hydro-electric turbine BUYER'S GUIDE

by Ken Gardner
& Ian Woofenden

Co-author Ian Woofenden holds a 4-inch pitch diameter Pelton runner while standing in front of an 96-inch pitch diameter Pelton runner at turbine manufacturer Canyon Industries.

Courtesy Dana Brandt

If your stream or pond has sufficient head (vertical drop) and flow, a microhydro-electric system can be a cost-effective and reliable choice to provide renewable electricity for your home. To tap the power in falling water effectively, you need to understand basic physics, how each component works, and how to select and install the appropriate turbine and balance-of-system components for your site.

Head & Flow, Energy & Power

Hydropower results from the marriage of two forces—gravity and the flow of water—both used to determine how much power and energy can be had. Gravity is what creates the pressure between the inlet and outlet of the turbine. For every 2.31 feet of vertical drop in the pipe, 1 pound of pressure per square inch (psi) is gained. This vertical drop is also called "head"—the vertical distance between where water is taken out of a stream and where it leaves your turbine. The horizontal distance between the source and turbine is also important because of pipe cost and friction losses in the pipe—but it does not affect the basic head measurement.

Flowing water, whether measured in gallons per minute, cubic feet per second, or some other measure, is the other key factor in the hydropower equation. A continuous flow of falling water is needed to make electricity. Measuring this flow accurately is crucial to hydro site assessment and system design.

Once you have these two measurements, you can make at least a rough estimation of the power available. Multiplying the gross head (in feet) by the flow (in gallons per minute) and dividing by a specific factor will give you the potential output wattage. The factor, which is derived from real-world experience with hydro systems, will vary from 9 for larger AC systems to 13 or more for smaller battery-based systems.

Once you have figured power (watts), it's easy to calculate energy (watt-hours): Just multiply by 24 hours in a day to arrive at daily watt-hours, since hydro turbines run around the clock. The relationship of power production with water flow and head is linear, meaning that a site with 1 unit of water flow times 2 units of elevation difference will give roughly the same power production as a site that experiences 2 units of water flow times 1 unit of elevation difference, if all other things are equal. For example: If your stream has 120 feet of head and 45 gallons per minute of flow, you might expect to generate about 11 kilowatt-hours per day.

120 ft. head x 45 gpm ÷ 12 factor x 24 hrs./day = 10,800 watt-hrs./day

Hydropower Equation

Power in kilowatts can be determined by the following equation:

kW = H x Q x 62.4 x 0.746 ÷ 550 x e

where

H = head, in ft.

