Island Power ×2

Off-Grid & On-Grid

by Eric Youngren

Left: Just below the spring, the hydro intake collects 50 to 1,200 gallons per minute, depending on the season.

Above: Both systems utilize butt-welded, high-density polyethylene (HDPE) pipe.

During the winter of 2003, I built my first microhydro system on Orcas Island in Washington state's San Juan islands. At the time, I was installing RE systems all around the Islands. I found a spot on my family's land where I planned to build an off-grid, microhydro-powered homestead. The system was designed and the cash saved for the materials.

As luck would have it, one day I got a call from *Home Power's* Ian Woofenden, who lives on nearby Guemes Island, inquiring about any microhydro projects that could serve as a hands-on workshop.

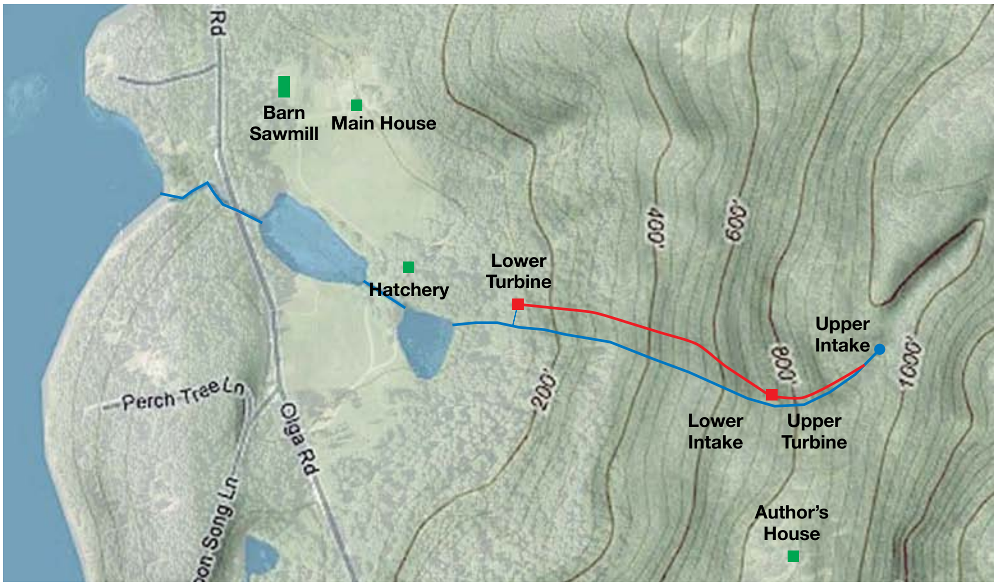
I jumped at the chance to have a 20-person crew for a day. Installation of the 4-inch-diameter HDPE pipe would be a big job and a good time to have a bunch of people to help. The workshop also provided a serious deadline, an extra impetus to get the rest of the system elements in place. Our goal was to be ready with everything so that the workshop participants could install the pipe, connect the turbine, wire the controller and batteries, and then open the valves to make power—all on the same day.

Microhydro History

In 1978, my family moved to Orcas Island from the suburbs of Seattle. As a kid, I spent many happy days playing in the creek that flows through my family's land, from the spring 1,000 feet up the side of the mountain to where the water joins the ocean in East Sound. Like most kids, I learned about the power of flowing water by playing with it. We built pools and dams in the creek, digging new channels for the water to follow as it was pulled ever downward by gravity's incredible power. In the early '80s, my dad and some of his friends started raising salmon in the ponds and creek channels of the lower sections of the creek (see "Long Live The Kings" sidebar).

Starting with the first homesteaders in 1875, everyone who has lived on this land has captured and utilized the bounty of water flowing down the mountain for drinking and irrigation. In earlier days, they also made electricity with the water, but the last hydro-electric system (before I started installing them) appears to have stopped working in the 1950s or early 60s, around the time when the local rural electric co-op installed submarine high-voltage cables to bring Columbia River-generated grid power to the islands.

