Design of Microhydro Electric Systems

An Online Continuing Education Course for Engineers

Course Number: R-1004

Credit: 1 Hour / 1 PDH / 1 CPD

Microhydro Electric Systems

If you're considering building a small hydropower system on water flowing through your property, you have a long tradition from which to draw your inspiration. Two thousand years ago, the Greeks learned to harness the power of running water to turn the massive wheels that rotated the shafts of their wheat flour grinders. And in the hydropower heyday of the 18th century, thousands of towns and cities worldwide were located around small hydropower sites.

Today, small hydropower projects offer emissions-free power solutions for many remote communities throughout the World- such as those in Nepal, India, China, and Peru—as well as for highly industrialized countries, like the United States.

This course will help you determine whether a small hydropower system will work for your power needs and whether your location is right for hydropower technology. It will also explain the basic system components, the need for permits and water rights, and how you might be able to sell the excess electricity you generate.

Uses of Hydropower

In the United States today, hydropower projects provide 66 percent of the nation's renewable electricity generation and about 7 percent of the nation's total electricity.

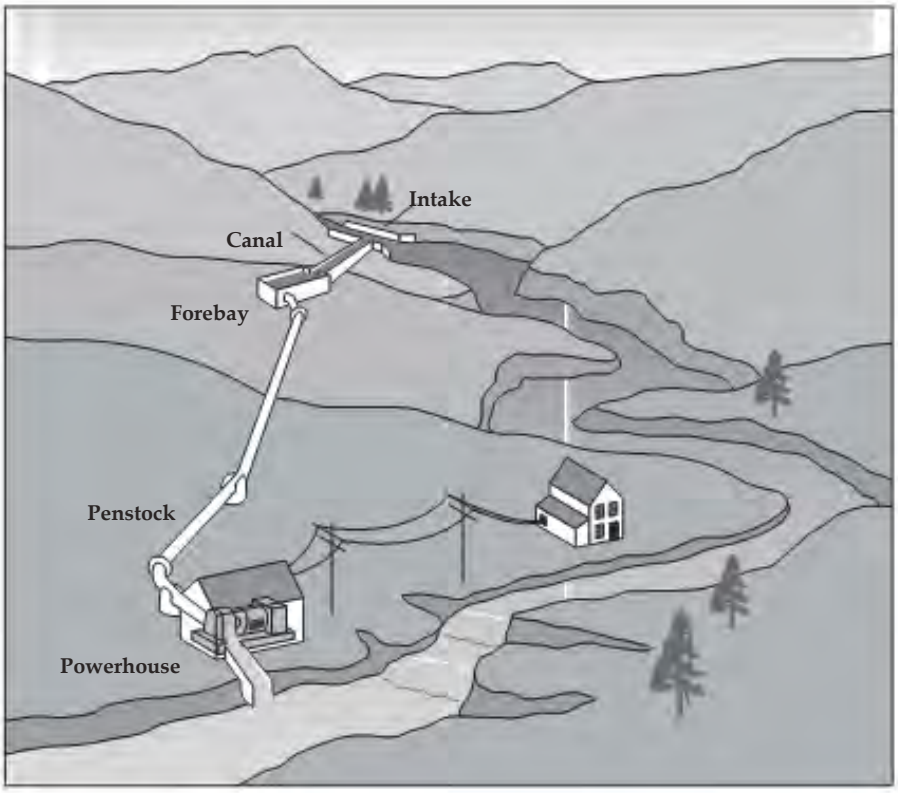
This small-scale hydropower system is helping an Alaskan community save money on their electricity.

A 10 kW system can provide enough power for a large home, a small resort, or a hobby farm.

The vast majority of the hydropower produced in the United States comes from large-scale projects that generate more than 30 megawatts (MW)—enough electricity to power nearly 30,000 households. *Small-scale hydropower systems* are those that generate between .01 to 30 MW of electricity. Hydropower systems that generate up to 100 kilowatts (kW) of electricity are often called *microhydro systems.* Most of the systems used by home and small business owners would qualify as microhydro systems. In fact, a 10 kW system generally can provide enough power for a large home, a small resort, or a hobby farm.

How Hydropower Works

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. Although there are several ways to harness the moving water to produce energy, *run-of-the-river systems,* which do not require large storage reservoirs, are often used for microhydro, and sometimes for small-scale hydro, projects. For run-of-the-river hydro projects, a portion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (*penstock)* that delivers it to a waterwheel or turbine. The moving water rotates the wheel or turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes, such as pumping water, or it can be used to power an alternator or generator to generate electricity. This course will focus on how to develop a run-of-the-river project.



In this microhydropower system, water is diverted into the penstock. Some generators can be placed directly into the stream.