Q = flow, in cubic ft. per second

62.4 lbs. = weight of 1 cubic ft. of water

0.746 kW = 1 hp

550 foot-lbs./sec. = 1 hp

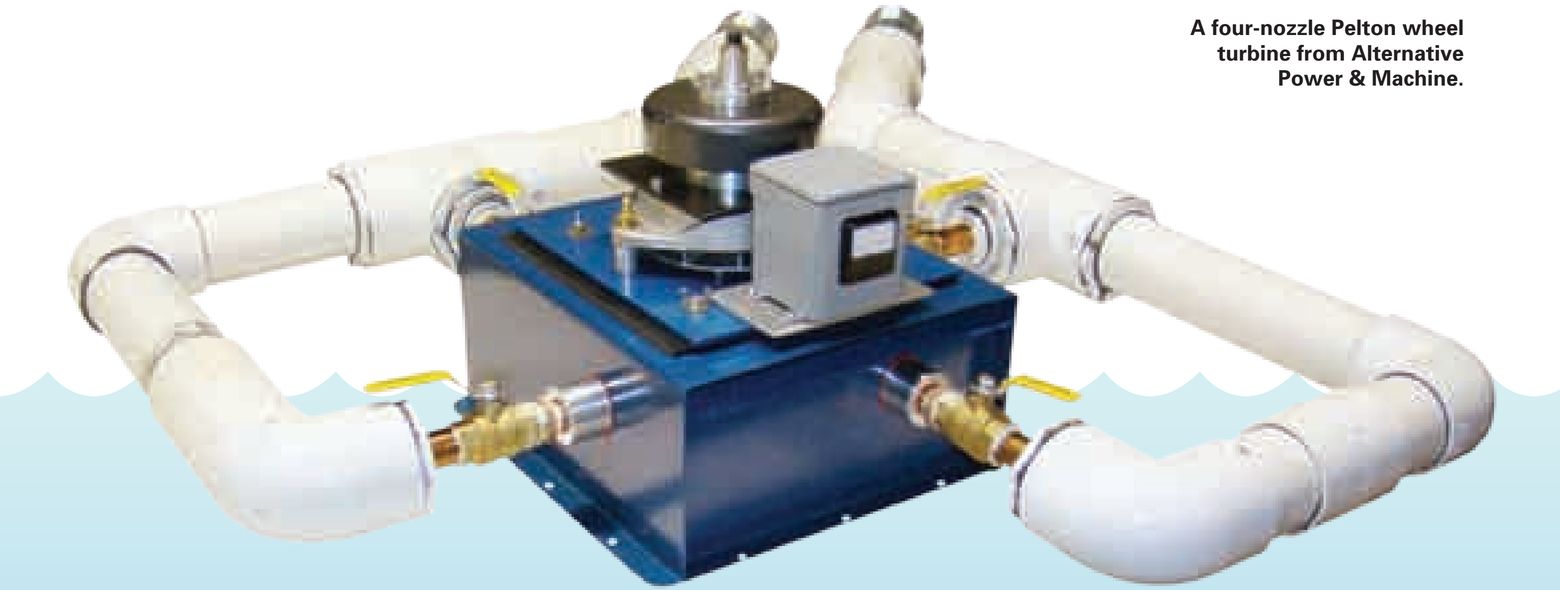
e = an overall efficiency factor* (usually 0.5 for small microhydro systems)

Combining and reducing all these factors results in the following equation:

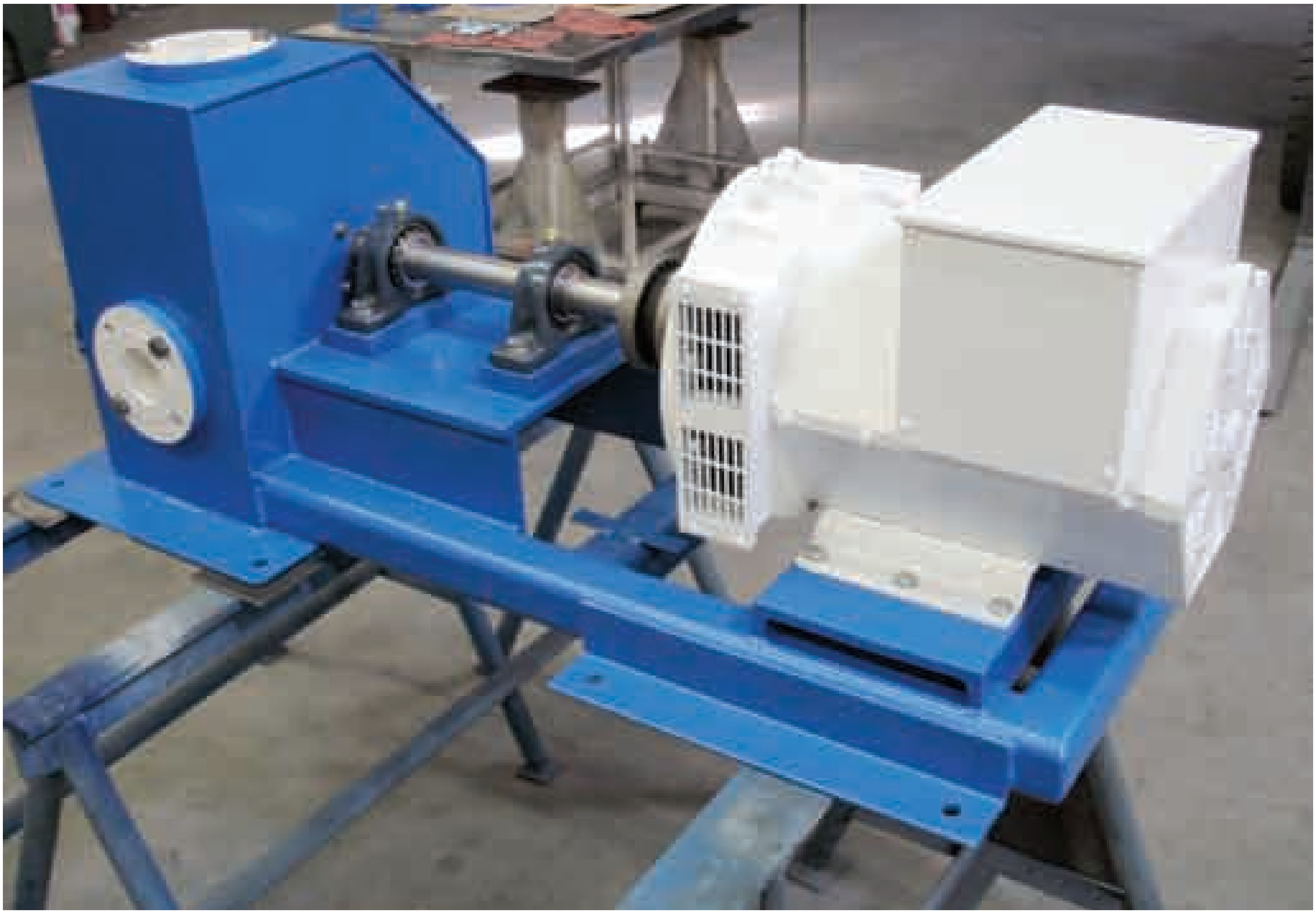
kW = H x Q ÷ 24, when using cfs; or

W = H x Q ÷ 12, when using gpm

*Note that the efficiency factor can range from 9 for larger AC systems to 13 or more for smaller battery-based systems, and will need to be estimated for your specific site.



A four-nozzle Pelton wheel turbine from Alternative Power & Machine.



A two-nozzle Pelton wheel turbine from Dependable Turbines.

Basic System Components

A hydro-electric system, like any renewable electricity system, is a collection of components. Buying only the turbine will get you nowhere. Hydro systems typically contain these basic components, listed here with their basic purpose:

- Intake structure and screen: Direct clean water into the pipe
- Penstock (pipeline): Carries water to the turbine
- Diversion or weir (used in some systems): Diverts or backs up water to be delivered into the penstock and/or turbine
- Turbine: Converts falling water to electricity
- Controls: Manage turbine and electrical components
- Dump or diversion load: Removes excess energy
- Battery bank (not used in some systems): Stores energy and provides surge capability
- Metering: Monitors system performance
- Disconnects and overcurrent protection: Provide a way to shut the electrical system down and to protect wires from too much current

Hydro system design is not simple, nor is it recommended for those with little experience with electrical, mechanical, and hydraulic systems. Because good hydro sites are few and far between, it is sometimes difficult to find expertise. Many systems are also deep in the back woods and not on public display, so you may need to do some research and networking to find the right people to help you.

System Configurations

Hydro systems come in four primary configurations, with other variations and permutations. Which type you choose depends on your site, goals, budget, and energy needs.

Battery-based off-grid systems are appropriate for smaller systems far from the utility lines, where the peak load exceeds the peak generation on a regular basis. If your hydro system produces 800 W, you'll generate about 19 kWh per day, which is substantial. But without a battery bank and higher-powered inverter, you could not run many appliances or electronics simultaneously, and many loads, such as an 1,100 W microwave, would be impossible to power.

Batteryless off-grid systems are appropriate when the generating capacity is 2 kW or more. As household loads decrease and increase, load-control governors constantly adjust the amount of energy to the diversion load to maintain a constant voltage and frequency. Because the system cannot store energy, considerable amounts of power are typically diverted to the diversion load. For this reason, it's worth considering how to use it most effectively. One of the most common ways to use the excess energy is for heating water for domestic use.