As a teenager, I learned about the basics of hydro power and started reading *Home Power* magazine, scheming and planning for the day when I could build a system of my own. I learned about the power potential of head and flow, and the dangers of water hammer through trial-and-error experiments and the occasional, spectacularly wet, destructive blowout. I came to truly understand how voltage and amperage combine to create electrical power when it was explained how these two variables behave in the same way that head and flow combine to create hydro power.



Two hydro turbines utilize over 750 vertical feet of head from a mountainside spring near East Sound on Orcas Island, in Washington State.

System 1: DC Off-Grid

Planning the Penstock

For my home site on the family property, I chose a spot up the hill to be close to the spring—a 1-acre flat shelf about 900 feet up that projects out from the steeper slopes of the mountain above and below it. The spring sits about 80 vertical feet above the house, and about 700 feet to the northeast.

I found evidence of previous plans for hydro power: A small intake pond had been excavated in the creek at a spot with rough road access. A simple plywood dam and plastic-lined pond backed up the water to channel it through a rectangular weir for measuring creek flow. That was the easiest and most logical place to build the intake for my system. Because it sat about 50 vertical feet above the house site, I would also be able to use the hydro intake to supply pressurized domestic water to the house. A narrow, level bench at the bottom of a 100-foot drop, about 50 feet lower than the house site and 650 feet to the north, was the best place to site the turbine.

Because of the steep, forested terrain, all the conduit trenching was done by hand, with a mattock and 4-inch-wide trenching shovel. We set into the trench 2-inch-diameter PVC conduit, with plastic pull boxes every 200 feet, and a 1.5-inch plastic pipe for bringing domestic water along with the power to the house.

The Harris Hydro 5-inch Pelton turbine is driven by four nozzles at about 50 psi, spinning a permanent-magnet generator that produces up to 1 kW during the wet season.

DC System Tech Specs

Overview

System type: Off-grid, battery-based microhydro-electric with PV

System location: Eastsound, Washington

Site head: 110 ft.

Hydro resource flow (dry season): 50 gpm

Hydro resource flow (wet season): 150 gpm

Hydro production (dry season): 400 AC kWh per month avg.

Hydro production (wet season): 700 AC kWh per month avg.

Civil Works

Diversion: 12 ft. long by 2 ft. high by 4 in. thick cedar timber weir

Intake: 1.75 sq. ft. stainless steel Hydro-Shear screen

Penstock: 320 ft., 4 in. diameter HDPE, SDR 11

Powerhouse: 8 by 12 ft., lumber frame, locally milled Douglas fir

Hydro Turbine

Turbine: Harris Hydro, 48 V, permanent magnet, four-nozzle Pelton

Runner diameter: 5 in.

