AC 2011-2507: PRACTICAL ISSUES ENCOUNTERED IN BUILDING AN INTEGRATED PHOTOVOLTAICHYDROBIOFUEL ELECTRICAL POWER SYSTEM IN A REMOTE LOCATION AS A STUDENT PROJECT

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Practical Issues Encountered in Building an Integrated Photovoltaic – Hydro -Biofuel Electrical Power System in a Remote Location as a Student Project

Abstract

Description and specifications for a completed photovoltaic – hydroelectric – biofuel electrical power system installed at the Taylor Wilderness Research Station (TWRS) in central Idaho. Students performed this successful project entirely, from writing the NSF funding proposal to designing and installing the equipment. It is currently operating as specified, providing power to TWRS, a remote site 60 km from the nearest neighboring electrical power system. Specification and installation of the hydroelectric system, replacing an again incumbent and upgrading a water collection system. Specification and installation of 4.3kW photovoltaic panels and controller. Interconnection to fossil fuel / biofuel generator. Inverter and energy storage description. Grid interconnection to load, including all electrical interconnection, construction of an appropriate power house, and buried cabling to nine-cabin and research laboratory load. This project was managed as a teaching opportunity in accordance with a successful model proposed by Klein et. al. Professor and students presented the keys to the caretaker on 23 July 2010.

Introduction

An integrated electric power system has been designed for and installed in the Taylor Wilderness Research Station (TWRS) in central Idaho. It consists of a hydroelectric generator, a photovoltaic array, a fossil fuel generator, appropriate interconnections, and interface units for compatibility and control of the various generators and loads. Design and installation of this 5.3kW average, 25kW peak electric power system was entirely a student project from start to finish. As explained in this paper, this project is complete; the customer received the keys on 23 July 2010.

A prize-winning ASEE paper presented at the 2010 ASEE Annual Conference in Louisville describes the design of this system.[1] While that paper was being presented in June 2010, installation of the system was ongoing. This paper presents the completed system, showing photographs of the major components, explaining all major specifications and presenting the few improvements from the earlier design. At the 2008 ASEE Annual Conference in Pittsburgh, we presented a successful model for organizing and teaching students using large, daunting projects like this.[2] This model again proved successful in enabling completion of this project on time and within budget. A team of four undergraduates, under the supervision of a professor and one graduate student, designed the system during calendar year 2009. The graduate student, who had written the successful proposal for funding this project under the professor's supervision, polished the design and completed the installation, supervising bidding and contractors, and performing the lion's share of the installation himself. This paper presents his results.

The Taylor Wilderness Research Station (TWRS) Site

TWRS is a pristine wilderness research site in the mountains of central Idaho, about 65 km west of Challis, 130km east of Cascade, and 200 km north of Boise. Along Big Creek, the main tributary of the Central Fork of the Salmon River and split by three small streams, the site is surrounded on all sides by mountains that tower more than 2000 meters above it on all sides less than a couple kilometers distant. It is accessible only by mule from a trailhead 60km distant or by a harrowing ride in a light plane. TWRS was originally homesteaded within a year of President Lincoln's signing the Homestead Act. The homesteader willed the property to the University of Idaho in 1910. It has since served as a superb research facility for a wide variety of work in natural resources biology. Its unique location and ecology makes it one of the finest facilities of its kind in the world. Adding an 800-Watt hydroelectric facility in 1998 (also a student project) [3] greatly expanded its capabilities and, in 2001, saved the facility from one of the region's greatest forest fires. This small but successful electrical power system served past its ten-year design life and was replaced in 2010 with an integrated hydroelectric-photovoltaic-fossil fuel / biofuel electric power generation system. This paper describes the successful completion of an entirely student-led project to design and build that replacement system.

Hydroelectric Generation

Clean, renewable hydroelectric power serves as a baseline source of energy for the project. Pioneer Creek passes through the middle of the property and provides a water right of 0.27 cubic feet per second, sufficient for about 800 W with 77 feet of head. The project budget is sufficient for a unit that provides 1500 kW continuous power at 240 Volts AC with a peak short term capacity of 2.0kW. Its installed cost is $9,000 and it has a 20-year service life. It is turbine-based, a robust technology requiring minimal annual maintenance. It operates at 65% efficiency, which is quite good for units of this size. Because this new unit is dimensionally smaller than the old unit, it fits into the existing space and takes advantage of the existing water supply system. Improved water collection methods designed under a separately funded project yield authorized water capture with advanced, less invasive methods and easier maintenance. The turbine is shown in Figure 1.

Figure 1. Hydroelectric turbine.

