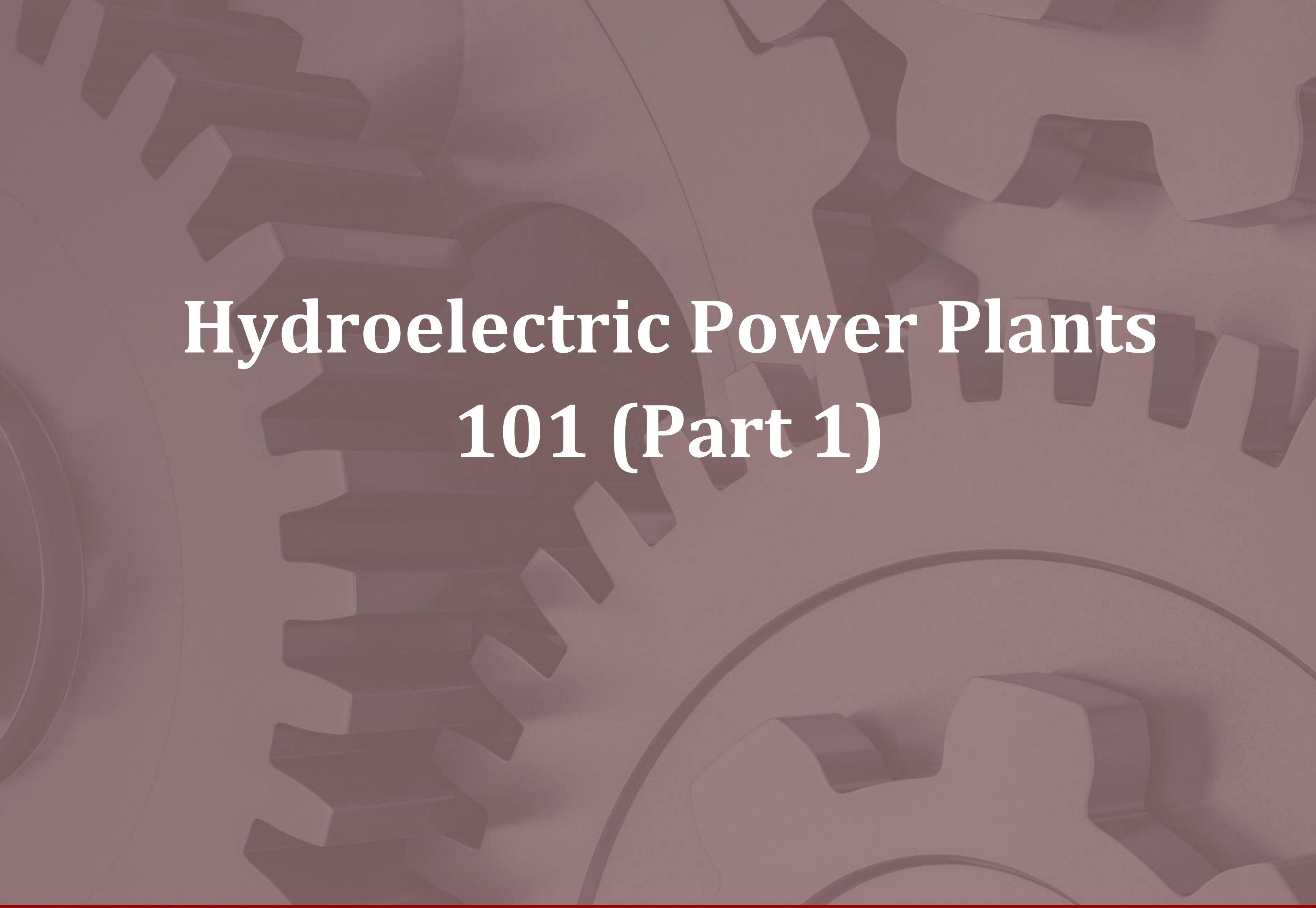

Hydroelectric Power Plants 101 (Part 1)

An Online Continuing Education Course for Engineers

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Introduction

Hydropower is renewable, clean, and does not leave any waste behind. Hydropower is known for clean production, not producing greenhouse gasses or other air pollutions. Obviously, this renewability is a significant advantage. Dams are oftentimes built to store water. The environmental impact of adding hydroelectric power plant to an existing dam is minimal if any. However, significant changes can occur when an existing dam site is developed for power generation. For example, water that would greatly aerate while flowing over the dam spillway is now funneled through turbines where little aeration can occur. The subsequent major difference in the rate of aeration at a certain location in the river can have a significant impact on the dissolved oxygen content for a considerable reach of the river. In certain areas, especially those near large municipalities, the environmental impact can be significant.

