STN IEC 61 140 are:

- Dangerous alive parts are not open public.
- Accessible contact parts may not be under tension at normal conditions or at breakdown. The protection at normal conditions provides the basic protection.

To keep the above norms the keeper of the power plant is responsible. He/she is also responsible to familiarize of service with the security rules according to the electro-technical qualification in the meaning of Notice 74/1996 Z.z.

The electric equipment of a power plants has to cover min. IP 20 (avoid the touch of a finger or small piece). Also it is necessary to secure protection of touch from dangerous voltage on moving parts, for example: self acting feed.

5.2 Secure of safety at the process of a hydroelectric dam

The keeper is responsible to keep all norms determined by the energy company according to the law 50/1976 Zb., the water law 138/1973 Zb., the energy law 79/1957 Zb. and their execution rules.

The terms for safety security include these requirements:

- The economic working of mechanisms includes the accessory and the objects
- The security of the people who are in the object (with knowingness of the keeper)
- The service of all incoming ways to the objects, equipments, the security of movement along the stairs, ladders etc.
- Assign the functionality of all constructions, on the place of danger fall, it is not allowed to remove the banister and other secure issues as shaft. All wholes in the ground have to be covered or fenced. All floors have to be clean and flat.
- Assign proper lighting during operation.
- Put up the security communication as is -no entry to an unwanted person-. The tables have to be placed on designated places and readable.
- The communication, the escape ways and all the passages among the machines have to be free; it is not allowed to narrow them.
- The entry to higher placed components, fixture, stoppers have to meet requirements for security work in heights.
- The rotation parts and others dangerous parts of the machines have to be covered or fenced and can not be removed while operating.
- The auxiliary equipment for maintenance work should be placed in a special room.
- A worker who takes care of the electric equipments in the hydropower plant has to be informed on all rules about the work on electric machines for the workers without the qualification in meaning STN and the ordinance to 74/1996 Z.z

6 Environmental aspects

6.1 Choosing the location

The methods for choosing a location are described in the second chapter. The most suitable locations are the ones which in the past had run small water sources of electric energy as mills or sawmills. The best is if small parts of buildings are still present. The significant condition is to solve the property of the land (purchase or rental).

6.2 Territorial, construction and hydro-legal pursuance

After the issue of the property of the land it is necessary to get permission for the construction of a hydropower plant. At the construction pursuance it is important to proceed in harmony with the construction law 50/1976 Zb. and law 237/2000 Zb. which makes the charge for water by the law about water 184/2002 Zb.

To the construction pursuance is necessary to assign the project documentation which consists from:

- The region-planning groundwork and documentation
- The documentation needed for getting the territorial decision
- The project of the construction needed for getting the building permit

To prepare the project it is necessary to document all packages of the records. The documentation can be divided into the following:

- Topographic records –using official maps with scale of 1:5000
- Geological records – using results of the geological study in certain locations
- Hydrologic records – counting the area of the catchments, the total precipitation, the daily flows and others
- Data about water quality
- Fulfilments of the requirements for nature protection
- Other inquired data according to the location

The project of the construction includes the data that refer to the purpose of the building and targets, which the investor wants to achieve with the building, including the conditions, which have to be kept while building. Also it serves for choosing of potential construction companies.

Assignments of the construction consist from:

- **Covering letter** – This contains the identifying piece of information on the construction and the investor, the basic data about the building, the substantiation of construction and its location.
- **Project documentation** – This contains the situations with placement of the buildings to environs and markings of the agricultural and forest ground. The sketch-map, usually with a scale of 1:1500 contains marked builds and building / construction sites, the

underground distribution network and canalization, the categorisation of the protective zone and objects, possibly vegetation which is appointed to deforestation. The project documentation contains also the architectonic and dispositional arrangement of objects.

The project documentation is needed also for retrieval of opinion from the responsible authority, determined by the built law.

The construction pursuance consists of:

- The water-legally pursuance – Its result is the stance of the company which takes care of the river basin in which the location of the buildings is placed. Within the pursuance the build of power plant with the reference to its effect on surface and underground water, or potential sampling of surface water, outlet of the waste water, the draining of the grounds, the protection of fishing, regime of the flow of high water, an influence on the winter regime of water-course and conduit of ices, and others factors is particularly judged.
- The negotiation of conditions of the built and operating in the power plant with relevant authority of the public administration.
- The negotiations with distribution network of energy in the place and conditions of the connection to the public distribution network.
- The negotiations with the deputies of the communities and the cadastres which the build has to bear with.