The turbine was initially set up for testing in the university's hydraulics laboratory. Its performance was to specifications in the lab. It was then installed on site in June 2010 (all dates in this paper are in 2010 unless stated otherwise) and its performance was verified to specifications. It replaced the existing Pelton Wheel unit described in our paper presented at the 1999 ASEE Annual Conference. This new turbine now provides baseline electric power to the facility.

Photovoltaic Generation

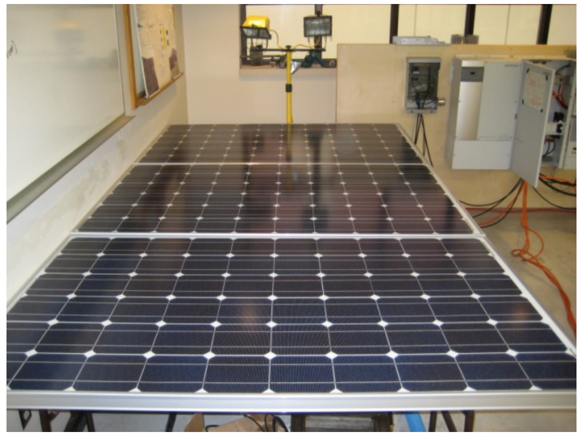

Figure 2. Solar panels tested in lab.

Solar flux at the site peaks at 485 Watts per square meter, a rather modest number with a seasonal minimum of 200 Watts per square meter, a strong seasonal variation typical of high latitudes. Mountainous terrain further reduces available solar flux from its June peak of fourteen hours per day to a December minimum of four hours per day. Fortunately, the load profile matches this seasonal variation.

The photovoltaic array consists of a pair of nine-panel arrays of 235-Watt modules that produces 4.23 kilowatts at rated operating conditions in summer and about one kilowatt in winter. Three such panels are shown in Figure 2 ready for testing in a main campus laboratory. The cells have a higher than typical efficiency of 19.7% and provide about 200 Watts per cell. They withstand 2.5cm diameter hail and 80km/hour winds, worse than any conditions ever recorded since on-site monitoring began in 1864.

Figure 3. First solar panel installed. New power house is to the right of the solar panel.

Photovoltaic panels were installed in June. The customer expressed a desire for a site where vegetation screens the panels from view from most of the facility. The first set of panels, completed in May, is shown in Figure 3. The remaining panels were installed in early July. Maintenance is minimal, occasionally cleaning the surface and, in winter, removing snow. Warranty for the solar collection system is 20 years at rated power output. The design allows for installation of up to 20kW of expansion within the screened area.

Energy Storage

Figure 4. Battery bank in lab.

Energy storage, necessary to meet energy demand when the sun is not shining, is in the form of valve-regulated, sealed lead acid (VRLA) batteries. The anticipated summer peak daily requirement is nearly 35 kWh. Hydroelectric and solar generation capacity provide 110% of that total, leaving 5kWh to be stored for later use. The design calls for thirty-two VRLA batteries that store 2.6kWh each providing 6.0 Volts and 440 Ampere-hours. These batteries were arranged in four series strings of eight batteries each, yielding a 48 Volt storage system that stores 83.2kWh, compatible with the power management system. With the power management system that was chosen, these batteries can handle 12 kW peak loads. At $310 per battery, this is the least cost storage technology. Though maintenance is more work than some other storage forms, new dual-shell technologies reduce the task to a simple monthly refilling of electrolytes. The caretakers are already familiar with the task.

The first string of eight such batteries is shown in Figure 4 as the students set them up for testing in the laboratory. These performed to specification and were then moved to the site and installed in June.

Energy Conversion Power Electronics

Energy management is provided by two commercial units designed for projects of this nature. Such units have proved to be reliable and practical, a way to realize an integrated energy system that operates successfully for many years. There is a photovoltaic controller to manage the generation of solar power and an inverter/controller to manage the system power integration.

The photovoltaic controller is a Xantrex Solar Charge Controller (SCC), one for each nine-panel array. The SCC regulates power flowing from each solar array, reducing the photovoltaic panels' 90Volts DC and increasing the current for compatibility with the power system's inverter/controller. This unit was tested in the lab and performed to specifications. It was moved to the site for installation in June.