While hydropower plants have no fuel cost, their construction and capital equipment costs (per unit of installed capacity), are substantially greater than thermal power plants. On the other hand, a substantially larger fraction of the investment capital for hydropower development in a region can remain in that region since much of the work can be done by the local engineers and contractors. The more sophisticated thermal power plants are normally designed and built by experts coming from outside of that region. This means that a large amount of the capital will leave the local economy.

Hydropower facilities require minimal maintenance and less skilled personnel as compared to thermal power plants, therefore have lower operation and maintenance cost.

There are other advantages for hydropower, especially for the small units. Small hydropower facilities can be more cost-effective. Utilizing modular construction for small hydropower facilities has led to approximately 30% cost saving. In many cases, in developing countries, the small hydropower station becomes a catalyst for the development of small manufacturing facilities.

It has been illustrated by the Curuá-Una Dam in the Amazonian portion of Brazil that hydroelectric dams in tropical forest areas emit greenhouse gases, which include CO_2 and methane. CO_2 originates from the decay of the above-water portions of trees standing in the reservoir. Methane, however, originates from soft vegetation that decays under anaerobic conditions on the bottom of the reservoir. Macrophytes (water weeds) and vegetation, growing in the drawdown zone and are flooded when the reservoir water level rises, emit methane.

Some methane is released from the reservoir surface through bubbling and diffusion, but larger amounts are released from water passing through the turbines and spillway. Methane concentration in the water increases with depth. Turbines and spillway draw water from sufficient depth to have substantial methane content. It is believed that, by 1990 (13 years after filling), the Curuá-Una Dam had emitted 3.6 times more greenhouse gases than would have been emitted by generating the same amount of electricity from oil.

Hydropower Plants Types

Hydroelectric power plants can be *single-purpose* or *multi-purpose*. The only purpose of a single-purpose plant is the production of electricity. In multi-purpose facilities, however, hydropower is developed in conjunction with irrigation, flood control, navigation, and water supply. Hydropower plants may be categorized by the type of utilization, as well. A baseload plant provides all or part of a sustained and constant portion of the electrical load. Energy from these plants, which is available all the time, is called “firm power.” Peak load facilities provide power requirements above the baseload needs to meet variations in the power demand. The electrical production capacity for such plants is relatively high, and the water discharged can be changed readily to meet the peak demands. These plants can start and stop more rapidly and economically than thermal (fossil/nuclear) power plants.

Run of the river hydroelectric power plants utilize the energy of the flowing water to generate electricity. The absence of a large dam and reservoir is how they differ from conventional hydroelectric facilities. A short penstock or dam directs water through the turbines. The natural flow of the river remains relatively unchanged except for the oxygen content. A more complex development occurs when water is diverted from the river into a canal or long penstock. Water leaving the turbines is eventually thrown back to the river at a lower level downstream. This results in a major change in the flow of water in a given reach of the river, sometimes for a considerable distance. For the run of the river plants, power generation fluctuates with the river flow, and firm power is considerably low.

Pumped storage hydropower (PSH) is a modified form of the conventional hydropower technology used to store and manage energy or electricity. Pumped storage hydropower projects use electricity to store potential energy by transferring water between upper and lower reservoirs. During the pumping mode, low-cost off-peak electricity is converted to potential energy and stored in the form of water at an upper elevation. This is why it is sometimes referred to as a “water battery.” Pumping water uphill for temporary storage “recharges the battery.” During high electricity demands, the stored water is released through the turbines to generate electricity. Turbines are, in fact, the same pumps running in reverse. Although pumping water consumes more electricity than that generated by the turbine, this system still generates revenue by generating and selling electricity during peak demands, when electricity prices are the highest. Current pumped storage cycle (combined pumping uphill and generation downhill) energy efficiencies exceed 80%, comparing very favorably to other energy storage technologies. Additionally, PSH provides longer storage duration more economically than other storage technology.

Tidal power plants have also been developed in the areas where there are large tidal fluctuations. The gravitational pull of the moon and sun along with the rotation of the earth cause the tides. In some places, tides cause water levels near the shore to vary up to 40 feet. A complete bay or estuary is enclosed by a low dam, and low head turbines are used to harness the energy in the tidal cycle. Sluice gates open to let water flow in during the rising tide and then close with returning tide as water directed through a standard hydro-turbine.