Battery-based on-grid systems are very similar to their off-grid counterparts. The first of two primary differences is that excess energy can be sold to the grid for payment or credit. The other is that the grid can be used for backup if the hydro system doesn't provide enough energy.

Batteryless on-grid systems use the grid as the "dump load," sending excess energy back to the utility's grid for their customers to use. These systems still may require a controller and dump load which only come into play in the event of a utility outage. Batteryless grid-tied systems are perhaps the simplest and most reliable systems because they incorporate no batteries but have the grid available. Their drawback is the lack of backup for any utility outages.

Turbine Types

All hydro-electric turbine generators, like electric motors, work on the principle of electrons moving through wire as a result of wires passing through magnetic fields (the electromagnetic effect). Hydro-electric turbines use the moving water to turn a wheel and provide the rotational movement necessary to cause the electromagnetic effect in their generators.

Microhydro turbines are generally classified in the range of 100 W to 100 kW, though most turbines used by homeowners are less than 25 kW. Another classification is based on the "head" (water pressure) that drives the turbine.

An LH1000 turbine from Energy Systems & Design, capable of 1 kW.

The ES&D turbine without its draft tube, showing the propeller.

Low-head turbines are used in systems with 3 to 20 feet of head. **Medium-head** turbines are for 20 to 60 feet of head, and **high-head** turbines can use 60 to 1,000 feet (or more) of head.

Low-head turbines are typically "reaction" turbines, in which the turbine blades are submerged and produce electricity as an integral reaction with the water pressure. Because they work with low head, these turbines normally require a significant amount of water to produce useful power. For instance, the Energy Systems and Design LH-1000 low-head propeller turbine requires 1,000 gpm of water operating at 10 feet of head to produce 1,000 W.

Medium-head turbines are often reaction turbines. A Francis turbine is a common type. Medium-head turbines often have adjustable flow-control devices to deal with variable water flow under the same head conditions.

A two-nozzle Pelton wheel turbine from Canyon Hydro.

Another type of reaction turbine is a pump that runs in reverse as water flows through its centrifugal works (see the "Pumps as Turbines" sidebar). These can be a simple and cost-effective solution in the right situations.

High-head turbines are the most common microhydro turbines installed in residential systems and are known as impulse or impact turbines. Water is passed through nozzles, converting pressure into velocity and sending a jet of water that "impacts" buckets or vanes attached to a rotating wheel, making it turn.

Electricity produced by most micro-hydro turbines is unregulated and is normally converted from "wild" (unregulated voltage and frequency) AC to DC using a rectifier. DC is then used to charge batteries from which an inverter can provide true 60 Hz AC electricity.

Larger (2 to 100 kW) microhydro turbines can produce 60 Hz electricity directly through regulation using an electronic load governor, which maintains a constant load on the generator through dump loads when electricity is not needed.

Off-grid microhydro turbines require the means to "dump" excess energy when batteries are full or AC loads are reduced. Generally it is best to have redundant (duplicate) diversion loads and/or an overvoltage trip device for protection in the event that a dump load or charge controller fails.

Turbine Specifications

Model is dependent on each manufacturer. Each manufacturer should be contacted to verify a turbine will suit a particular site.

The **generator type** associated with microhydro power is normally either a permanent magnet, a wound-field, or induction. Most smaller turbines use permanent magnet generators, some of which have adjustable gaps between the magnets and the windings for tuning the output. Stand-alone synchronous generators have a wound-field that produces its own magnetic excitation, and induction generators receive their magnetic excitation from the stator, either via capacitors or the grid.

Hydro Induction Power's four-nozzle turgo turbine.

An Energy Systems & Design turbine.

This Francis runner is an example of a reaction turbine, which is submerged in water and rotates with the force of water flowing through the equipment.

A turgo runner which accepts water from nozzles that point down on the spoons from above, at an angle.

In a Pelton runner design, water impacts the wheel's spoons parallel to the plane of rotation.