For this project, an inverter/controller designed to interface the system's separated generation and load organizes a coordinated, reliable power grid. Inputs are 90 Volts DC from the solar arrays, 240 Volts AC from the turbine generator rectified to 48V DC, and 48V DC from the battery storage array. Loads are 120/240V AC for research equipment and domestic appliances. There are several manufacturers who make appropriate units for this range of capabilities. For this project, a commercial unit manufactured by Xantrex Technologies of Arlington, Washington, was chosen. It was set up in the laboratory, as shown in Figure 5, to test its performance. Battery storage, 240V AC from the lab supply, the generator, and 90 Volts DC were connected to the Xantrex controller. It performed to specifications, converting the various inputs appropriately, supplying appliance loads, and charging the storage batteries. It was moved to the site and installed in June.

Figure 5. Central distribution, main controller, and diversion load in lab.

For interface to the energy storage, the hydroelectric generator input is transformed and rectified and the resulting DC is connected to the DC part of the interconnections. The transformer / rectifier unit is shown in Figure 6. It was installed on the site in June. Two senior undergraduates, mentored by a graduate student, designed, built, and tested this transformer / rectifier unit on campus.

This unit gave the only problem that we experienced in installation, other than enormous rocks that made burying the cables an adventure. The terminal block at the upper left had an oxidized terminal that overheated during initial testing in the field, cracking the housing. A replacement was flown in from Missoula, Montana, and carefully prepared and installed. It has performed flawlessly for several months and shows no significant heating on infrared imaging while in operation during the summer months.

Figure 6. Transformer / rectifier.

Fossil Fuel / Biofuel Generator

We will use the incumbent fossil fuel generator per our energy use plan. We have written proposals for funding to provide a more suitable replacement, based on the University of Idaho's highly successful biofuels research, but none have yet been granted.

Diversion Load

A diversion load, controlled by the main inverter/controller dissipates excess generation when the battery storage is full. We found this to be an effective way to maintain system stability with the incumbent system. At 1.0 kW, this load is a little larger than its predecessor's 400 Watts. This is sufficient to completely avoid disconnecting the baseline water turbine, yielding automatic control and security of the entire electrical system at all times. It was tested in the laboratory as shown in Figure 5 (labeled "Caution Hot" in that figure). It performed to specifications and was moved to the site and installed in June.

Electrical Interconnection

The expansion of the system requires additional wiring and interconnection of the new components to the parts of the incumbent system that we intend to keep. New elements include the photovoltaics, the new battery storage, the new generator, and the controllers that supervise the expanded system. The incumbent elements include the entire grid that forms the load and the controller in the old power house. The system has both DC and AC elements. The schematic is most easily divided into those parts, DC and AC.

The DC schematic is shown in Figure 7. The hydroelectric input, solar array, and battery storage are shown on the left. There are three controllers: one to control the photovoltaics, one to control the diversion load, and the main controller to interface the AC and DC systems. All were installed in the lab for testing as shown in Figure 5. They have all been moved to the site and installed.

The wiring and protection (fuses) were installed on site. Appropriate trenches were built and conduit was laid. The electricians pulled the wire as a rough-in as the power house was being built. As each solar panel was installed, it was wired into the grid. Final connection of all equipment to the grid was completed in late June.

