Water / Eau

Les microcentrales hydro-électriques dans les années 90

Paul Cunningham, un expert de renommée mondiale en microcentrales hydroélectriques, nous plonge dans le sujet de l'énergie renouvelable.

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Micro Hydro Power in the Nineties

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Micro hydro power was once the world’s prominent source of mechanical power for manufacturing. Micro hydro is making a comeback for electricity generation in homes. Increasing numbers of small hydro systems are being installed in remote sites in North America. There’s also a growing market for micro hydro electricity in developing countries. This article is a technical over-view.

Micro hydro power is gradually assuming the decentralized form it once had. Water power predates the use of electricity. At one time hydro power was employed on many sites in Europe and North America. It was primarily used to grind grain where water had a vertical drop of more than a few feet and sufficient flow. Less common, but of no less importance, was the use of hydro to provide shaft power for textile plants, sawmills and other manufacturing operations.

Over time thousands of small mills were replaced by centrally-generated electric power. Many major hydroelectric projects were developed using large dams, generating several megaWatts of power. In many areas, hydro electric power is still used on a small scale and is arguably the most cost-effective form of energy.

Renewable energy sources such as wind and solar are being scaled up from residential to electric utility size. In contrast, hydro power is being scaled down to residential size. The small machines are similar in most ways to the large ones except for their scale.

Siting a hydro system is much more site-specific than a wind or photovoltaic (PV — solar electric) system. A sufficient quantity of falling water must be available. The vertical distance the water falls is called head and is usually measured in feet, meters, or units of pressure. The quantity of water is called flow and is measured in gallons per minute (gpm), cubic feet per second (cfs), or liters per second (l/s). More head is usually better because the system uses less water and the equipment can be smaller. The turbine also runs at a higher speed. At very high heads, pipe pressure ratings and pipe joint integrity become problematic. Since power is the product of head and flow, more flow is required at lower head to generate the same power level. More flow is better, even if not all of it is used, since more water can remain in the stream for environmental benefits.

A simple equation estimates output power for a system with 53% efficiency, which is representative of most micro hydro systems:

Net Head* (feet) x Flow (US gpm) / 10 = Output (Watts)

* Net head is the pressure available after subtracting losses from pipe friction. Most hydro systems are limited in output capacity by stream conditions. That is, they cannot be expanded indefinitely like a wind or PV system. This means that the sizing procedure may be based on site conditions rather than power needs. The size and/or type of system components may vary greatly from site to site. System capacity may be

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dictated by specific circumstances (e.g. water dries up in the summer). If insufficient potential is available to generate the power necessary to operate the average load, you must use appliances that are more energy-efficient and/or add other forms of generation equipment to the system. Hybrid wind/PV/hydro systems are very successful and the energy sources complement each other.

The systems described here are called "run of river"; i.e. water not stored behind a dam. Only an impoundment of sufficient size to direct the water into the pipeline is required. Power is generated at a constant rate and if not used, it is stored in batteries or sent to a shunt load. Therefore, there is little environmental impact since minimal water is used. There is also much less regulatory complication.

System Types

If electric heating loads are excluded, 300-400 Watts of continuous output can power a typical North American house. This includes a refrigerator/freezer, washing machine, lights, entertainment and communication equipment, all of standard efficiency. With energy-efficient appliances and lights and careful use management, it is possible to reduce the average demand to about 200 Watts continuous.

Power can be supplied by a micro hydro system in two ways. In a battery-based system, power is generated at a level equal to the average demand and stored in batteries. Batteries can supply power as needed at levels much higher than that generated and during times of low demand the excess can be stored. If enough energy is available from the water, an AC-direct system can generate power as alternating current (AC). This system typically requires a much higher power level than the battery-based system.

Battery-Based Systems

Most home power systems are battery-based. They require far less water than AC systems and are usually less expensive. Because the energy is stored in batteries, the generator can be shut down for servicing without interrupting the power delivered to the loads. Since only the average load needs to be generated in this type of system, the pipeline, turbine, generator and other components can be much smaller than those in an AC system.

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Power = The rate of doing work
(IE Watts or horsepower)

1 Watt = 1 Volt X 1 Ampere

1 Horsepower = 746 Watts

1000 Watts consumed = 1 kiloWatt-Hour
(IE the unit found on utility bills)
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Very reliable inverters are available to convert DC battery power into AC output (120 volt, 60 Hz). These are used to power most or all home appliances. This makes it possible to have a system that is nearly indistinguishable from a house using utility power.

