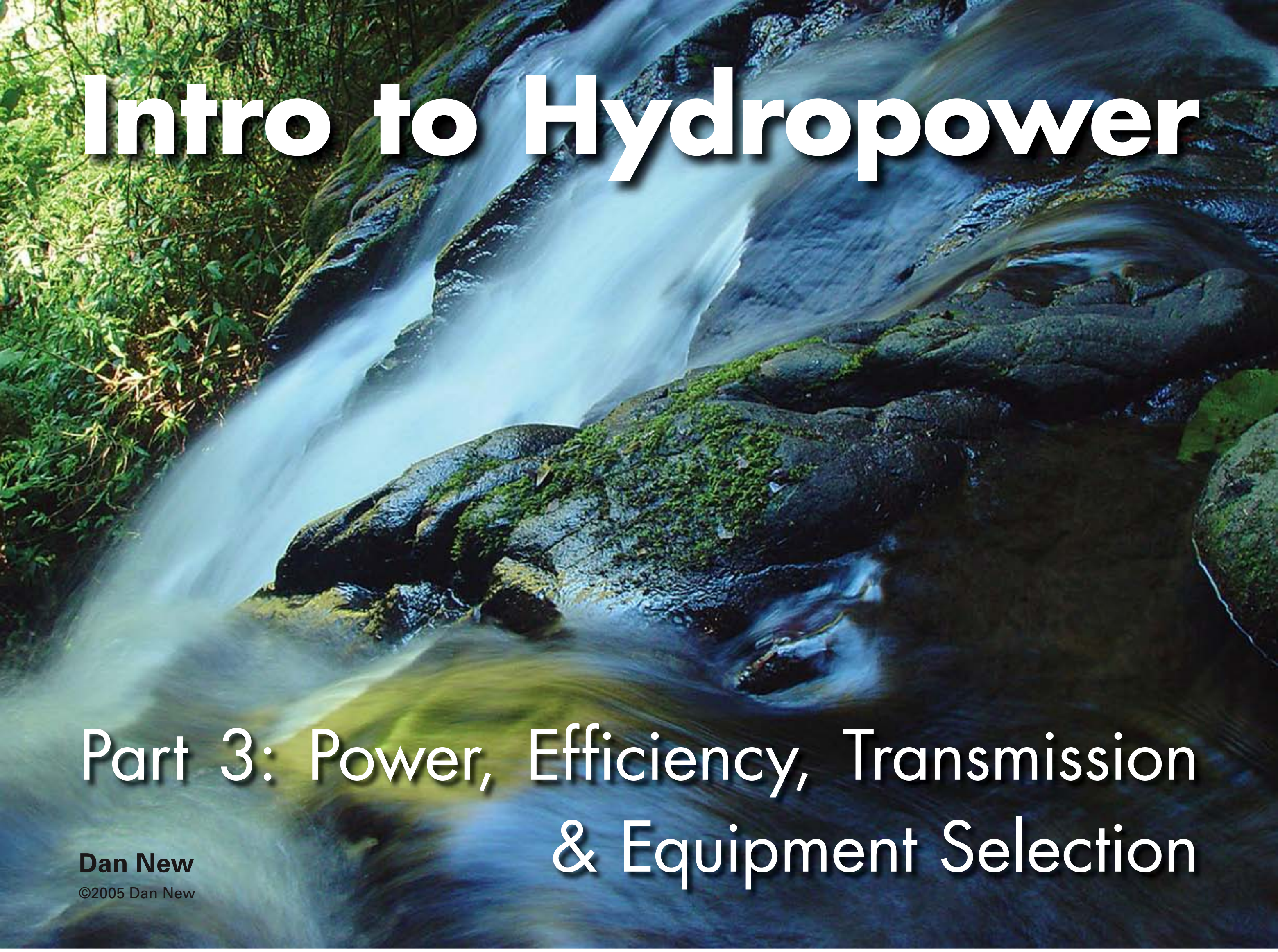

Intro to Hydropower

Part 3: Power, Efficiency, Transmission & Equipment Selection

Dan New

Photo courtesy of Eugenio Garcia Lopez

Compared to solar- or wind-powered systems, small-scale hydroelectric systems are almost always the least expensive way to make your own electricity. Most people don't have a stream with adequate flow and vertical drop, but if you do, pat yourself on the back. You're the envy of your renewable energy neighborhood!