Is Hydropower Right for You?

Of course to build a small hydropower system, you need access to flowing water. A sufficient quantity of falling water must be available, which usually, but not always, means that hilly or mountainous sites are best.

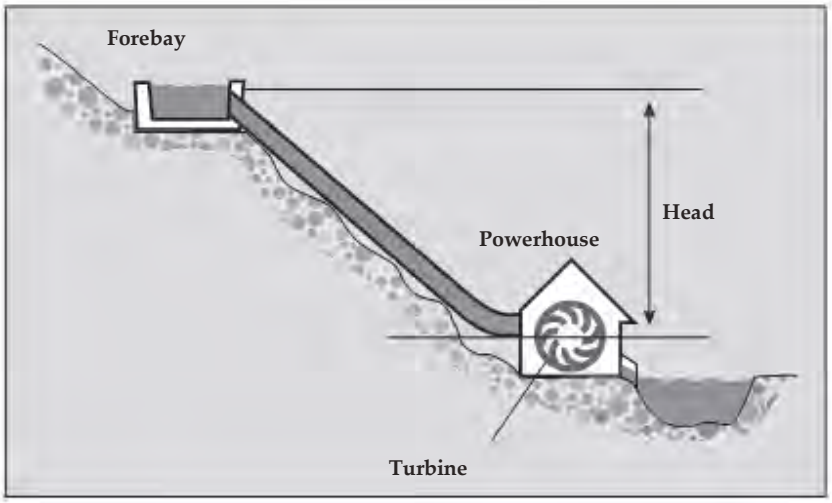
Next you'll want to determine the amount of power that you can obtain from the flowing water on your site. The power available at any instant is the product of what is called *flow* volume and what is called *head.*

Determining head

Head is the vertical distance that water falls. It's usually measured in feet, meters, or units of pressure. Head also is a function of the characteristics of the channel or pipe through which it flows.

Most small hydropower sites are categorized as low or high head. The higher the head the better because you'll need less water to produce a given amount of power, and you can use smaller, less expensive equipment. Low head refers to a change in elevation of less than 10 feet (3 meters). A vertical drop of less than 2 feet (0.6 meters) will probably make a small-scale hydroelectric system unfeasible. However, for extremely small power generation amounts, a flowing stream with as little as 13 inches of water can support a submersible turbine, like the type used originally to power scientific instruments towed behind oil exploration ships.

When determining head, you need to consider both *gross head* and *net head.* Gross head is the vertical distance between the top of the penstock that conveys the water under pressure and the point where the water discharges from the turbine. Net head equals gross head minus losses due to friction and turbulence in the piping.



Head is the vertical distance the water falls. Higher heads require less water to produce a given amount of power.

To get a rough estimate of the vertical distance, you can use U.S. Geological Survey maps of your area or the *hose-tube* method. The hose-tube method involves taking stream-depth measurements across the width of the stream you intend to use for your system—from the point at which you want to place the penstock to the point at which you want to place the turbine. You will need an assistant; a 20 to 30 foot (6 to 9 meters) length of small-diameter garden hose or other flexible tubing; a funnel; and a yardstick or measuring tape.

The quantity of water falling is called flow.

Stretch the hose or tubing down the stream channel from the point that is the most practical elevation for the penstock intake. Have your assistant hold the upstream end of the hose, with the funnel in it, underwater as near the surface as possible. Meanwhile, lift the downstream end until water stops flowing from it. Measure the vertical distance between your end of the tube and the surface of the water. This is the gross head for that section of stream. Have your assistant move to where you are and place the funnel at the same point where you took your measurement. Then walk downstream and repeat the procedure. Continue taking measurements until you reach the point where you plan to site the turbine.

The sum of these measurements will give you a rough approximation of the gross head for your site. Note: due to the water's force into the upstream end of the hose, water may continue to move through the hose after both ends of the hose are actually level. You may wish to subtract an inch or two (2 to 5 centimeters) from each measurement to account for this. It is best to be conservative in these preliminary head measurements.

If your preliminary estimates look favorable, you will want to acquire more accurate measurements. The most accurate way to determine head is to have a professional survey your site. But if you know you have an elevation drop on your site of several hundred feet, you can use an aircraft altimeter. You may be able to buy, borrow, or rent an altimeter from a small airport or flying club. A word of caution, however, while using an altimeter might be less expensive than hiring a professional surveyor, your measurement will be less accurate. In addition, you will have to account for the effects of barometric pressure and calibrate the altimeter as necessary.