Alternator: Permanent magnet 48 VDC

Rated peak power output: 1.5 kW

Hydro Balance of System

Hydro turbine controller: Trace C40, 40 A

Dump load: 48 VDC water heater element

Inverter: Two OutBack FX3048, 48 VDC nominal input, 120/240 VAC output

Circuit protection: 40 A Airpax DC circuit breaker

System performance metering: TriMetric 2020, FlexNet DC

Engine Generator

Make/model: Honda EU 2000

Energy Storage

Batteries: 8 Interstate UL-16, 360 Ah at 6 V each

Battery bank: 48 VDC nominal, 360 Ah total

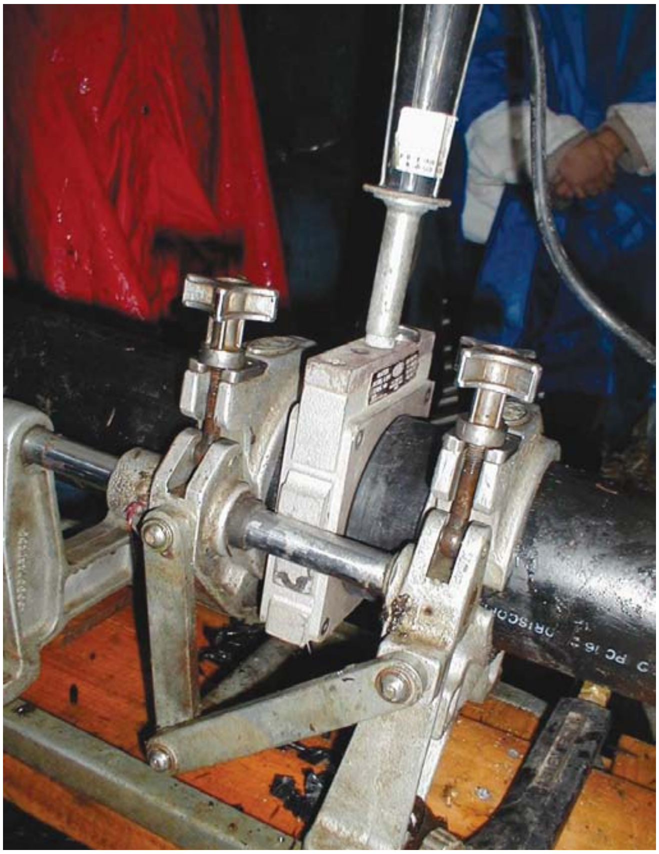
Battery/inverter disconnect: 100 A breakers

For the turbine base, I found a 24-inch-diameter cast concrete culvert pipe in a local boneyard of surplus and salvage materials. We used a gasoline-powered cut-off saw from the rental shop to shave 2 feet off one end so that it could be set vertically, holding the Harris turbine securely and allowing the water to exit freely out of the bottom. A rotary hammer and a cold chisel were used make a 6-inch-diameter hole in the side of the culvert about 4 inches from the end. The culvert was sunk vertically in a 1-foot-deep hole near the creek. We poured a concrete floor in the pipe level with the exit hole. Then, we dug a short trench across to the creek, caulked a 6-inch-diameter flexible plastic pipe to the tailwater exit hole and ran the other end into the creek below the turbine.