Pumps as Turbines

A pump-as-turbine (PAT) microhydro plant is just what it sounds like—the turbine is actually the impeller of a centrifugal pump "running backward" and the generator is simply the pump's induction motor. PAT installations have been running reliably and efficiently for years. Utilities around the world also use the concept in massive pumped-storage installations. For village and household scales, the technology was pioneered by Arthur Williams in his book *Pumps as Turbines: A User's Guide,* published by Intermediate Technology Development Group (ITDG, www.itdg.org). The Canadian hydro-power controls company Thompson & Howe uses PATs to power its factory. I've been working with the Border Green Energy Team (BGET) building PAT systems in Thailand for the past six years.

One key advantage of PATs is that centrifugal pumps are robust, mass-manufactured, more readily available, and less expensive than manufactured microhydro turbines. They're also easier to fix, since it's a lot easier to find a pump mechanic than a microhydro mechanic. A disadvantage is that unlike Peltons and turgos, a single installation is not efficient over a wide range of flows. This can be mitigated by having multiple PATs of different sizes each optimized for a different flow, and turning them on in combination to suit specific flow regimes. We generally design just for dry-season flow and use that year-round. Pump selection (head, flow, and mechanical characteristics) is key—if you're serious about it, read Williams's book.

A PAT system generally uses the pump's induction motor as an AC generator. For grid-tied installations, induction motors are usually the easiest rotating generation to interconnect directly. For stand-alone installations, capacitors are required to provide reactive power that allows the pump's induction motor to generate AC electricity. The process is not difficult, and is described in Nigel Smith's *Motors as Generators for Micro-Hydro Power*, also published by ITDG press. You can find the essential equations from both Williams's and Smith's books in a PAT design spreadsheet at www.palangthai.org/docs/.

—Chris Greacen

Maximum power is determined by the watts produced by the turbine at maximum water flow and net head. This number is used to calculate the size of charge controllers and dump loads necessary to protect turbines and battery banks, adding a safety factor.

Voltage of the type of generator used. Alternating current (AC) generators are used for either standard 60 Hz electricity or to produce "wild" unregulated voltage and frequency electricity, which is rectified to DC to charge batteries. "Wild" indicates that the turbine is not producing steady 60 Hz AC, and the frequency and voltage may vary. High-voltage generation (hundreds of volts instead of dozens of volts) can be useful in overcoming line losses.

AC/DC stands for alternating current and direct current. Most smaller (100 to 1,000 W; less than 2 kW; 48 kWh/day) hydro-electric turbines use permanent-magnet, "wild" AC generators. Most larger microhydro systems (2 to 100 kW) use either an induction or synchronous AC generators. Virtually all spinning generators make AC natively, and how it is transferred and conditioned is based on the application. Battery charging turbines end up producing DC. The grid and your home loads are AC systems, so turbines designed to directly interface with them produce AC in the end.

Grid connection is possible with certain makes and models. The grid connection for a smaller (less than 2 kW) hydro system commonly uses a grid-tied inverter, as for PV systems. Larger systems (2 to 100 kW) are connected through switchgear and inductive generators or synchronous generators and governors.

Runner type identifies the turbine wheel used to convert water power to rotational power, and is determined by the head and flow available. Through testing, manufacturers have determined the best runner types for various head and flow conditions. Common types are the Pelton wheel, the turgo, the crossflow, and the propeller. Your turbine supplier and contractor can give good advice about the choices.

Runner Material. Runners for microhydro applications are commonly made of an alloy, since these materials resist corrosion and are easily cast and machined into shape. Stainless is most common in larger systems. Stainless steel and various bronze alloys are common, long-lasting materials. Plastics are used for smaller, less expensive runners.