The project documentation should be enough for the civil engineer, who is authorized for that category of the buildings, for the development. He needs to be registered in a relevant register. The project of the building is an overall architectonic, technical, economic, ecologic and art solution of the built.

The project, attach to the Letter of application about the building approval includes:

- Covering letter
- Overall technical information
- Total situation of the built
- Coordination drawing of the built
- Documentation and drawings of buildings
- Building/construction site and the phases of the built
- Summary of the documents which includes point of view of competent authority

The building is divided into a built part and a technological part.

The built part includes the building of:

- Water tank
- Swell equipment
- Intake object with accessory
- Sewage
- Working and safety equipments
- Outlet object

The technological part consists of:

- Cradles
- Intake stopper
- Turbines
- Gearbox
- Generator
- Electro-technical part including the safety

7 Installations

Chronologically the construction contains the realization of the built, the mounting of the different techniques, the testing, and the test operation. This order has to be kept very strictly according to instructions which are published by the network distribution company, which is the customer of the produced energy made in small hydropower plants.

7.1 Realization of the built

Small hydropower plants are only possible to establish, restore or develop with the approval of the network company; furthermore it is important to keep all conditions which are determined by the built law and water law. The investor or keeper is obligated to discuss with the distribution network company all terms for connection to the public network, operation and business terms.
It is required to present the following data for this negotiation:

- The location of the built and the sketch map
- The presumptive installed output, the quantity of the yearly produced energy, the quantity sold to the distribution company (orientation daily or yearly graph of production).
- The type of generator – synchronous or the asynchronous generator
- The proposed plan for the realization of the built

When the output should be connected to the low tension network the discussions for agreements are lead by the distribution company.
When the output should be connected to the high tension network the discussions for agreements are lead by the management department of the network distribution energy company.

The distribution company issues the final formulation to the project documentation from the view of connection of the small hydropower plant.
The trade terms between the supplier and purchaser of energy are on the basis of a contract.

7.2 Installation of technology

After the ending of the construction part, the investor starts to install the technology, which also comes under the instruction of the distribution energy company. Small hydropower plants with an installed capacity over 100 kW are connected to the network vn through a blocked transformer (nn/vn), as long as the distribution company gives permission for this exception. If the hydropower plant has the voltage of the generator vn, a blocked transformer (vn/vn) is installed.

A small hydropower plant fixed by an asynchronous generator is possible to initialize to an output of 15 kV. The synchronous generators are connected to the network after completion of all the synchronous conditions.
The small hydropower plant has to be equipped by the switching spot which has to be accessible for all workers who work for the distribution company.

The position "switched –off" has to be locked and the space of taking over have to be equipped by a sign "Watch out! Deadly current!". For a small hydropower plant fixed by an asynchronous generator it is necessary to review the need of compensation of the "cos φ" which is compensated by capacitor batteries with a value 0.95.

The safety system installed in the hydropower plant is part of the technical equipment. It has to fill requirements for safety of workers and for protections of the devices of the distribution company. Of course it has to be in the harmony with the valid technical norms. The types of protection are chosen by the designer of the hydropower plant.

The safety system has to provide the following functions:

- Automatic disconnection of the small hydropower plant from the devices of public distribution when there is loss of voltage in the network already at the loss of one phase and automatic blocking against reconnection on until the return of the voltage in the network.
- Automatic disconnection of the hydropower plant (above 20 kW) from the network in the case that the generator comes into the motor condition.
- Security of the distribution network against too high voltages.
- Protections have to be equipped by a seal cover against unauthorized modification. The sealing of protections is done by workers of the distribution company after verification of the functionality, at the latest before starting the testing operation. Without the seal of protection the hydropower plant is not allowed to operate.
- Spare sources of electric energy, for example diesel-assembly have to be secured to avoid unwanted delivery and against wrongful manipulation.