In the first two articles in this series, I covered system components and design, and ways of measuring head (vertical drop) and water flow at your site. This time, I'll discuss calculating the power available from a given stream, system efficiency, options for transmitting electricity from your hydro turbine to your home, and several other factors that make a good hydro system.

Computing Water Power

Net head is the vertical drop from your pipeline intake to your turbine, adjusted for pipe friction (losses caused by water moving through a pipeline). Design flow is the amount of water you have to work with. See "Intro to Hydropower, Part 2" in *HP104* to learn how to measure these two important site variables. Once you've determined net head and design flow, you can begin to estimate the potential output of a hydro system. These computations are only rough estimates, and you should consult with your turbine manufacturer or equipment supplier for more accurate projections.

Both head and flow have a linear effect on power. Double the head and power doubles. Double the flow and power doubles. Keep in mind that total head will remain constant once your system is installed—you can count on it year-round. Increasing head is the least expensive way to increase power generation because it has minimal effect on turbine size. You can increase head by going higher up the creek to place the intake, or lower down for the turbine. Don't overlook the head that you have on your property.

In contrast, flow will likely change significantly over the course of a year, and it's rarely cost effective to size your hydro system for maximum, flood-level flow. *Always maximize head*, and work with your turbine supplier to determine the most practical design flow.

Accuracy is important! The design of your system revolves around your measurements of head and flow, and errors will directly affect the efficiency of your system. Take the time to measure head and flow carefully before you begin to evaluate hydro system components.

Efficiency & Losses

In addition to pipeline losses, small amounts of energy will be lost through friction within the turbine, drive system, generator, and transmission lines. Although some efficiency losses are inevitable, don't underestimate the importance of good design. Efficient systems produce greater output, often at a lower cost per watt. A system that is carefully matched to your site's head and flow usually won't cost any more than a less suitable design. But it will be much more efficient, producing more electricity from your available resource. Other improvements, such as larger pipeline diameter or a better drive system may yield enough added power to justify their higher cost.

Because of the many variables in system design, it is impossible to estimate efficiency without first knowing your head and flow. As a general guideline, however, you can expect a home-sized system generating direct AC power to operate at about 60 to 70 percent "water-to-wire" efficiency (measured between turbine input and generator output). Smaller DC systems generally have lower efficiencies of 40 to 60 percent, though recent testing by *Home Power* shows that some small turbines can achieve efficiencies in the low 70 percent range, depending on the system and electronics. If you have accurate measurements for your head and flow, your turbine supplier will be able to provide some preliminary estimates of efficiency, as well as ideas for optimization.

A Rough Formula

You can get pretty nerdy with power calculations for hydro systems. For larger systems, this is certainly justified, and any supplier worth dealing with can crunch the numbers. But when you're just getting an idea of the potential of your site, what's needed is a simple formula.

Net Head x Design Flow ÷ Adjustment Factor = Power in Watts

If you multiply the net head in feet by the flow in gallons per minute and divide by an adjustment factor, you'll get the continuous potential power output of the turbine in watts. Use a factor of 9 for AC systems, and a factor of 10 to 13 for DC systems.

So if you have 100 feet (30 m) of head and 200 gallons (757 l) per minute, using 10 as the factor, you'll get roughly 2,000 watts, or 2 KW. Multiply that by 24 hours in a day and you have 48 KWH per day (which is a lot).

Transmission

The last important measurement is the distance between your generator and either your battery bank (for DC systems) or where you'll be using the electricity (for AC systems). As with your pipeline, all you need to do is measure the distance along the route you plan to run your wiring.

Transmission lines are a lot like pipelines. Instead of moving water, they move electrical energy, but the same fundamentals of friction losses apply. Longer transmission lines, higher current, lower system voltage, and smaller wires all contribute to energy losses. You can minimize these losses, but the electricity you can actually use will always be somewhat less than what your system is generating.

