



Intro to Hydro power

Part 1: Systems Overview

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Hydropower is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and electricity is produced. Many other components may be in a system, but it all begins with the energy already within the moving water.

What Makes Water Power

Water power is the combination of *head* and *flow*. Both must be present to produce electricity. Consider a typical hydro system. Water is diverted from a stream into a pipeline, where it is directed downhill and through the turbine (flow). The vertical drop (head) creates pressure at the bottom end of the pipeline. The pressurized water emerging from the end of the pipe creates the force that drives the turbine. More flow or more head produces more electricity. Electrical power output will always be slightly less than water power input due to turbine and system inefficiencies.

Head is water pressure, which is created by the difference in elevation between the water intake and the turbine. Head can be expressed as vertical distance (feet or meters), or as pressure, such as pounds per square inch (psi). Net head is the pressure available at the turbine when water is flowing, which will always be less than the pressure when the water is turned off (static head), due to the friction between the water and the pipe. Pipeline diameter has an effect on net head.

Flow is water quantity, and is expressed as “volume per time,” such as gallons per minute (gpm), cubic feet per second (cfs), or liters per minute. Design flow is the maximum flow for which your hydro system is designed. It will likely be less than the maximum flow of your stream (especially during the rainy season), more than your minimum flow, and a compromise between potential electrical output and system cost.

You need not have this kind of head and flow to have a good hydropower site—but you could fantasize.

Head and flow are the two most important things you need to know about your site. You must have these measurements before you can seriously discuss your project, how much electricity it will generate, or the cost of components. Every aspect of a hydro system revolves around head and flow. In Part 2 of this series, we will discuss how to measure them.

Power Conversion & Efficiency

The generation of electricity is simply the conversion of one form of energy to another. The turbine converts the energy in the moving water into rotational energy at its shaft, which is then converted to electrical energy by the generator.

Energy is never created; it can only be converted from one form to another. Some of the energy will be lost through friction at every point of conversion. Efficiency is the measure of how much energy is actually converted. The simple formula for this is:

$$\text{Net Energy} = \text{Gross Energy} \times \text{Efficiency}$$

While some losses are inevitable as the energy in moving water gets converted to electricity, they can be minimized with good design. Each aspect of your hydro system—from water intake to turbine-generator alignment to transmission wire size—affects efficiency. Turbine design is especially important, and must be matched to your specific head and flow for best efficiency.

A hydro system is a series of interconnected components. Water flows in at one end of the system, and electricity comes out the other. Here is an overview of these components, from the water source to the electrical controls.

Water Diversion (Intake)

The intake is typically the highest point of your hydro system, where water is diverted from the stream into the pipeline that feeds your turbine. A diversion can be as simple as a screened pipe dropped into a pool of water, or as big and complex as a dam across an entire creek or river. A water diversion system serves two primary purposes. The first is to provide a deep enough pool of water to create a smooth, air-free inlet to your pipeline. (Air reduces horsepower and can damage your turbine.) The second is to remove dirt and debris.

Trash racks and rough screens can help stop larger debris, such as leaves and limbs, while an area of quiet water will allow dirt and other sediment to settle to the bottom before entering your pipeline. This helps reduce abrasive wear on your turbine. Another approach is to use a fine, self-cleaning screen that filters both large debris and small particles.

This variable-flow, crossflow turbine uses a belt-drive coupling to a 40 KW synchronous generator. It supplies electricity to a coffee processing plant in Panama.

Useful Hydro Conversions

Power*

1 horsepower = 746 watts

1 kilowatt = 1.34 horsepower

* Efficiency not accounted for

Static Head & Pressure

1 foot of head = 0.43 pounds per square inch (psi)

1 psi = 2.31 feet of head

Flow

1 gallon per minute (gpm) = 0.0022 cubic feet per second (cfs)