Determining flow

The quantity of water falling is called flow. It's measured in gallons per minute, cubic feet per second, or liters per second. The easiest way to determine your stream's flow is to obtain data from local offices of the U.S. Geological Survey, the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, your county's engineer, or local water supply or flood control authorities. If you can't obtain existing data, you'll need to conduct your own flow measurements

You can measure flow using the *bucket* method, which involves damming your stream with logs or boards to divert its flow into a bucket or container. The rate at which the container fills is the flow rate. For example, a 5-gallon bucket that fills in 1 minute means that your stream's water is flowing at 5 gallons per minute.

Another way to measure flow involves measuring stream depths across the width of the stream and releasing a weighted-float upstream from your measurements. You will need an assistant; a tape measure; a yardstick or measuring rod; a weighted-

Whatever the upfront costs, a hydroelectric system will typically last a long time and is relatively maintenance free.

float, such as a plastic bottle filled halfway with water; a stopwatch; and some graph paper. With this equipment you can calculate flow for a cross section of the streambed at its lowest water level.

First, select a stretch of stream with the straightest channel and the most uniform depth and width possible. At the narrowest point, measure the width of the stream. Then, holding the yardstick vertically, walk across the stream and measure the water depth at one-foot increments. To help with the process, stretch a string or rope upon which the increments are marked across the stream width. Plot the depths on graph paper to give yourself a cross-sectional profile of the stream. Then determine the area of each section by calculating the areas of the rectangles (area = length x width) and right triangles (area = ½ base x height) in each section.

Next, from the same point where you measured the stream's width, mark a point at least 20 feet upstream. Release the weighted-float in the middle of the stream and record the time it takes for the float to travel to your original point downstream. Don't let the float drag along the bottom of the streambed. If it does, use a smaller float.

Divide the distance between the two points by the float time in seconds to get flow velocity in feet per second. The more times you repeat this procedure, the more accurate your flow velocity measurement will be.

Finally, multiply the average velocity by the cross-sectional area of the stream. Then multiply your result by a factor that accounts for the roughness of the stream channel (0.8 for a sandy streambed, 0.7 for a bed with small to medium sized stones, and 0.6 for a bed with many large stones). The result will give you the flow rate in cubic feet or meters per second.

Stream flows can be quite variable over a year, so the season during which you take flow measurements is important. Unless you're considering building a storage reservoir, you can use the lowest average flow of the year as the basis for your system's design. However, if you're legally restricted on the amount of water you can divert from your stream at certain times of the year, use the average flow during the period of the highest expected electricity demand.

Estimating power output

There is a simple equation you can use to estimate the power output for a system with 53 percent efficiency, which is representative of most small hydropower systems. Simply multiply net head (the vertical distance available after subtracting losses from pipe friction) by flow (use U.S. gallons per minute) divided by 10. That will give you the system's output in watts (W). The equation looks this: net head [(feet) x flow (gpm)]/10 = W.

Economics of a small system

If you determine that your site is feasible for a small hydropower system, the next obvious step is to determine whether it makes sense economically to undertake building a system.

Add up all the estimated costs of developing and maintaining the site over the expected life of your equipment, and divide the amount by the system's capacity in watts. This will tell you how much the system will cost in dollars per watt. Then you can compare that to the cost of utility-provided power or other alternative power sources. Whatever the upfront costs, a hydroelectric system will typically last a long time and, in many cases, maintenance is not expensive.

In addition, there are a variety of financial incentives available on the state, utility, and federal level for investments in renewable energy systems. They include income tax credits, property tax exemptions, state sales tax exemption, loan programs. and special grant programs, among others.

Contact your state energy office to see if your project may qualify for any incentives.

Environmental Issues

Large-scale dam hydropower projects are often criticized for their impacts on wildlife habitat, fish migration, and water flow and quality. However, small, run-of-the-river projects are free from many of the environmental problems associated with their large-scale relatives because they use the natural flow of the river, and thus produce relatively little change in the stream channel and flow. The dams built for some run-of-the-river projects are very small and impound little wa
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solar resources, batteries may not always be practical for hydropower systems. If you do use batteries, they should be located as close to the turbine as possible, because it is difficult to transmit low-voltage power over long distances.

Channels, storage, and filters

Before water enters the turbine or waterwheel, it is first funneled through a series of components that control its flow and filter out debris. These components are the headrace, forebay, and water conveyance (channel, pipeline, or penstock).

The *headrace* is a waterway running parallel to the water source. A headrace is sometimes necessary for hydropower systems when insufficient head is provided. They often are constructed of cement or masonry. The headrace leads to the *forebay,* which also is made of concrete or masonry. It functions as a settling pond for
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bines are more compact in relation to their energy output than waterwheels. They also have fewer gears and require less material for construction. There are two general classes of turbines: impulse and reaction.

Impulse

Impulse turbines, which have the least complex design, are most commonly used for high head microhydro systems. They rely on the velocity of water to move the turbine