Another technical equipment of the small hydropower plant is the device for measuring of electric energy delivered to the power system. The measuring had to take a note of invoicing, which is agreed between the supplier and customer. Electrometers for measuring of delivery and consumption of energy in a small hydropower plant have to be equipped by the brake against reverse. They have to be officially checked and calibrated. The measuring transformers also need to be calibrated. The location of the electrometer has to be discussed with the distribution company. It has to be always outside of the building, at the service pipe not longer then 50 m from the point of the public network. The own usage of small hydropower plant is secured from the bus bar nn, preferentially it is covered by the own production.

7.3 Testing, takeover negotiation

After the installation of the technology devices the keeper announces at the latest 30 days before hydropower plant is ready to start operating.

The participants at the transfer are the following divisions of distribution company:

- Authorization department of project documentation
- Section of technical inspection
- Section of business with electric energy
- Authorized distribution company

During the 30 days the department of security of the distribution company performs the test and the seal up operation.

At the transfer the keeper presents the following documents:

- Planning permission
- Expression of the distribution company to the project
- Drawing documentation of real technological parts
- Technical management
- Inspection management
- Authorized attests from the electric distributor, generators, protections, control systems etc.
- Confirmation of rightfulness of the organization preferably with qualifications of workers which performed the installation
- Confirmation of service of a training centre on hydropower plants
- Protocol about the handover and takeover of built
- Proposal and bank order; which can be in the period of 1 year supplement, or specified

The commission named by the participants performs the tranfer in the presence of investor (keeper), supplier of electro parts and designer perform the functional tests, mainly oriented on the protection of the distribution network before unwanted delivery of energy during times of breakdown in the network, repair and standing. Also the necessary measuring of the influence of the hydropower plant to the distribution network is done. The take effect of the protection is checked by the simulation of failures at the different regimes of operation of the hydropower plant.

The following measurements are carried out at the transfer:

- Functionality of active and empty electrometer the minimum and maximum output
- Control of network symmetry
- Keeping of prescribed tolerance and stability of the voltage

- Size of effectiveness at minimum and maximum output – compensation
- Size of the run up current and its influence on the decrease of the voltage at the point of connection to the grid (only when an asynchronous generator is used)

At the take over pursuance the commission writes down the minutes in which defects, if any, are initiated together with the dates of its mending.

7.4 Testing operation

The distribution energy company gives an approval for the period 1 – 3 months on testing operation.
During this testing operation all abilities of the power plant on the delivery of electric energy in desiderative quality are checked, without influences on the distribution network.
After testing and checking on the corrections of all defects mentioned in the record from the takeover pursuance, the keeper of the hydropower plant requires for written permission for permanent operation.
The permission is published by the department of technical control of the distribution company.

8 Working and service of a small hydropower plant

The main condition for the operation of a small hydropower plant is the publication of the working permission and the process of approval. The keeper of a small hydropower plant has to hand in the operating and manipulate order of the small hydropower plant to an authorized distribution company. The distribution company has to familiarize all employees, which have something to do with the small hydropower plant.

The keeper takes full responsibility for operating and work on electric devices of the small hydropower plant in meaning of the valid technical norms (in Slovakia the STN).

If there are problems during the operation of the small hydropower plant the distribution company has, according to the public network, the right to set additional requirements towards the keeper concerning the technical remedy needed for correction of any unwanted influence on the network.

The keeper is also obligated to make periodical inspections and archive all documentation about them.

8.1 Operating and manipulating order

- The manipulating order is a package of rules, principles and regulations for manipulating water. These come from the permission of the water-economic authority for the operating of a small hydropower plant. It describes how to handle surface water from the purposeful and economic view in a hydroelectric dam as well as the protection of that dam and improvement of water quality. It contains a graphic annex with a simplified scheme of objects of a small hydropower plant in lengthwise and crosswise profile. In a small hydropower plant till 100 kW the manipulating order can be the territory of the collective operating-manipulating order. If the water economic authority does not specify to develop a manipulating order, the manipulation of water is included in the water economic permission. For the processing of this order it is recommended for the keeper on the river to consult keepers of other small hydropower plants on the river.
- The operating order is an independent document. It describes the basic methods and conditions for start up of the hydropower plant, the operation and the service of the devices in the hydropower plant. At the same time the security of service and independent devices is described.