1 gpm = 0.000063 cubic meters per second

1 gpm = 3.8 liters per minute

1 cfs = 449 gpm

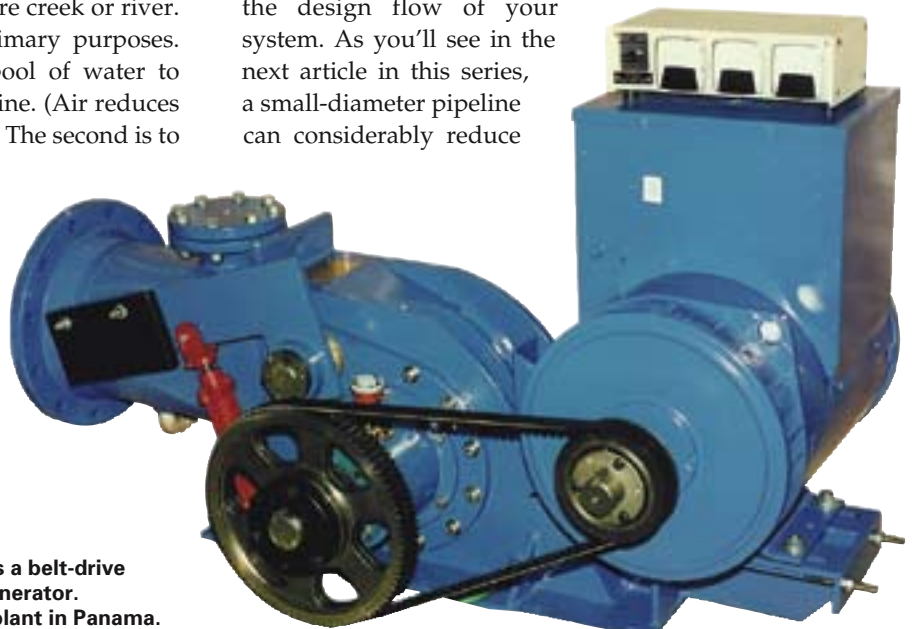
1 cfs = 0.283 cubic meters per second

1 cfs = 1,700 liters per minute

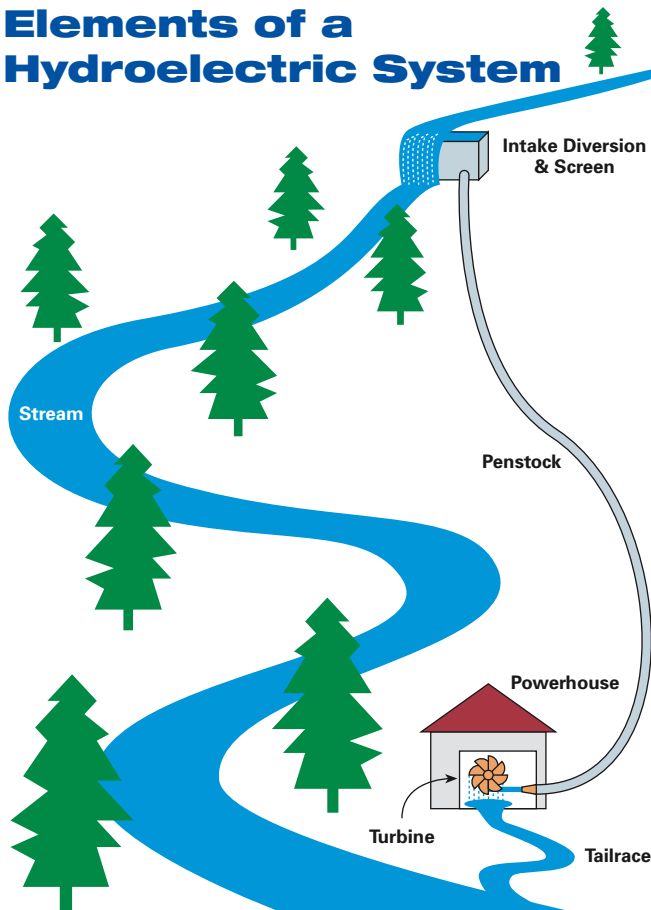
Pipeline (Penstock)

The pipeline, or penstock, not only moves the water to your turbine, but is also the enclosure that creates head pressure as the vertical drop increases. In effect, the pipeline focuses all the water power at the bottom of the pipe, where the turbine is. In contrast, an open stream dissipates the energy as the water travels downhill.

Pipeline diameter, length, material, and routing all affect efficiency. Guidelines are available for matching the size of your pipeline to the design flow of your system. As you'll see in the next article in this series, a small-diameter pipeline can considerably reduce



Elements of a Hydroelectric System



your available horsepower, even though it can carry all available water. Larger diameter pipelines have less friction as the water travels through.

Powerhouse

The powerhouse is simply a building or box that houses your turbine, generator, and controls. Its main function is to provide a place for the system components to be mounted, and to protect them from the elements. Its design can affect system efficiency, especially with regard to how the water enters and exits your turbine. For example, too many elbows leading to the turbine can create turbulence and head loss. Likewise, any restrictions to water exiting the turbine may increase resistance against the turbine's moving parts.

Turbine

The turbine is the heart of the hydro system, where water power is converted into the rotational force that drives the generator. For maximum efficiency, the turbine should be designed to match your specific head and flow. There are many different types of turbines, and proper selection requires considerable expertise. A Pelton design, for example, works best with medium to high heads. A crossflow design works better with lower head but higher flow. Other turbine types, such as Francis, turgo, and propeller, each have optimum applications.

Turbines can be divided into two major types. Reaction turbines use runners (the rotating portion that receives

the water) that operate fully immersed in water, and are typically used in low to moderate head systems with high flow. Examples include Francis, propeller, and Kaplan.