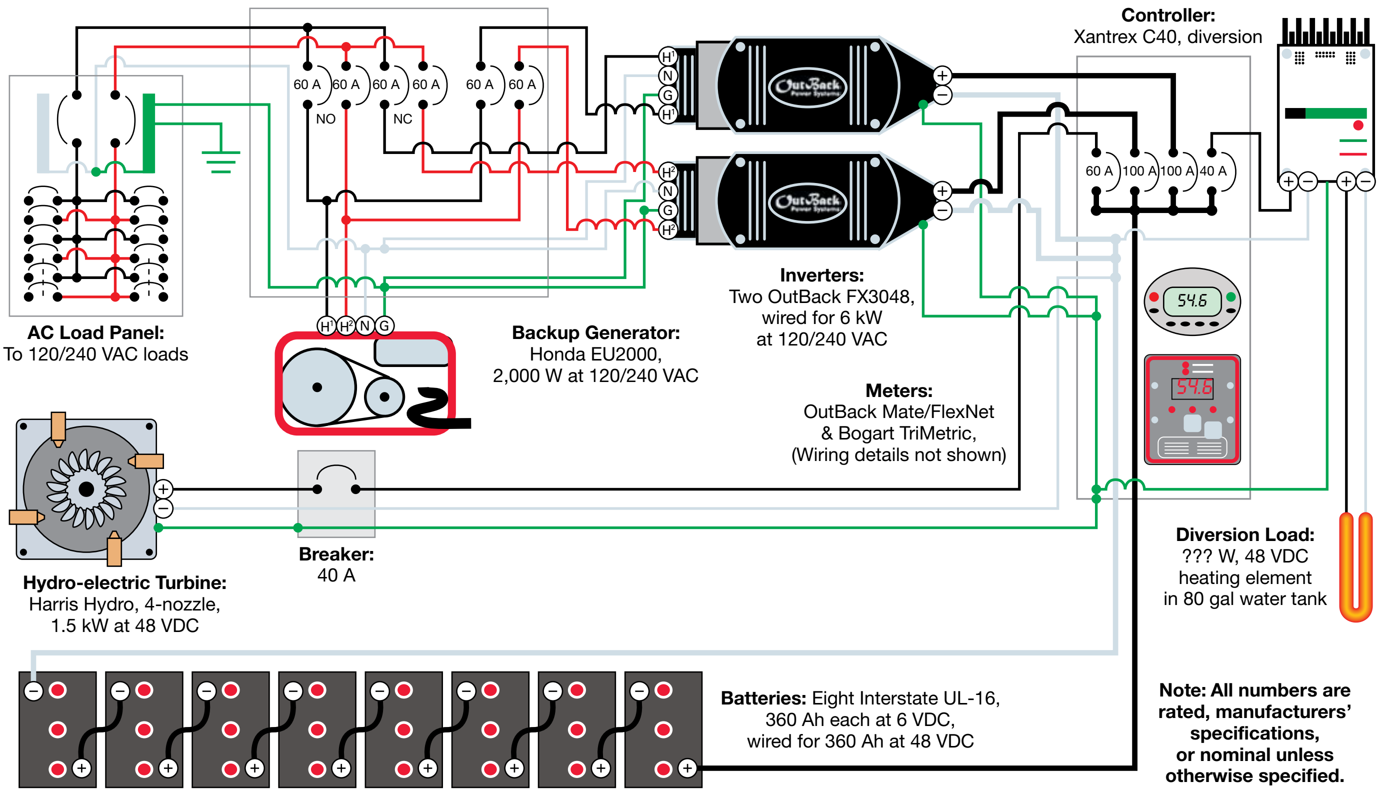
Installing the System

The penstock installation occurred on a rainy day in April 2003. Ian brought 20 workshop students. We rented a polyethylene pipe-welding machine from the pipe supplier and used a small pop-up canopy to keep the rain off the welding crew. The machine has a facer that cuts the pipe ends smooth so they will match and line up perfectly. A heater element softens the pipe ends until a small bead of soft plastic begins to form on the hot metal. At that point, the heater plate is removed and the ends are brought together quickly by pulling the lever on the pipe clamp jig and held under pressure until the joint cools. It is a relatively simple process that makes a strong and leakproof joint with only a minimal bead on the inside of the pipe to minimize water friction in the line.

A polyethylene welding machine was used to assemble the upper penstock.



Hydro System 1: Off-Grid



OutBack Power Systems inverters convert DC hydro power to AC for the author's home.

Our pipe-welding station was at the top of the penstock installation to take advantage of gravity. As each 20-foot section of pipe was added to the penstock, we simply dragged the lengthening pipe 20 feet down the hill. However, as the penstock got longer, it became heavier and wanted to slide down the hill on its own. We used rope to temporarily anchor it to trees and roots during the descent. Once all 300 feet were in place, we attached a bolted flange adapter with a rubber gasket to the PVC manifold at the turbine. Later, I added galvanized cable anchors bolted to the bedrock and boulders to permanently hold the pipe in place on the steep hillside.

The turbine was set on top of the vertical concrete culvert section using a frame of cedar 2 by 4s. This allowed a friction fit for the turbine—the frame held it securely, yet the turbine could still be easily removed from the base without tools for maintenance and nozzle replacement. The 48-volt DC wiring was placed in flexible plastic conduit to allow the turbine to be lifted up and swung to ground level to access the nozzles on the underside without needing to disconnect any wiring.

Connecting to the Turbine

The turbine is a four-nozzle, vertical-shaft Pelton design. Borrowing ideas from other systems I had seen on the island, I used flexible hose with cam-lock quick-disconnect fittings for connection to both the turbine nozzles and the manifold. The manifold is made from PVC wye fittings that reduce and split the single 4-inch pressure line into five 2-inch pipes, with

Water pressure was used to blast the trench for the lower penstock.

brass gate valves in each pipe. A fifth valve, at the very end of the penstock, is for supplying water to the building site. A 4-inch-diameter wye on the penstock above the manifold is for future system expansion. By adding a second turbine in parallel, more power can be made during the highest flow times of the year (winter/spring).