The input voltage to the batteries in a battery-based system commonly ranges from 12 to 48 Volts DC. If the transmission distance is not great then 12 Volts is often high enough. A 24 Volt system is used if the power level or transmission distance is greater. If all of the loads are inverter-powered the battery voltage is independent of the inverter output voltage and voltages of 48 or 120 may be used to overcome long transmission distances. Although batteries and inverters can be specified for these voltages, it is common to convert the high voltage back down to 12 or 24 Volts (battery voltage) using transformers or solid state converters.

Wind or solar power sources can assist in power production because batteries are used. Also, DC loads (appliances or lights designed for DC) can be operated directly from the batteries. DC versions of many appliances are available, although they often cost more and are harder to find, and in some cases, quality and performance vary.

AC-Direct Systems

This is the system type used by utilities. It can also be used on a home power scale under the right conditions. In an AC system, there is no battery storage. This means that the generator must be capable of supplying the instantaneous demand, including the peak load. The most difficult load is the short-duration power surge drawn by an induction motor found in refrigerators, freezers, washing machines, some power tools and other appliances. Even though the running load of an induction motor may be only a few hundred Watts, the starting load may be 3 to 7 times this level or several kiloWatts. Since other appliances may also be operating at the same time, a minimum power level of 2 to 3 kiloWatts may be required for an AC system, depending on the nature of the loads.

In a typical AC system, an electronic controller keeps voltage and frequency within certain limits. The hydro's output is monitored and any unused power is transferred to a "shunt" load, such as a hot water heater. The controller acts like an automatic dimmer switch that monitors the generator output frequency cycle by cycle and diverts power to the shunt load(s) in order to maintain a constant speed or load balance on the generator. There is almost always enough excess power from this type of system to heat domestic hot water and provide some, if not all, of a home's space heating.

System Components

An intake collects the water and a pipeline delivers it to the turbine. The turbine converts the water's energy into mechanical shaft power. The turbine drives the generator which converts shaft power into electricity. In an AC system, this power goes directly to the loads. In a battery-based system, the power is stored in batteries, which feed the loads as needed. Controllers may be required to regulate the system.

Pipeline

Most hydro systems require a pipeline to feed water to the turbine. The exception is a propeller machine with an open intake. The water should pass first through a simple filter to block debris that may clog or damage the machine. The intake should be placed off to the side of the main water flow to protect it from the direct force of the water and debris during high flows.It is important to use a pipeline of sufficiently large diameter to minimize friction losses from the moving water. When possible, the pipeline should be buried. This stabilizes the pipe and prevents critters from chewing it. Pipelines are usually made from PVC or polyethylene although metal or concrete pipes can also be used.

Impulse Runner

Francis Runner

Turgo Runner

Turbines

Although traditional waterwheels of various types have been used for centuries, they aren't usually suitable for generating electricity. They are heavy, large and turn at low speeds. They require complex gearing to reach speeds to run an electric generator. They also have icing problems in cold climates. Water turbines rotate at higher speeds, are lighter and more compact. Turbines are more appropriate for electricity generation and are usually more efficient.

There are two basic kinds of turbines: impulse and reaction.

Impulse machines use a nozzle at the end of the pipeline that converts the water under pressure into a fast-moving jet. This jet is then directed at the turbine wheel (also called the runner), which is designed to convert as much of the jet's kinetic energy as possible into shaft Common impulse turbines are pelton, turgo and cross-flow.

In reaction turbines the energy of the water is converted from pressure to velocity within the guide vanes and the turbine wheel itself. Some lawn sprinklers are reaction turbines. They spin themselves around as a reaction to the action of the water squirting from the nozzles in the arms of the rotor. Examples of reaction turbines are propeller and Francis turbines.

Turbine Applications

In the family of impulse machines, the pelton is used for the lowest flows and highest heads. The cross-flow is used where flows are highest and heads are lowest. The turgo is used for intermediate conditions. Propeller (reaction) turbines can operate on as little as two feet of head. A turgo requires at least four feet and a pelton needs at least ten feet. These are only rough guidelines with overlap in applications.

The cross-flow (impulse) turbine is the only machine that readily lends itself to user construction. They can be made in modular widths and variable nozzles can be used.