Impulse turbines use runners that operate without being immersed, driven by one or more high-velocity jets of water. Examples include Pelton and turgo. Impulse turbines are typically used with moderate-to-high head systems, and use nozzles to produce the high-velocity jets. Some impulse turbines can operate efficiently with as little as 5 feet (1.5 m) of head.

The crossflow turbine is a special case. Although technically classified as an impulse turbine because the runner is not entirely immersed in water, this "squirrel cage" type of runner is used in applications with low to moderate head and high flow. The water passes through a large, rectangular opening to drive the turbine blades, in contrast to the small, high-pressure jets used for Pelton and turgo turbines.

Regardless of the turbine type, efficiency is in the details. Each turbine type can be designed to meet vastly different requirements. The turbine system is designed around net head and design flow. These criteria not only influence which type of turbine to use, but are critical to the design of the entire turbine system.

Minor differences in specifications can significantly impact energy transfer efficiency. The diameter of the runner, front and back curvatures of its buckets or blades, casting materials, nozzle (if used), turbine housing, and quality of components all affect efficiency and reliability.

An in-stream screen keeps debris and silt out of the penstock at the small-stream intake for a microhydro system in Washington.



Drive System

The drive system couples the turbine to the generator. At one end, it allows the turbine to spin at the rpm that delivers best efficiency. At the other, it drives the generator at the rpm that produces correct voltage and frequency—frequency applies to alternating current (AC) systems only. The most efficient and reliable drive system is a direct, 1:1 coupling between the turbine and generator.

This is possible for many sites, but not for all head and flow combinations. In many situations, especially with AC systems, it is necessary to adjust the transfer ratio so that both turbine and generator run at their optimum (but different) speeds. These types of drive systems can use either gears, chains, or belts, each of which introduces additional efficiency losses into the system. Belt systems tend to be more popular because of their lower cost.

Generator

The generator converts the rotational energy from the turbine shaft into electricity. Efficiency is important at this stage too, but most modern, well-built generators deliver good efficiency. Direct current (DC) generators, or alternators

At the bottom of the penstock, a manifold routes water to the four nozzles of a Harris Pelton turbine that drives a permanent magnet alternator.



Hydro Terms

Flow

Refers to the quantity of water supplied from a water source or exiting a nozzle per unit of time. Commonly measured in gallons per minute (gpm).

Francis Turbine

A type of reaction hydro-turbine used in low to medium heads. It consists of fixed vanes on a shaft. Water flows down through the vanes, driving the shaft.

Friction Loss

Lost energy due to pipe friction. In hydro systems, pipe sized too small can lead to serious friction losses.

Head

The difference in elevation between a source of water and the location at which the water from that source may be used (synonym: vertical drop). Expressed in vertical distance or pressure.

Headrace

A flume or channel that feeds water into a hydro turbine.

Hydroelectricity

Any electricity that is generated by the flow of water.

Impulse Turbine

Turbines with runners that operate in air, driven by one or more high-velocity jets of water from nozzles. Typically used with moderate- to high-head systems. Examples include Pelton and turgo.

Intake

The structure that receives the water and feeds it into the penstock (pipeline). Usually incorporates screening or filtering to keep debris and aquatic life out of the system.

Pelton Wheel

A common impulse turbine runner (named after inventor Lester Pelton) made with a series of cups or "buckets" attached to a hub.

Penstock

The pipe in a hydro system that carries the water from the intake to the turbine.

(continued)

More Hydro Terms

Pipe Loss (Frictional Head Loss)

The amount of energy or pressure lost due to friction between a flowing liquid and the inside surface of a pipe.

Pressure

The "push" behind liquid or gas in a tank, reservoir, or pipe. Water pressure is directly related to "head"—the height of the top of the water over the bottom. Every 2.31 feet of vertical head gives 1 psi (pound per square inch) of water pressure.

Reaction Turbine

Turbines with the runner fully immersed in water, typically used in low- to moderate-head systems with high flow. Examples include Francis, propeller, and Kaplan.

Runner

The wheel that receives the water, changing the pressure and flow of the water to circular motion to drive an alternator, generator, or machine.

Tailrace

The pipe, flume, or channel in a hydroelectric system that carries the water from the turbine runner back to the stream or river.

Trash Rack

A strainer at the input to a hydro system. Used to remove debris from the water before it enters the pipe.

Turgo

A type of impulse hydro runner optimized for lower heads and higher volumes than a Pelton runner.



Shown from beneath—the 4-inch (10 cm) turgo runner in an Australian-made Platypus turbine.