From the turbine, 2-gauge wiring runs up the hill 650 feet to the batteries in the power house. A Trace C-40 diversion-load controller keeps the batteries from being overcharged by dumping excess current into a 48 V heater element in a water storage tank.

After the pipeline installation, I built a proper intake dam, with cedar timbers set across the creek. A 16-inch square of stainless steel Hydro-Shear screen placed under the overflow notch captures water but allows debris to be washed easily across the surface of the screen. After seven years of continual operation, the intake screen is still working perfectly, with the only screen-clogging problem being a slow growth of algae that needs to be scrubbed off with a wire brush every few years.

System 2: AC Grid-Tied

In Sync with the Grid

After the success of the system at the top of the creek, we decided to move ahead with an even larger system, using the remaining 650 feet of elevation that the creek drops after it passes my turbine and before it reaches the salmon ponds, stream channels, and incubator boxes in the hatchery building at the bottom of the hill. The hillside is steep, rocky and very porous—so much that the entire creek goes subterranean for most of the way down the mountain. At the base of the hill, the water resurfaces through the lower springs, which sit just above the highest hatchery ponds.

Our plan was to capture the water just below the Harris turbine system, run it down the hill in the shortest route possible to a power house just above the highest hatchery ponds. An existing road would enable us to minimize the impact to the land, and the tailrace would reintroduce the water into the watershed just above the lower springs, keeping the water flow to the hatchery unchanged.

This grid-tied system couples a 60 W AC induction motor/generator to the utility grid through a grid-protection control panel. Our local utility, Orcas Power and Light Co-op, gave us permission to interconnect a system up to 100 kW. During the peak winter to spring season, the creek flow regularly exceeds 1,000 gallons per minute (gpm) and we wanted to maximize power production during those peak months. Dan New from Canyon Hydro flew over from Deming and we hiked the watershed. After some assessment, we decided to use 800 gpm as our design flow rate. Canyon's engineers designed a system using a two-nozzle, 10.5-inch Pelton turbine.

A 6-inch penstock was chosen to keep head loss within reason. I located used 6-inch, thin-wall steel pipe with ends

Left: The author connects the 6-inch steel pipe to the HDPE pipe with a flange adaptor.

Right: One thousand lineal feet of steel pipe was used in the bottom of the lower penstock. The steep terrain necessitated creative installation and anchoring systems.

The Canyon Industries turbine consists of a 10.5-inch Pelton turbine and a 60 kW, 480 VAC, three-phase alternator.

AC System Tech Specs

Overview

System type: Grid-tied, batteryless microhydro-electric

System location: Eastsound, Washington

Site head: 650 ft.

Hydro resource flow (dry season): 50 gpm

Hydro resource flow (wet season): 1,200 gpm

Production (dry season): 7,000 AC kWh per month

Production (wet season): 32,000 AC kWh per month

Civil Works

Diversion: Stone & concrete weir

Intake: 12 sq. ft. stainless steel Hydro-Shear screen

Penstock: 700 ft. of 6 in. HDPE & 1,000 ft. of 6 in. diameter, 0.141 in. thick, roll-grooved steel with Victaulic couplers

Power house: 20 by 20 ft. concrete foundation & timber frame

Hydro Turbine

Turbine: Canyon Hydro model 1051-2, two-nozzle Pelton

Runner diameter: 10.5 in. cast stainless steel

Rated peak power output: 60 kW

Balance of System

Hydro turbine controller: Thomson & Howe grid protection panel, 480 V, 3-phase, 60 Hz

for use with Victaulic couplings—two cast-iron jaws bolted around a rubber gasket to make a watertight and high-pressure-worthy joint. That steel pipe was the least expensive pipe available for the higher-pressure sections of the run. The pressure at the top of the pipe was lower, so we started with 700 feet of 100 PSI-rated HDPE plastic pipe for the top section, reserving the steel pipe for the bottom 1,000 feet.