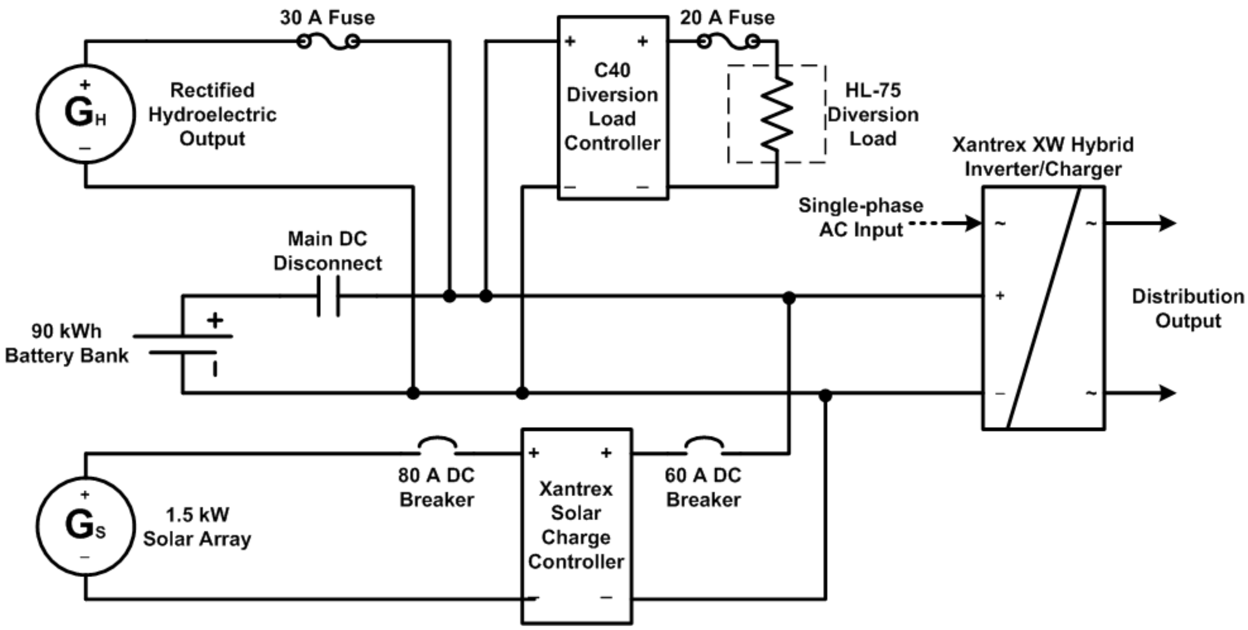

Figure 7. DC grid interconnections.

The AC grid has also been installed. A schematic is shown in Figure 8. The hydroelectric generator and the fossil fuel generator are shown at the left of this figure. The transformer and rectifier (the same items as shown in the DC schematic) provide energy to the DC grid interface. The load is shown on the right side of the AC schematic. This wiring has been pulled. The trench linking the power house to the load is shown open in Figure 3. All elements were installed in June.

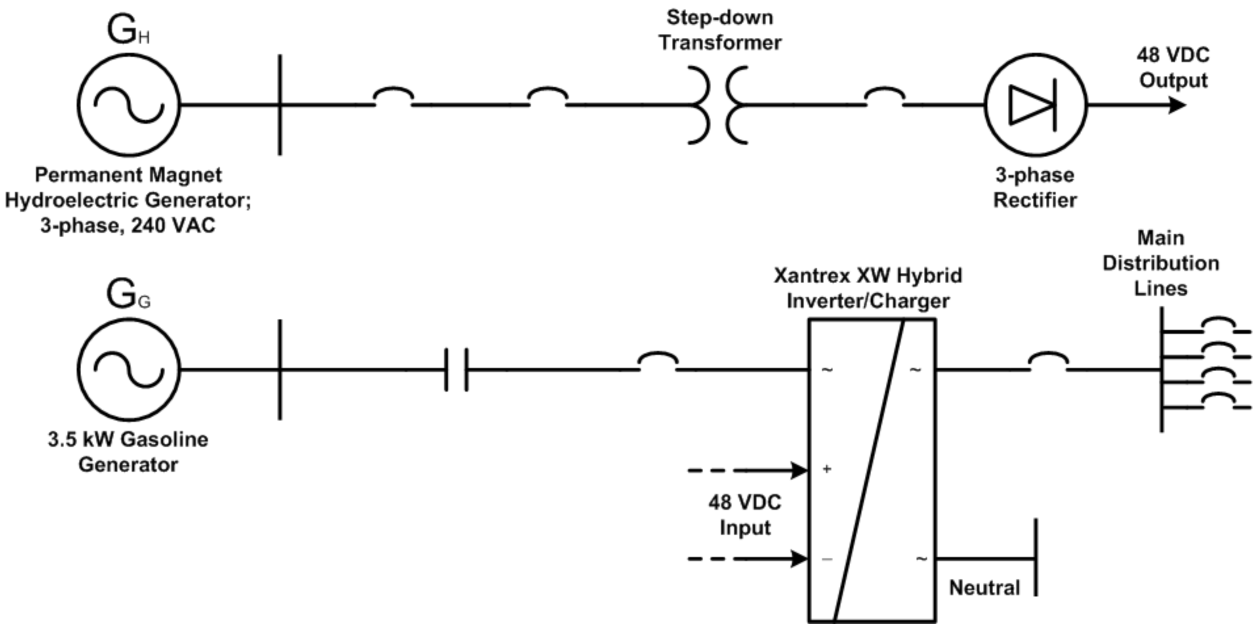

Figure 8. AC grid interconnections.

New Power House

A new shed (a.k.a., the power house) has been built on site to house the battery storage, the inverter/controller, and the diversion load. A photograph is shown in Figure 9. Its proximity to the photovoltaics is shown in Figure 3. This building was contracted to a carpenter well know for quality construction in this remote part of the State of Idaho. He completed it in a few days in May. It now houses the batteries on racks as designed and the controller and diverter equipment. Final connection of all components has been completed. The generator has been installed at the old power house[3] near Pioneer Creek, which bisects the facility, replacing the incumbent hydroelectric generator, as described earlier in this report.