There are three ways to reduce or compensate for transmission line losses:

- Use a shorter transmission line
- Use larger wires
- Increase the voltage on the transmission line

Shorter lines and larger wires will reduce line losses for any system, but voltage considerations are significantly different between DC and AC systems. Transformers may be used to reduce wire size in long transmission lines, and step-down, MPPT controllers can allow your turbine to run at high voltage while charging your battery at a lower voltage. Your turbine supplier can help you determine the best solution for your site.

Example DC system

Gross head: 135 feet (41 meters)

Measured flow: 25 to 100 gpm, (1.6 to 6.3 l/s)

Pipeline length: 900 feet (274 m)

Gross power: 350 to 1,200 watts

A DC, battery-based system with an inverter is the best choice for a hydro site with the above parameters. If an AC turbine were used, peak usage would be limited to about 1,200 watts at peak flow. This peak power figure would not be sufficient to run the combined electrical loads of most households. Installation of a turbine with DC output would allow energy storage in a battery bank, and an inverter or inverters would be able to provide as much instantaneous power as was required by the residence.

With a design flow of 100 gpm, using 3-inch diameter PVC pipe would result in a head loss of 2.33 feet per 100 feet of pipe, for a net head of 114 feet (35 m), and a maximum power output of about 1,200 watts at maximum flow. Over a 24-hour period, this system would produce 28.8 KWH. As summer approached and the flow rate dropped off to the site's minimum of 25 gpm, the same 3-inch pipe would result in a net head of 133 feet (41 m), and a power output of about 350 W, or 8.4 KWH per day. This would typically be enough energy to power all the electric appliances in an efficient home, excluding cooking, space heating, and water heating.

Example AC System

Gross head: 230 feet (70 meters)

Measured flow: 220 gpm to 900 gpm (14–56 l/s)

Pipeline length: 1,700 feet (518 m)

Gross power: 5 to 20 KW

Clearly, a direct-generating AC system could be built at this site. The flow range could support development of a 5, 10, or 20 KW system, depending on the selection of pipe diameter. As an example, by choosing 6-inch diameter PVC pipe and planning on a design flow of 450 gpm (28 l/s), head loss would be about 1.3 feet per 100 feet of pipe, for a calculated net head of 208 feet (63 m), and an expected system output of 10.5 KW. This would be a very nice system to supply all the energy needs of a home/shop/greenhouse complex.

What Makes a Quality Hydro System?

Think of a hydroelectric system in terms of efficiency and reliability. In a perfect world, efficiency would be 100 percent. All the energy within the water would be transformed to the rotating shaft. There would be no air or water turbulence, no mechanical resistance from the turbine's bearings or drive system, and the runner would be perfectly balanced. The signs of energy loss—heat, vibration, and noise—would be absent. Of course, the perfect turbine would also never break down or require maintenance.

Obviously, no turbine system will ever achieve this degree of perfection. But it's good to keep these goals in mind, because better efficiency and reliability translate into more power and a lower cost per watt. Quality components and careful machining make a big difference in turbine efficiency and reliability. Here are just a few of the things to consider when selecting a turbine.

A 3.75-inch pitch diameter Pelton runner from Harris Hydro for high head, low flow sites.

Turbine Runner

The runner is the heart of the turbine. This is where water power is transformed into the rotational force that drives the generator. Regardless of the runner type, its buckets or blades are responsible for capturing the most possible energy from the water. The curvature of each surface, front and rear, determines how the water will push its way around until it falls away. Also keep in mind that any given runner will perform most efficiently at a specific head and flow. The type and size of your runner should be closely matched to your site characteristics.

Look for all-metal runners with smooth, polished surfaces to eliminate water and air turbulence. One-piece, carefully machined runners typically run more efficiently and reliably than those that are bolted together. Bronze manganese runners work well for small systems with clean water and heads up to about 500 feet (152 m). High-tensile stainless steel runners are excellent for larger systems or abrasive water conditions. All runners should be carefully balanced to minimize vibration, a problem that not only affects efficiency, but can also cause unnecessary wear on the turbine over time.