What I did not anticipate was how much labor it would take to install the heavy steel pipe on the steep rocky mountainside. If I were to do it again, I'd use two parallel runs of 4-inch-diameter, heavy wall HDPE. The material would have cost more than the 6-inch steel pipe, but the installation would have taken a few weeks, rather than a few months! A single run of 6-inch, heavy wall HDPE would have reduced the internal dimension significantly and introduced too much head loss. Two runs of 4-inch, heavy wall HDPE would have had enough internal dimension to keep head loss in the allowable range.

We installed the system during the spring and summer of 2006, preparing the route using "hydro excavation." A long stretch of 1 1/2-inch HDPE pipe connected to my hydro penstock and a high-pressure fire hose with a long brass nozzle was used to shoot a jet of water to clear the route for the penstock. Some of the sections needed substantial amounts of earth cleared to make a straight path. It's really quite impressive how much dirt and rock high-pressure water can move!

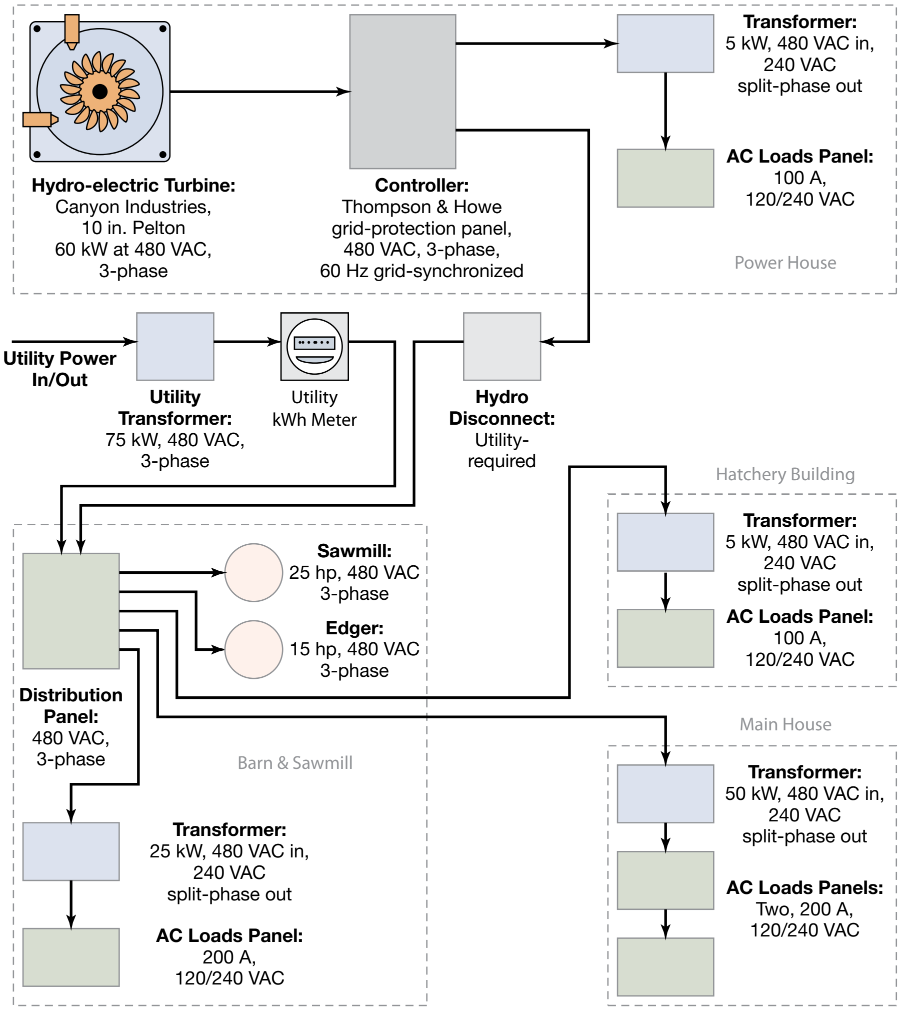
The 20-foot sections of 6-inch pipe each weighed about 250 pounds and required about four people to move. We devised pipe-lifting and positioning techniques using ropes, straps, "come-along" hand winches, and a rope capstan winch mounted on a chain-saw body, combined with tree-mounted anchor points, blocks of timber, or "cribbing," and hydraulic jacks.