Figure 9. New power house.

Data Collection

Concurrent with installation, data collection will be initiated for the electrical subsystems of the project. A Xantrax Gateway and a NI-DAQ 6008 collects the data. LabView programming on a small computer controls the data collection and sends the data to main campus by an unmanned emailing system. The sensors for the NI-DAQ 6008 use a Maxim 4081 Current Sense Amplifier and a LM324N Operational Amplifier configured as a voltage follower. This data is available for research and study through the archives of the university library. The system was installed concurrently with the electrical system on site. A more user-friendly archiving system will be installed within the next two years as part of a larger data collection project sponsored by the National Science Foundation, a project made possible by this electrical installation.

Project Assessment

This project began with a serendipitous convergence of requirements for a student's to maintain a scholarship and a need to replace an aging power generation system. The student, Justin Schlee, received a McNair Scholarship. One of the requirements to maintain the scholarship is to write a proposal for a research project. When he asked his professor to suggest a project, the professor gave him a choice: write a pro forma proposal that the professor would grade and certify completion or write a real proposal to compete for a National Science Foundation grant. Justin chose the latter. He wrote his part of a half-million dollar grant proposal for wilderness biology research, enabled by an electric power system. Justin wrote for the project described in this paper. His professor taught him how to write a grant proposal, but Justin wrote the grant proposal. We won the grant. Assessment: successful learning of the McNair requirement to write a research proposal.

Per a successful model that his professor had developed for supervising similar projects[2], Justin chose to supervise four undergraduate students in their senior design project. This gave him extra manpower and it gave him the opportunity to learn realistic technical project leadership and management. The undergraduate students completed their project on time and within budget. They built several of the main subsystems of the Taylor project in the laboratory. All subsystems worked to specifications. The undergraduates finished their degrees and all four found multiple job offers despite a poor economy. Assessment: successful undergraduate senior design project learning; successful graduate student supervision and leadership.

Justin finished the remaining subsystems. He managed the project to completion:

- Managed the budget to acquire all parts,
- Paid his stipend,
- Organized and funded all transportation of equipment to the Taylor site (35 sorties in a light plane),
- Wrote the contract to hire a carpenter to build the shed,
- Dug the trenches and installed most of the equipment,
- Wrote the contract to hire electricians to complete the wiring and to verify code compliance,
- Supervised an intern (undergraduate student) to help with the construction,

- Collected system performance data and archived it at the university library via a satellite Internet connection; interfaced successfully with university information technology resources,
- Tested and verified performance, and
- Handed the keys to the caretaker.

Justin completed the project on time and within budget. Assessment: successful learning of project management.

The university president and the Dean of Natural Resources inspected the project three weeks after completion. The university president reported successful completion to the Board of Regents. Assessment: successful graduate student project.

All four undergraduates and their supervising graduate student found multiple job offers in the electric power industry in a region rich in renewable energy resources and projects. If employers are willing to compete to pay for this competence, our assessment is for successful learning of the concepts, methods, and leadership principles for entry into the renewable resources industry.

In October 2010, the National Science Foundation awarded a new grant for natural resources research. The proposal based part of its work solidly on the availability of clean renewable electric power in a pristine, remote research station. Assessment: successful learning and accomplishment of a renewable energy project objectives.

Conclusions

This paper describes the completion of the new electrical power system at the University of Idaho's Taylor Wilderness Research Station, one of the world's finest facilities of its kind for natural resources biology work in a pristine and remote environment. Formal design of the electrical system was originally a senior undergraduate project, completed in March in accordance with our documented model for teaching within such large projects. Each major subsystem is described as it was installed on site. Installation began in April, as soon as weather permitted, and the professor and his students presented the keys to the caretakers on 23 July 2010. Overview schematics are shown in this paper; fully detailed plans, blueprints, and schematics are filed at the University of Idaho. Installation of the hydroelectric generator and its connections in the incumbent power house, including improvements to the water supply system, is presented. Installation of the photovoltaic units is described. An automated interconnect to a fossil fuel / biofuel generator is included. A new power house was built in May to hold battery storage, inverter/controller, transformer/rectifier, and diversion load. Qualified electricians made all appropriate electrical installation and connections. The upgraded electrical installation has been completed successfully as an entirely student designed and student-led project. By assessment criteria listed in the paper, the project taught proposal writing, project management, personnel leadership, and completion to specifications and within budget. Four undergraduates and a graduate student all found jobs within the electric power industry in a region rich in renewable energy projects.

References

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