Turbine Housing

The turbine housing must be well built and sturdy, since it manages forces of the incoming water as well as the outgoing shaft power. In addition, its shape and dimensions have a significant effect on efficiency. For example, consider

The author inspects a 990-pound, 22-inch pitch diameter Turgo-style runner for an 880 KW turbine.

a Pelton-type turbine. As an impulse turbine, it is driven by one or more jets of water, but spins in air. This means that both hydrodynamic and aerodynamic forces must be considered in the design of the housing. It must minimize the resistance from splash and spray, and smoothly exhaust tail waters, yet also be sized and shaped properly to minimize losses due to air turbulence. Similarly, housings for high-flow designs like crossflow and Francis turbines must be precisely engineered to smoothly channel large volumes of water through the turbine without causing pockets of turbulence.

Look for a smoothly welded housing that is carefully matched to the proper runner for your site. Keep in mind that both the water forces and the runner will be producing considerable torque, so the housing material and all fittings should be heavy duty. Mating surfaces, such as pipe flanges and access covers, should be machined flat and leak free. Since water promotes rust and corrosion, make sure all vulnerable surfaces are protected with high-quality powder coating or epoxy paint. All bolts should be stainless steel.

Like this Energy Systems & Design alternator from a Stream Engine turbine, many small, DC, hydroelectric units now use more efficient, brushless, permanent magnet alternators.

Other Turbine Considerations

All surfaces that carry water can impact efficiency, from the intake to your pipeline to the raceway that carries the tail waters away from your turbine. Look for smooth surfaces with no sharp bends. Jets and flow control vanes should be finely machined with no discernable ripples or pits.

Efficiency is important, but so are durability and dependability. Your hydroelectric project should deliver clean electricity without interruption. The quality of components and their installation can make a big difference on the quality of your life in the years to come. Look for quality workmanship in the design and construction of seal systems, shaft material and machining, and all related components. Pay particular attention to the selection and mounting of bearings; they should spin smoothly, without grating or binding.

Alternator

In the past, most small, battery-charging, hydroelectric turbines relied on off-the-shelf alternators with brushes. These alternators work well, especially when a specific stator is chosen, based on the parameters of a given hydro site. Swapping out the stator optimizes the alternator's rpm, and increases the turbine's output. While these types of alternators are still used due to their low cost, they are not ideal. The major drawback is that the alternator's brushes need regular replacement. These days, brushless permanent magnet (PM) alternators are available, and are a better choice, since they eliminate the need for brush replacement. In addition, brushless permanent magnet alternators perform at higher efficiencies, increasing your hydro system's output.

Regardless of type, an alternator's output is always AC. The frequency of the AC will vary depending on the rotational speed of the alternator, which is a direct function of the pressure available at the turbine. This AC output is not usable as is, because AC appliances are designed to run at a specific frequency. Larger AC-direct turbines are designed to run at a specific speed (and therefore a fixed frequency), with governors to regulate the speed. The AC output of smaller, battery charging units is always rectified to DC, so the energy generated by the turbine can be stored in batteries. The system's inverter converts this DC to AC at a fixed frequency.

Alternative Power and Machine, Energy Systems and Design, and Harris Hydroelectric all manufacture turbines with brushless PM alternators. These alternators are very flexible in terms of their output voltage. The AC output of the turbine can be rectified to DC at the turbine for short transmission runs. High-voltage units operating at 120 VAC or higher can transmit the AC output of the turbine over longer distances. This AC output is then stepped down at the batteries to match the nominal battery voltage, and rectified to DC. In addition, transformers can be used to further step up the output voltage for transmission. Finally, the specific wiring configuration (delta, wye, etc.) of the alternator is flexible, allowing the output to be optimized for a specific hydro site.

For larger, AC-direct turbines, good quality alternators are available from a number of sources, and the reputation of the generator manufacturer is an excellent place to begin your selection process. Marathon Electric, Kato Engineering, and Stamford Newage, are all well known and respected small generator builders serving an international market.