Parts of the route passed over exposed bedrock, so we used a 1-inch-diameter rotary-hammer to drill anchor holes for securing eye bolts and pipe anchor attachments with two-part epoxy. In places without exposed bedrock, the hillside is loose shale rock that provided little solid ground to attach to. In those locations, we dug holes for gabions—large wire cages filled with rocks and concrete—into the loose rocky hillside to form a solid anchor point and prevent the heavy, water-filled pipe from sliding downhill.

The Canyon turbine arrived with a steel frame designed to be cast into the concrete of the power house floor. The middle of the frame is left open so the water can exit the turbine. We built a concrete basement under a third of the power house floor, with a pedestal to hold the turbine. The floor above the tailrace section is 4-inch-thick, red cedar planks. A 2-foot gap in the wall at the lowest level is connected to a short concrete-sided channel to the streambed.

We had to address long-distance electrical transmission issues to get the power to the grid. We relocated the utility's transformer closer to the power house and switched from 120/240 single-phase to 480 V three-phase power. By switching to 480 VAC, the energy from the turbine can travel on smaller-gauge wire. The 480 V power also powers an electric sawmill and several large wood-processing machines in the shop.

Hydro System 2: Grid-Tied



The author with the 10.5-inch Pelton runner for the Canyon Industries turbine.

Production Payoffs

These two systems have given me quite an education in hydro-electricity, and energy economics in general. The contrasts between the systems are insightful. My small off-grid system was built for about $7,000 and paid for itself almost immediately, since the cost of bringing in grid power to the remote home site would have been at least $10,000. Now, we'll never need to pay a utility bill. The 23+ kWh that it produces each day is more than enough for my off-grid home. Because electricity consumption is moderate, the investment in generation was scaled to match it.

The bigger grid-tied system took much more time and effort to complete, and cost more than $100,000. In hindsight, there was a fair bit of hubris in our design decision to maximize the power potential of the creek. That system will take at least a decade to return the investment, assuming it's pushing out as much power as possible all the time. We are

The main component of system integration is a Thompson & Howe grid-protection panel that disconnects the turbine from the grid during power outages and maximizes power output by regulating flow rates, maintaining consistent head pressure.

LONG LIVE THE KINGS

Restoring Wild Salmon

In 1980, Jim Youngren and his friend Walt Moller had the idea of raising salmon in the watershed. There were no native salmon because the final 20 feet of the creek's drop to the bay was over steep rocky cliffs that no salmon or sea-run trout could jump. So they sourced some fertilized salmon eggs from a mainland fish hatchery and raised them in ponds. When they released the first batch of a few thousand smolts to the ocean they really had no idea if they would come back or not. But they did! A few years later they were back, ready to spawn and die—beginning the cycle anew. A concrete fish ladder was built where the creek meets the bay to provide the salmon with a way to get up into the fresh water to fully mature before spawning. That was 30 years ago and the fish are still coming back, supported now through the efforts of the nonprofit group, Long Live the Kings (www.lltk.org).

power producers now, keeping the electrons flowing out to the grid, in exchange for checks from the utility. That's a totally different perspective on microhydro from my off-grid system that churns away in the background, keeping our small bank of batteries charged and dumping surplus power to heat water most of the time.

Access

Eric Youngren (eric@solarnexusinternational.com) is a NABCEP-certified PV installer with more than 10 years of experience designing and installing RE systems. In 2008, he founded Solar Nexus International, a value-adding distributor of pre-integrated solar systems and manufacturer of the SolarNexus off-grid power system appliance.

Components:

Canyon Hydro • www.canyonhydro.com • 60 kW hydro plant

Harris Hydro • 707-986-7771 • Home-scale hydro plant

Hydroscreen • www.hydroscreen.com • Hydro-Shear intake screen

Thomson & Howe Energy Systems Inc. • www.smallhydropower.com/thes.html • Hydro controls & grid-protection panel