Hydropower Plants Sizes

Hydroelectric power plants range in size from large power plants that supply many consumers with electricity to small, mini, and micro plants that individuals operate for their own energy needs or to sell power to utilities. Although definitions may somewhat vary, the following may be used to categorize the hydropower plant based on their sizes.

Large Hydropower: Facilities that have a capacity of more than 30 MW (megawatts).

Small Hydropower: Facilities that generate 15 MW or less.

Mini Hydropower: Facilities that generate 1 MW or less.

Micro Hydropower: A micro hydropower plant has a capacity of up to 100 kilowatts. A small, mini, or micro-hydroelectric power system can produce enough electricity for a home, farm, ranch, or village.

There is approximately 2,200 GW of developed and potential hydropower existing in the world. The total potential is considered developable based on physical, economical, and environmental considerations. Hydropower is the US largest source of clean, renewable electricity. It accounts for 52% of the nation’s renewable electricity generation and 7% of the total electricity generation.

The Three Gorges Dam, in China, is currently the world's largest hydroelectric power plant, as of the year 2012. Prior to that, the Itaipú Hydroelectric Power Plant in Brazil and Paraguay was the world's largest. The Three Gorges Dam has a generating capacity of 22,500 MW compared to 14,000 MW for the Itaipu Plant. Nevertheless, over a year-long period, both these plants generate about the same amount of electricity, because of seasonal variations in water availability on the Yangtze River in China limit power generation at Three Gorges for a number of months during the year.

In the United States, the Grand Coulee Dam on the Columbia River, Washington is the largest, with a generating capacity of about 6,800 MW. This plant is 7th largest overall worldwide.

Typical large scale hydropower installations have a project life span in excess of 50 years, whereas useful life for micro hydropower facilities (< 100 kW) operating under adverse conditions found in many rural applications can be as low as 10 years.

Hydroelectric Power Plants

Water stored in the reservoir behind a dam has potential energy relative to the downstream reservoir or tailrace. Hydroelectric power plants convert the potential energy of the stored water into electricity. The quantity of water in the reservoir and the falling distance (head, the difference between free surface of the supply reservoir and that of the tailrace) determines the amount of available energy. Head, which has the unit of length, is, in fact, energy per unit weight of the water in the supply reservoir relative to the tailrace.

If water is allowed to flow freely under gravity as a free surface stream such as a river instead of flowing through the turbine, it will dissipate its (potential) energy into ambient in the form of heat. In a hydroelectric power plant, this energy is extracted in the turbine and converted to electricity in the generator.

Figure 1 shows a schematic of a typical reaction turbine installation. H_0, the elevation of the upstream reservoir free surface relative to the tailrace free surface, indicates gross head available to the hydraulic turbine. When water is sent to the turbine, through the pressurized pipe (penstock), part of this head will be lost to friction. The net head available to the turbine at the inlet, section 1, will be H_1. At the turbine inlet (section 1), most of the energy in water is in the form of pressure and some in the form of velocity (kinetic). Obviously, water still has some potential energy as well, due to its elevation relative to the tailrace.