8.2 States of emergency at the operation of a small hydropower plant

States of emergency at the operation of small hydropower plant are states, during which decrease of its efficiency, possibly the total failure or stopping occurs.
The following states of emergency are considered:

- Operation during low flows
- Operation during floods
- Winter-operation

The influence of the states of emergency has to be included already at the selection of the location suitable for building a small hydropower plant. The effectiveness of its investments has to be calculated first, because they can differ very much depending on the location and the water-stream. The influence of the states of emergency are also accounted for in the forecast of the yearly production of electric energy.

8.3 Automation of operation of a small hydropower plant

The automation of small hydropower plant enables its uninterrupted working with a minimally demand on service. The security system notifies any dangerous situation of equipment which is than secured. The regulations of a hydropower plant include a calculation of dangerous conditions which are not registered by the automated control and which the keeper or service has to detect during a regular check of the functioning of hydropower plant.

The automation of a hydro power plant can be divided as follows:

- Shear automation – provides a disconnection and signalizes a breakdown situation. For the operation of a small hydropower plant it is needed to be present.
- Complete automation – provides absolute operation. Checking of the operation by presence is needed every one or two weeks only.

The complete automation contains:

- Regulation of the turbines, so that normal operation and reaction on the fault states are secured.
- Self-acting disconnection and connection of the generator to the network at the beginning and ending of breakdown conditions.

A power source connected to the public distribution network has to be secured on the following items:

- Connection of the generator to the network - the synchronous alternator has to be phasing.
- Disconnection of the generator and security of the turbines against over-running - an unexpectedly upgrading of revelation - at the breakdown points as well as voltage failure in the network, the short, starting output of the generator or over-heating of mechanical parts.

9 Technical service

The overview of regular technical service is initiated in the operating book of each hydropower plant.
The keeper has to plan a complete check up by professionals every three years. If the hydropower plant has wooden buildings the check up has to be done every two years.
The check up of the lightning conductor has to be done every five years.

10 Training

To be able to perform good training and measuring it is necessary that turning electric machines, which are controlled by electric jets with power-switch, are at the disposal.

For example:

The control of requirements of near-phasing and phasing of synchronous alternator
Even though, that presently automatic phasing is very often used the exercise is still useful. The exercise comprises, after spinning of the alternator, the mechanical check of the accomplishment of the phasing conditions and subsequently the connection of the alternator to the public distribution network.

The measuring of electric energy produced and transferred to the public network and the own usage of the power plant
During simulation of the performance of hydropower plant this measurement can be realized, if possible, during an excursion in the hydropower plant.
Apart from these measurements it is possible to realize other exercises. This could for example be the working of the generator of the asynchronous motor, or measuring on protections with simulations of failures of the hydropower plant.

11 Questions

1. From which century we utilize hydro energy for generation of electricity?
2. What is the main principle of hydropower utilization? (text and physics formulas)
3. What are the main parameters of a hydropower plant?
4. Name the types of hydropower plants?
5. What is the main principle of re-pumping power plant?
6. How can hydropower plants be divided according to the declivity?
7. How can hydropower plants be divided according the size of the dam and installed electric power?
8. Which are the things that have to be considered when looking for suitable locations for the building of a hydropower plant?
9. What are the main parts of A hydropower plant?
10. Presently what kind of turbines are most used?
11. How can turbines be divided according to the flow of waters?
12. Describe the synchronous alternator and explain its activity.
13. What does the word Vah cascade mean?
14. What are the three most widely known power plants in Slovakia?
15. Who is responsible for safety during operation of a hydropower plant and working on their electric devices?
16. What are the grades of automation of a hydropower plant and what does complex automation of small hydropower plant mean?
17. Explain the way of phasing of a synchronous alternator to the net.

12 Teacher’s handbook

12.1 Introduction

This is the general course of information on hydro energy. This chapter contains the ground information about the hydropower utilization for generation of electricity. All students familiarize themselves with many types of hydropower plants and with types of turbines. The students will be learning how and where which type of hydropower plant to locate as well as concerning the individual conditions and facilities.