One critical aspect of AC is frequency, typically measured as cycles per second (cps) or Hertz (Hz). Most household appliances and motors run on either 50 Hz or 60 Hz (depending on where you are in the world), as do the major grids that interconnect large generating stations. Frequency is determined by the rotational speed of the generator shaft; faster rotation generates a higher frequency. In battery-based hydro systems, the inverter produces an AC waveform at a fixed frequency. In batteryless hydro systems, the turbine controller regulates the frequency.

A view into a turbine shows a relatively large (2 feet in diameter) Pelton wheel. Peltons vary in size from 3 inches to 13 feet or more, depending on head and flow.



with rectifiers, are typically used with small household systems, and are usually augmented with batteries for reserve capacity, as well as inverters for converting the electricity into the AC required by most appliances. DC generators are available in a variety of voltages and power outputs.

AC generators are typically used with systems producing about 3 KW or more. AC voltage is also easily changed using transformers, which can improve efficiency with long transmission lines. Depending on your requirements, you can choose either single-phase or three-phase AC generators in a variety of voltages.

AC Controls

Pure AC hydro systems have no batteries or inverter. AC is used by loads directly from the generator, and surplus electricity is burned off in dump loads—usually resistance heaters.

Governors and other controls help ensure that an AC generator constantly spins at its correct speed. The most common types of governors for small hydro systems accomplish this by managing the load on the generator. With no load, the generator would “freewheel,” and run at a very high rpm. By adding progressively higher loads, you can eventually slow the generator until it reaches the exact rpm for proper AC voltage and frequency. As long as you maintain this “perfect” load, known as the design load, electrical output will be correct. You might be able to maintain the correct load yourself by manually switching devices on and off, but a governor can do a better job—automatically.

By connecting your hydro system to the utility grid, you can draw energy from the grid during peak usage times when your hydro system can't keep up, and feed excess electricity back into the grid when your usage is low. In effect, the grid acts as a large battery with infinite capacity.

If you choose to connect to the grid, however, keep in mind that significant synchronization and safeguards must be in place. Grid interconnection controls do both. They will monitor the grid and ensure that your system is generating compatible voltage, frequency, and phase. They will also

The underside of a low-head, high-flow Nautilus turbine showing the Francis runner, and above it, the innovative nautilus-shaped headrace.



A Power Pal turbine with a Francis runner direct-coupled to the alternator above.



instantly disconnect from the grid if major fluctuations occur on either end. Automatic disconnection is critical to the safety of all parties. At the same time, emergency shutdown systems interrupt the water flow to the turbine, causing the system to coast to a stop, and protecting the turbine from overspeed.

DC Controls

A DC hydro system works very differently from an AC system. The alternator or generator output charges batteries. A diversion controller shunts excess energy to a dump load. An inverter converts DC electricity to AC electricity for home use. DC systems make sense for smaller streams with potential of less than 3 KW.

AC systems are limited to a peak load that is equivalent to the output of the generator. With a battery bank and large inverter, DC systems can supply a high peak load from the batteries even though the generating capacity is lower.

Series charge controllers, like those used with solar-electric systems, are not used with hydro systems since the generators cannot run without a load (open circuit). This can potentially damage the alternator windings and bearings from overspeeding. Instead, a diversion (or shunt) controller must be used. These normally divert energy from the battery to a resistance heater (air or water), to keep the



A Canadian-made Energy Systems and Design turbine uses a permanent magnet alternator and a turgo runner.

battery voltage at the desired level while maintaining a constant load on the generator.

The inverter and battery bank in a DC hydro system are exactly the same as those used in battery-based, solar-electric or wind-electric systems. No other special equipment is needed. Charge controller settings may be lower than used in typical PV and wind systems, since hydro systems are constant and tend to run with full batteries much of the time.

Head, Flow, & Efficiency

If you expect to sell electricity back to the utility, pay extra attention to the efficiency of your hydro system because higher output and a lower cost-per-watt will go

straight to your bottom line. Your turbine manufacturer can give you guidance on the most efficient design, as well as grid interconnection controls and safeguards. If you're off-grid, and your site doesn't have lots of head and flow, high efficiency can make the difference between ample electricity for your needs and having to use a backup, gasoline-powered generator.

Whether a hydro system generates a few watts or hundreds of megawatts, the fundamentals are the same. Head and flow determine how much raw water power is available, and the system efficiency affects how much electricity will come out the other end. Each component of a hydro system affects efficiency, so it's worthwhile to optimize your design every step of the way.

Is hydropower feasible for you? The next article in this series will help you answer this question. I'll discuss methods for measuring head and flow, offer tips for determining pipeline size, and provide formulas for calculating electrical output and efficiency.

Access

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"Hydro in the Blood: An Interview with Dan New of Canyon Industries," *HP79*

"Powerful Dreams: Crown Hill Farm's Hydro-Electric Plant," by Juliette & Lucien Gunderman, *HP96*

"From Water to Wire: Building a Microhydro System," by Peter Talbot, *HP76*