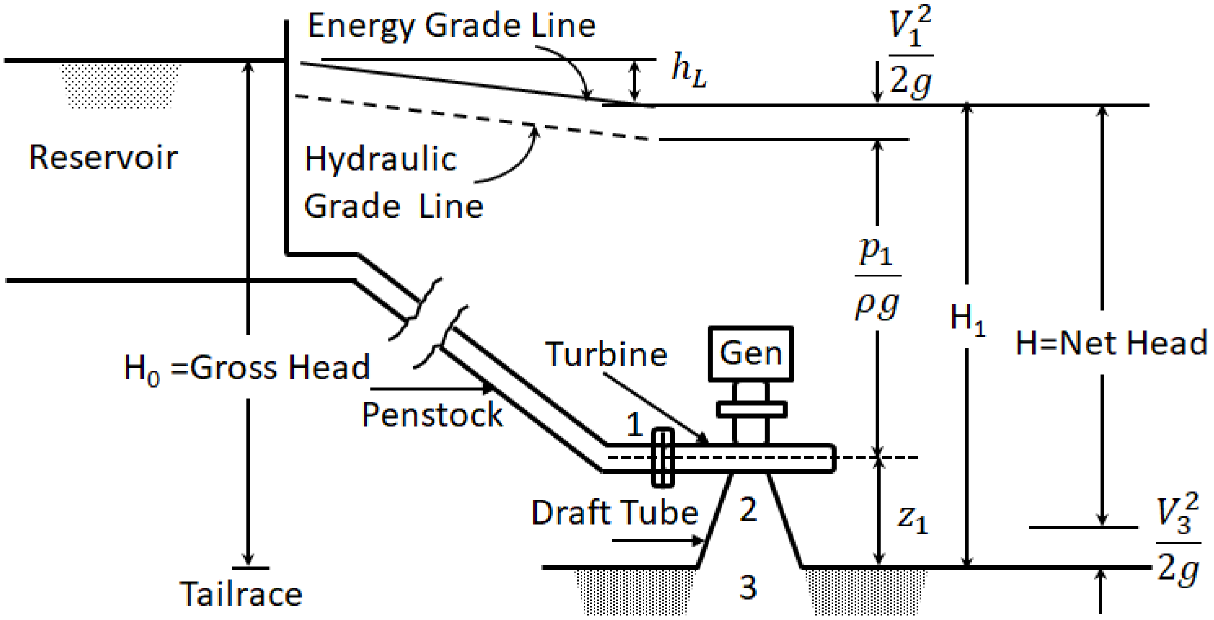

Figure 1: Schematic of typical reaction turbine installation, showing definitions of head terminology

$$H_0 = Gross\ Head = H_1 + h_L$$ (Eqn. 1)

$$H_1 = \frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1$$ (Eqn. 2)

Where,

p_1 and V_1 = Water pressure and velocity at the inlet to the turbine (spiral casing)

z_1 = Turbine inlet elevation, with respect to the tailrace

h_L = Head loss in penstock

All terms on the right-hand side of equation 2 have the dimension of length (head, energy per unit weight of water). These terms are:

$\frac{p_1}{\rho g}$ = Static Pressure head

$\frac{V_1^2}{2g}$ = Dynamic Pressure head (kinetic energy per unit weight of the flowing water)

z_1 = Elevation head

Energy Grade Line (EGL): Points on EGL are representatives of total head height ($H = p/\rho g + V^2/2g + z$) at each section along the penstock. If the flow of water was frictionless, and no work is done on or by the flowing water, then EGL would be horizontal. EGL makes a step change whenever energy is added to (pump) or removed from (turbine) water.

Hydraulic Grade Line (HGL): Points on HGL are representatives of the sum of the elevation and pressure heads ($z + p/\rho g$) at each section along the penstock.

The difference in the heights between EGL and HGL represents the dynamic head ($V^2/2g$).

To gain maximum power output from a hydraulic turbine, mechanical energy in water leaving the turbine must be minimized. This can be done by making the outlet pressure, flow velocity, and elevation as small as possible. The turbine must be installed as close to the tailwater level as possible. In order to utilize the head from the turbine installation point, a piece of pipe called a draft tube is installed at the end of the turbine. Draft tubes, usually in the form of a diverging duct or pipe, transfer water exiting the turbine in section 2 to the tailrace in section 3. In addition to utilizing the elevation head downstream of the turbine, draft tubes reduce the exit kinetic energy, which is a loss, from $V_2^2/2g$ to $V_3^2/2g$. Obviously, part of the recovered energy will be lost to friction in the draft tube.

$$\frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 = \frac{p_{atm}}{\rho g} + \frac{V_3^2}{2g} + draft\ tube\ friction\ loss$$
(Eqn. 3)

$$Net\ Head = H = H_1 - \frac{V_3^2}{2g} = H_0 - (h_L + \frac{V_3^2}{2g}) \qquad \text{(Eqn. 4)}$$

H (Net Head) is the m … nverted to electricity. As
seen, minimizing the … he draft tube will
maximize the turbine … l be given as,

$$P = \rho g H Q \qquad \text{(Eqn. 5)}$$

Obviously, part of this e … turbine and
generator. The power o … as:

$$P(kW) = \eta\gamma(\mathrm{lb}/ft^3)H(\quad ec\,)/1000$$
(Eqn. 6)

Where,

$P =$ Generator output (kV

η = Overall turbine and ge

$\gamma = \rho g =$ Water specific weight (lb/ft^3 or N/m^3)