12.2 Course description

The course is controlled by an instructor and is given mostly for students within basic technical education as well as for workers and people, who are interested in this issue.
Most of the course has a theoretical character.
The course is divided into the following 10 units:

1. Introduction to Hydropower including historical development
2. Basic principles of hydropower utilization
3. Technical equipment of a hydropower plant
4. Description of some implemented projects
5. Safety precautions
6. Environmental aspects
7. The building and installation process of a hydropower plant
8. Working and service of a small hydropower plant
9. Technical service
10. Training of personnel

12.3 Course objectives

After completing the course students are able to:

- List the functions of hydropower plants
- Have a complete view of the types of hydropower plants
- Have a view on the composition and functions of the individual components of hydropower plants
- Explain the advantages of utilizing energy of water movement
- Explain the main principle of hydropower plants

12.4 Course outline

The following table lists the course outline:

Day	AM:	PM:
	07.50 – 08.35 10.15 – 11.00	13.00 – 13.45
1.	Lesson 1, 2	Lesson 3
2.	Lesson 4, 5	Lesson 6
3.	Lesson 7, 8	Lesson 9, 10
4.	Excursion at a hydropower plant (3 hours).	
5.	Excursion at another type of hydropower plant (one all day).	

12.5 Media

A computer and a projector are needed for presentation of information.

A computer, a beamer, a television and a video–player are useful for presentation of themes which concern hydro energy.

The instructor can use the records on the CD-ROM and present some of them to the students with a beamer. Students can get a copy of the lections on CD-ROM.

12.6 Instructor feedback

For feedback on this course, please, contact:

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12.7 Sources

For the development of this course, the following sources have been used:

[1] **Ing. Vladimír Seewald, DrSc.:** Hydroenergetika – významná súčasť elektrizačného systému SR, VIAC Trenčín 1998
[2] **Ing. Pavel Kminiak:** Vodné mikroelektrárne, ALFA Bratislava 1990
[3] **Ing. Ladislav Voženílek – Ing. František Lstibůrek**: Základy elektrotechniky II
[4] **V. Ondrušek – M Dušička:** Význam a využitie hydroenergetického potenciálu Slovenska
[5] **EE –** odborný časopis pre elektroniku a energetiku: vydáva HMH, s.r.o Bratislava
[6] **Slovenská energetika:** spravodajca Slovenských elektrární, a.s. Bratislava
[7] **Publikácie Slovenských elektrární, a.s.:** Program DSM

12.8 Questions and answers

1. From which century we utilize hydro energy for generation of electricity?
   We have been using water for producing of electric energy since the 19th century.

2. What is the main principle of hydropower utilization? (text and physics formulas)
   Hydro energy proves itself by the movement effect which is depends on the flow velocity and also on the pressurize effect of the height of the water column.

   The carry out work – energy can be expressed as following:

   Kinetic Energy
   $E_k = \frac{1}{2} . m. C^2$, at which
   m = weight of water (kg)
   C = water speed ($m.s^{-1}$)

   Potential Energy
   $E_p = m. g. \ H$, at which
   g = acceleration of free fall (g = 981 $m.s^{-2}$)
   H = height declivity (m)

   Pressure Energy
   $E_t = p. m / \rho$, at which
   ρ = water density ($kg.m^{-3}$)
   p = specific pressure (Pa)

   As the law of energy conservation is applicable in nature, the total amount of energy which is given by the sum of kinetic, potential and pressure energy is constant. Only their proportions are changing.

3. What are the main parameters of a hydropower plant?
   The main parameters are Theoretical hydro-energetic potential. The formula is:

   $P = \rho.g. Q.H$ (MW)

   At which:
   H = net head (the difference between water level in front of and behind the turbine) (m)
   Q = average overflow ($m^3.s^{-1}$)
   ρ = water weight
   g = acceleration of gravity

4. Name the types of hydropower plants?
   Water-gate - head hydropower plants
   Derivative – flume hydropower plants
   Pump through the hydropower plants
   Dam – accumulation hydropower plants
   Hydropower plants using the ocean energy

5. What is the main principle of re-pumping power plant?
   Pump through the hydropower plants – enable to accumulate hydro energy by pumping through water from a lower reservoir to an upper reservoir. The hydropower plant works in two modes. When electricity consumption is low, energy is spent on the pumping of water. When electricity consumption is high, water is sluiced from the upper reservoir and electricity is produced during this sluicing.