Most developed sites now use impulse turbines. These turbines are very simple and relatively cheap. As the stream flow varies, water flow to the turbine can be easily controlled by changing nozzle sizes or by using adjustable nozzles. In contrast, most small reaction turbines cannot be adjusted to accommodate variable water flow. Those that are adjustable are very expensive because of the movable guide vanes and blades they require. If sufficient water is not available for full operation of a reaction machine, performance

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suffers greatly.

An advantage of reaction machines is that they can use the full head available at a site. An impulse turbine must be mounted above the tailwater level and the effective head is measured down to the nozzle level. For the reaction turbine, the full available head is measured between the two water levels while the turbine can be mounted well above the level of the exiting water. This is possible because the "draft-tube" used with the machine recovers some of the pressure head after the water exits the turbine. This cone-shaped tube converts the velocity of the flowing water into pressure as it is decelerated by the draft tube's increasing cross section. This creates suction on the underside of the runner.

Crossflow Turbine

Propeller Turbine

Centrifugal pumps are sometimes used as practical substitutes for reaction turbines with good results. They can have high efficiency and are readily available (both new and used) at prices much lower than actual reaction turbines. However, it may be difficult to select the correct pump because data on its performance as a turbine are usually not available or are not straightforward.

One reason more reaction turbines are not in use is the lack of available machines in small sizes. There are many potential sites with 2 to 10 feet of head and high flow that are not served by the market.

Generators

Most battery-based systems use an automotive alternator. If selected carefully, and rewound when appropriate, the alternator can achieve very good performance. A rheostat can be installed in the field circuit to maximize the output. Rewound alternators can be used even in the 100–200 Volt range.

For higher voltages (100–400 Volts), an induction motor with the appropriate capacitance for excitation can be used as a generator. This will operate in a small battery charging system as well as in larger AC direct systems of several kiloWatts.

Another type of generator used with micro hydro systems is the DC motor. Usually permanent magnet types are preferable. However, these have serious maintenance problems because the entire output passes through their carbon commutators and brushes.

Batteries Lead-acid deep-cycle batteries are usually used in hydro systems. Deep-cycle batteries are designed to withstand repeated charge and discharge cycles typical in RE systems. In contrast, automotive (starting) batteries can tolerate only a fraction of these discharge cycles. A micro hydro system requires only one to two days storage. In contrast, PV or wind systems may require many days' storage capacity because the sun or wind may be unavailable for extended periods. Because the batteries in a hydro system rarely remain in a discharged state, they have a much longer life than those in other RE systems. Ideally, lead-acid batteries should not be discharged more than about half of their capacity. Alkaline batteries, such as nickel-iron and nickel-cadmium, can withstand complete discharge with no ill effects.

Controllers

Hydro systems with lead-acid batteries require protection from overcharge and over-discharge. Overcharge controllers redirect the power to an auxiliary or shunt load when the battery voltage reaches a certain level. This protects the generator from overspeed and overvoltage conditions. Overdischarge control involves disconnecting the load from the batteries when voltage falls below a certain level. Many inverters have this low-voltage shutoff capability.

An ammeter in the hydro output circuit measures the current. A voltmeter reading battery voltage roughly indicates the state of charge. More sophisticated instruments are available, including amp-hour meters, which indicate charge level more accurately.

Conclusions

Despite the careful design needed to produce the best performance, a micro hydro system isn't complicated. The system is not difficult to operate and maintain. Its lifespan is measured in decades. Micro hydro power is almost always more cost-effective than any other form of renewable power.

Who should buy a micro hydro system?

In North America, micro hydro is cost-effective for any off-grid site that has a suitable water resource, and even for some that are on-grid. Homeowners without utility power have three options: purchasing a renewable energy system, extending the utility transmission line, or buying a gasoline or diesel generator. Transmission line extension can be expensive because its cost depends on distance and terrain. Even the initial cost of a hydro system may be lower. A gasoline generator may be cheaper to purchase but is expensive to operate and maintain. The life-cycle cost of the hydro system (3–25 ¢/kWh) is much lower than that of a generator (60–95 ¢/kWh). Once the hydro system is paid for, there's no monthly electricity bill and minimal maintenance costs. Since utility rates tend to rise, the value of the power increases, making your investment "inflation-proof."

Notes to budding renewable energy enthusiasts:

The future has potential if you use your head. There are many opportunities in this field for creative people with talents ranging from engineering to writing, if you’re willing to find them and persevere. Remember what head, flow, and love have in common: more is better!

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