(continued on page 108)

Microhydro Turbine Buyer's Guide

Manufacturer	Model	Generator Type	Max. Power (W)	Voltage	AC or DC	Grid Connection Possible?	Runner Type
Alternative Power & Machine www. apmhydro.com	1032 DC	Permanent magnet	750	12 – 120	DC	Direct	Pelton
	1032 AC	Permanent magnet	1,100	24 – 480	Wild AC	Direct	Pelton
	1038 DC	Permanent magnet	960	12 – 120	DC	Direct	Pelton
	1038 AC	Permanent magnet	1,200	24 – 480	Wild AC	Direct	Pelton
	36	Wound field	3,300	12 – 120	DC	Direct	Pelton
Canyon Hydro www. canyonhydro.com	6010	Synchronous or induction	20,000	120, 240, 480	AC	Direct	Pelton
	751	Synchronous or induction	40,000	120, 240, 480	AC	Direct	Pelton
	1051	Synchronous or induction	80,000	120, 240, 480	AC	Direct	Pelton
	1215	Synchronous or induction	100,000	120, 240, 480	AC	Direct	Pelton
	1220	Synchronous or induction	80,000	120, 240, 480	AC	Direct	Pelton
Dependable Turbines www. dtlhydro.com	Pelton	Wound field	2,000	12/24/48	DC	Direct	Pelton
	Pelton	Synchronous or induction	27,000	120 – 480	AC	Direct	Pelton
	Pelton	Synchronous or induction	70,000	120 – 480	AC	Direct	Pelton
	Turgo	Synchronous or induction	90,000	120 – 480	AC	Direct	Turgo
	Fixed Flow Pumps	Synchronous or induction	250,000	120 – 480	AC	Direct	Pumps
Ecoinnovation www. ecoinnovation. co.nz	PowerSpout - BE	Permanent magnet	1,200	12/24/48	DC	No	Pelton
	PowerSpout - ME	Permanent magnet	1,200	100 – 120	DC	Yes	Pelton
	PowerSpout - GE	Permanent magnet	1,200	300 – 400	DC	Yes	Pelton
	PowerSpout - HE	Permanent magnet	1,200	300 – 500	Either	No	Pelton
Energy Systems & Design www. microhydropower. com	LH 1000 standard	Adjustable PMA	1,000	12, 24, 48, 120, 240	Either	Inverter	Propeller
	LH 1000 low volume	Adjustable PMA	500	12, 24, 48, 120, 240	Either	Inverter	Propeller
	Stream Engine/ standard	Adjustable PMA	2,000	12, 24, 48, 120, 240	Either	Inverter	Turgo
	Stream Engine/ low flow	Adjustable PMA	2,000	12, 24, 48, 120, 240	Either	Inverter	Custom
	Stream Engine/ Easy Tune	Adjustable PMA	3,000	12, 24, 48, 120, 240	Either	Inverter	Turgo or Custom
Harris Hydro 707-986-7771	Harris 12v	Adjustable PMA	750	12	DC	Direct	Pelton
	Harris 24v	Adjustable PMA	1,500	24	DC	Direct	Pelton
	Harris 48v	Adjustable PMA	1,500	48	DC	Direct	Pelton
Hydro Induction Power www. hipowerhydro.com	HV1200	Induction	1,200	240, 440	Either	Direct	Turgo
	HV2000	Induction	2,000	240, 440	Either	Direct	Turgo
	HV4000	Induction	4,000	240, 440	Either	Direct	Turgo
	LV750	Permanent magnet	750	12, 24, 48	DC	No	Turgo
	LV1500	Permanent magnet	1,500	12, 24, 48, 120	DC	Direct	Turgo
PowerPal www.powerpal. com	200LH	Permanent magnet	200	110	AC	No	Propeller
	500LH	Permanent magnet	500	110	AC	No	Propeller
	1000LH	Permanent magnet	1,000	110	AC	No	Propeller
	200HH	Permanent magnet	200	110	AC	No	Turgo
	500HH	Permanent magnet	500	110	AC	No	Turgo

[a]For use with step-down transformer/rectifier to DC system; [b]Turgo runners have 7-inch outside diameter (pitch diameter listed); [c]Built-in shunt reads from the supplied DMM. Charge controllers & dump loads are extras.