6. How can hydropower plants be divided according to the declivity?
   Law-pressure plants – head from 15 to 20 m
   Medium-pressure plants – head to 100 m
   High-pressure plants – head from 100 m

7. How can hydropower plants be divided according the size of the dam and installed electric power?
   - **Big hydropower plants – their installed power is bigger than 10 MW – in Slovakia these are derivative, accumulation and re-pumping hydropower plants.**
   - **Small hydropower plants - their installed power is less than 10 MW.**

8. Which are the things that have to be considered when looking for suitable locations for the building of a hydropower plant?
   If we want to use hydropower effectively in certain location, we must take care of head and overflow on that place. The production of the electricity must be profitable and must not invade the ecosystem.
   The amount of energy produced is influenced by declivity and water course.

9. What are the main parts of a hydropower plant?
   Intake
   Conduit and sewage
   Production parts
   electro- technical equipment and connection to the distribution network.

10.Presently what kind of turbines are most used?

Francis' turbine
Pelton's turbine
Kaplan's turbine
Banki's turbine
Girard's turbine

11.How can turbines be divided according to the flow of waters?

Axial flow turbine - water races parallel with the turbine's axis. (Kaplan's turbine)

Radial flow turbine - water races perpendicularly to the turbine's axis. If water flows from the shaft, the turbine has an internal intake - centrifugal. If water flows to the shaft the turbine has an external intake – centripetal.

Radial - axial turbine - water flows by the runner wheel rotary, than changes direction which is approximately parallel with the axis (Francis' turbine).

Diagonal turbine – water races by the runner obliquely to the shaft.

Tangential turbine - water flows to the paddle wheels of the runner at the direction tangent to the circle of the paddle wheel (Pelton's turbine).

Double flow rate - water enters centripetally and get out centrifugally (Banki´s turbine).

12.Describe the synchronous alternator and explain its activity.

The synchronous hydro alternator is a multiple slow - running synchronous machine.
In the grooves of the magnetic circuit of the stator a three-phase winding, connected to the star or triangle, is poured. On the terminal extensions of the rotor a one-way field winding, which is through the circles and brushes connected to the source of the one way current, is placed. As source the exciter - derivational dynamo, placed on the one shaft with alternator - is used.
The advantage of a synchronous alternator is that it has an ideal ballast characteristic and high overload. If power is added to the electric system, phase problems have to be solved. If the condition of phase (identical train of phases, the value of voltage, the value of frequency, and nominal value of voltage net and alternator) are in order, then, during the operation, frequency and voltage are kept at the values in the network. By this way all big hydropower plants are developed.

13.What does the word Vah cascade mean?

By the building of 25 power plants the trim stream of rivers Vah and Orava have been reached. This way a flood protection has been created. Inside the power plants are 73 mechanisms. An installed power capacity of approximately 2200 MW significantly contributes to the producing of electric energy.

14.What are the three most widely known power plants in Slovakia?

The three most widely known and typically interesting ones are the hydroelectric dams Gabcikovo, Liptovska Mara and Cierny Vah.

15.Who is responsible for safety during operation of a hydropower plant and working on their electric devices?

The keeper of a power plant has the responsibility for safety during operation and during working on electric devices, all according to the national technical norms(in Slovakia the STN, which are in accordance with normalization of European Union (EN).

16.What are the grades of automation of a hydropower plant and what does complex automation of small hydropower plant mean?

- **Shear automation – provides a disconnection and signalizes a breakdown situation. For the operation of a small hydropower plant it is needed to be present at the power plant.**
- **Complete automation – provides absolute operation. Checking of the operation by presence is needed every one or two weeks only.**

The complete automation contains:

- **Regulation of the turbines, so that normal operation and reaction on the fault states are secured.**
- **Self-acting disconnection and connection of the generator to the network at the beginning and ending of breakdown conditions.**

17.Explain the way of phasing of a synchronous alternator to the net.

Control of requirements of near-phasing and phasing of synchronous alternator:
After spinning of the alternator, a mechanical check of the accomplishment of the phasing conditions is performed and subsequently the connection of the alternator to the public distribution network is made.