For a household- or ranch-sized AC-direct turbine under 50 KW, you would normally choose a single-phase output, two bearing alternator. Quality alternators are available in a variety of voltages, phases, and output frequencies to match your local utility electricity. Three-phase units are selected for larger projects, for large motor loads, or complex distribution schemes.

If you are able to match your turbine speed to a common generator synchronous speed, then use a direct-drive coupling between the turbine shaft and generator shaft if

The balance of system components for a DC hydro system are very much like a photovoltaic system, except the charge controller shunts to a diversion load.

possible. It may be worth the investment in a slower speed generator to make this possible. If it is necessary to use a belt drive between the major components, then avoid two-pole generators, and pay the extra money to install a four-pole generator. Four-pole units have a 60-Hertz synchronous speed of 1,800 rpm, half the speed of the two-pole units, four times the weight, and six times the life. A standard feature in most industrial-quality generators will be an automatic voltage regulator (AVR). The AVR will maintain steady voltage over a broad range of generator loads.

In an AC hydro system, an electronic load governor automatically adjusts the load on the generator to maintain constant voltage.

Turbine Supplier

When it comes to suppliers, there is no substitute for experience. While the principles of hydropower can be mastered indoors, it is real world experience that teaches both the highlights and pitfalls of diverting water from a stream, pressurizing it, and forcing it through a turbine. A turbine supplier with many years of field experience will be invaluable as you design and build your hydro system.

Look for an experienced supplier that specializes in the size and type of hydro system you intend to build. A good supplier will work with you, beginning with your measurements of head and flow, to help you determine the right pipeline size, net head, design flow, turbine specifications, drive system, generator, and load management system. You should be able to count on your supplier to make suggestions for optimizing efficiency and dependability, including their effects on cost and performance. A good turbine supplier is your partner, and should take a personal interest in your success. After all, a satisfied customer is very good for business.

Next Steps

Armed with four essential measurements—head, flow, pipeline length, and transmission line length—you're ready to begin evaluating your site for a hydroelectric system. As we discussed in Part 1 of this series, there are many choices to make about DC vs. AC, intake designs, turbine types, etc. Many of these decisions will become obvious once your four measurements are complete.

Advice from turbine suppliers can be invaluable during your design process. If you provide them with your measurements, most suppliers will propose a system that is tailored to your site characteristics. You may find that a given supplier will specialize in certain types of systems (like DC or AC), but most are happy to refer you to someone else when appropriate.

Emphasize efficiency. Your head and flow determine how much raw water power is available, but efficiency determines how much of it you'll be able to transform into usable electricity. There are cost trade-offs, of course, but in many cases, a more efficient system will result in a lower cost per watt. This is especially important if you're thinking of connecting to the grid, where higher efficiency means more dollars in your pocket.

I hope you have found this series of articles on hydropower helpful. I've only scratched the surface of this substantial topic, but I hope I've whetted your appetite. As you've seen, the concepts behind hydropower are simple. Water turns a turbine, the turbine spins a generator, and electricity comes out the other side. Even a novice with little or no experience could produce some hydroelectricity—given enough water power.

Do you have a stream? Of the three most popular renewable energy technologies, hydropower delivers the most watts for the investment, and can be most accurately assessed. A few quick measurements will tell you if you have hydro potential. In any event, you'll have a great time playing in the water.

Access

Dan New, Canyon Hydro, 5500 Blue Heron Ln., Deming, WA 98244 • 360-592-5552 • Fax: 360-592-2235 • dan.new@canyonhydro.com • www.canyonhydro.com

Energy Systems & Design, PO Box 4557, Sussex, NB, E4E 5L7, Canada • 506-433-3151 • Fax: 506-433-6151 • hydropow@nbnet.nb.ca • www.microhydropower.com

Harris Hydroelectric, 632 Swanton Rd., Davenport, CA 95017 • 831-425-7652 • www.harrishydro.com

Alternative Power & Machine, 4040 Highland Ave., Grants Pass, OR 97526 • 541-476-8916 • altpower@grantspass.com • www.apmhydro.com