Runner Material	Runner Diameter (In.)	Number of Nozzles	Nozzle Sizes (In.)	Head Range (Ft.)	Flow Range (gpm)	Controls & Overspeed Control	Controls, Dump Load & Metering Included
Plastic (SS optional)	5.4	1 – 4	1/16 – 3/4	4 – 1,000	3 – 240	N/A	Ammeter
Plastic (SS optional)	5.4	1 – 4	1/16 – 3/4	4 – 1,000	3 – 240	N/A	Controls & load optional
Plastic (SS optional)	5.4	1 – 4	1/16 – 3/4	4 – 1,000	3 – 240	N/A	Ammeter
Plastic (SS optional)	5.4	1 – 4	1/16 – 3/4	4 – 1,000	3 – 240	N/A	Controls & load optional
Plastic (SS optional)	5.4	1 – 4	1/16 – 3/4	4 – 1,000	3 – 240	Field control only	Ammeter
Bronze alloy	6.0	1 – 2	≤ 1.0	80 – 200	100 – 650	Yes	Yes
Bronze alloy	7.5	1 – 2	≤ 1.0	80 – 350	100 – 800	Yes	Yes
Bronze alloy or SS	10.5	1 – 2	≤ 1.0	200 – 600	100 – 1,000	Yes	Yes
Bronze alloy or SS	12.5	1 – 2	≤ 1.5	80 – 500	100 – 1,900	Yes	Yes
Bronze alloy	12.0	1 – 2	≤ 2.0	60 – 200	100 – 2,250	Yes	Yes
Bronze	6.5	1 – 4	Custom	< 1 80	< 66	Optional	Optional
Bronze	8.0	1 – 2	Custom	< 285	< 660	Yes	Optional
Bronze	10.0	1 – 2	Custom	< 415	< 1,190	Yes	Optional
Bronze	8.0	1 – 2	Custom	< 265	< 2,400	Yes	Optional
Bronze	12.0		Custom	< 295	< 6,200	Yes	Optional
Glass-filled nylon	9.2	2	0.12 – 0.9	10 – 330	2 – 127	External voltage regulator & dump load	Optional
Glass-filled nylon	9.2	2	0.12 – 0.9	10 – 330	8 – 127	120 VDC voltage controller	Controls & load
Glass-filled nylon	9.2	2	0.12 – 0.9	10 – 330	8 – 127	400 VDC voltage controller	Controls & load
Glass-filled nylon	9.2	2	0.12 – 0.9	10 – 330	8 – 127	External voltage regulator & dump load	Optional
Bronze	5.0	N/A	N/A	2–10	500 – 1,000	Not included	Ammeter[c]
Bronze	5.0	N/A	N/A	2–10	250 – 500	Not included	Ammeter[c]
Bronze	4.0[b]	1 – 4	1/8 – 1	5–100s	< 100s	Not included	Ammeter[c]
Bronze	4.0	1 – 4	1/8 – 1/2	20 – 100s	100s	Not included	Ammeter[c]
Bronze	4.0[b]	1 – 4	1/8 – 1	< 100s	100s	Not included	Ammeter[c]
Bronze	4.0	1 – 4	1/8 – 1/2	25 – 300	3 – 200	Not included	Ammeter
Bronze	4.0	1 – 4	1/8 – 1/2	25 – 300	3 – 200	Not included	Ammeter
Bronze	4.0	1 – 4	1/8 – 1/2	25 – 300	3 – 200	Not included	Ammeter
Hardened SS	4.0	4	1/8 – 5/8	60 – 600	5 – 600	Optional	Meter
Hardened SS	4.0	4	1/8 – 5/8	60 – 600	5 – 600	Optional	Meter
Hardened SS	4.0	4	1/8 – 5/8	60 – 600	5 – 600	Optional	Meter
Hardened SS	4.0	1 – 4	1/8 – 5/8	15 – 100	5 – 100	Optional	Meter
Hardened SS	4.0	1 – 4	1/8 – 5/8	50 – 600	5 – 100	Optional	Meter
Cast iron	4.5	1	N/A	4.9	< 550	Auto. ELC	Air heater load
Cast iron	8.5	1	N/A	4.9	< 1,100	Auto. ELC	Air heater load
Cast iron	12.4	1	N/A	4.9	< 2,130	Auto. ELC	Air heater load
Cast iron	7.0	1	1.1	16 – 20	< 100	Auto. ELC	Air heater load
Cast iron	7.0	1	1.1	23 – 36	120 – 145	Auto ELC	Air heater load

PMA = Permanent magnet alternator; SS = Stainless steel; Auto ELC = Automatic electronic load controller

Runner diameter selection is associated with the velocity of water impacting the runner, which is directly related to available head. The higher the head, the smaller the runner diameter for a given/constant shaft speed. Under ideal conditions, the runner velocity is approximately half the water jet velocity. For practicality, runners for smaller turbines are usually limited to just a few. The runner's speed is adjusted by means of the generator field in relation to battery voltage, or using belt pulley ratios in relation to the output frequency of direct AC systems Again, your suppliers are your best resources for helping make this choice.

Number of nozzles is a choice dependent on the range of water flow available to the turbine. Nozzles are opened or closed (manually for most small turbines, and occasionally automatically for larger turbines) to maintain maximum pressure in the turbine pipeline while taking advantage of available flow. Having multiple nozzles is especially important where stream flow varies widely over the year, so you have the option of using more or less water.

Nozzle size options are associated with available water flow. Smaller-diameter nozzle sizes are used for lower-flow situations. Nozzles are sized by manufacturers based on potential range of flow. Generally, these parts are removable and replaceable. Larger systems sometimes have adjustable "needle nozzles" or "spear valves."

Head range is associated with types of turbine runners that can be used. Higher-head turbines use impact runners, which are generally Pelton or turgo designs. Mid-range turbines (suitable for 20 to 60 feet of head) use reaction runners, which are submerged fully or partially, and include Francis and propeller runners. Low-head turbines (3 to 20 feet) may also use propeller reaction turbines.

Flow range will vary for every project site. The table shows the actual flow used in the turbine, which may be 10% to 50% of the stream flow.

Controls and over-speed control are necessary for stand-alone AC turbines to maintain 60 cycles per second output under varying load conditions. Electronic load governors usually provide this control for AC units, shunting energy to resistive loads. Control is also necessary for grid-tied systems when utility outages occur. Without the load of the utility grid, a hydro turbine will over-speed, possibly resulting in mechanical and electrical failure.

Controls, dump load, and metering included describes what comes with a turbine and what must be purchased separately.

Turbine Selection

Turbine selection usually begins with determining the site's available head and flow, including variation in seasonal flows. Selection is also based on whether your system will be grid-tied or off-grid, and with or without batteries. Most turbine manufactures provide online questionnaires to assist in turbine selection.

Most turbine manufacturers publish test results for their turbines at various heads and flows, and with various turbine runners. Charts are prepared and compiled for various nozzle sizes and will be used by the manufacturer to recommend a specific turbine.

A PowerPal turgo turbine, rated at 200 W.

The intended use of energy will further determine turbine sizing. There is no point in generating more energy than can be used. Unlike PV systems, hydro-electric turbines generate electricity 24 hours a day, seven days a week. Unused energy must be shunted through to the grid, or to diversion loads—typically water or air heaters—to protect the generator. Inverters and battery banks for hydro-electric systems are normally sized to meet peak load, and store excess energy for these loads and motor-starting surges.

The location of a turbine relative to its interconnected battery bank or loads normally dictates turbine generation voltage. A distance of 100 feet or less may permit use of a low-voltage DC generation turbine. Transmission wire size and voltage drop beyond 100 feet may be excessive at low voltage and will often dictate the selection of an unregulated high-voltage AC turbine (400 to 500 V wild AC) feeding transformers at the battery shed, depending on the wattage.

Beyond Turbines

Careful planning is called for, even beyond the selection of the turbine. Each system component must be selected and integrated into the whole. For instance, the design and installation of valves, and connection and discharge pipes, are critical to the proper operation of hydro-electric turbines, because water discharging from a turbine will mix with air and commonly double in volume as it leaves the turbine. Advice from turbine manufacturers is also helpful when considering inlet and outlet piping size.

Access

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