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Feasibility, Design and Construction of a Small Hydroelectric Power Generation Station as a Student Design Project

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Abstract

An undergraduate capstone engineering design project now provides hydroelectric power to a remote wilderness location. Students investigated the feasibility of designing, building, and installing a 4kW hydroelectric system to satisfy the need for electric power to support the research and teaching functions of Taylor Ranch, a university facility far from the utility grid. After showing such a system to be feasible, they proceeded to design and build it. Technical issues and stringent environmental regulations are addressed. The students documented their design and developed instructions for installation and operation. The system was installed and currently provides electric power for Taylor Ranch. The first year of operation is briefly described and photographs of the equipment are presented.

Introduction

Taylor Ranch is a University of Idaho College of Forestry, Wildlife, and Range Sciences (CFWRS) field research and teaching facility. It is in the Frank Church Wilderness of Central Idaho, 400km southeast of the main campus. The only access to the site is by small plane or by a 60km-long foot trail. The University plans to increase the amount of research performed at the site, but an insufficient amount of electric power on site and the difficulty of transporting energy to the site has restricted those plans. Operating even a small fraction of the proposed research instruments and portable computers far exceeds the 200 watts of solar power available on site.

The CFWRS commissioned a student design team from Electrical Engineering to investigate, design, build, and test a small hydroelectric generating system. This paper reports how an Electrical Engineering senior capstone student design group completed this project. First, the three-person group assessed the feasibility of the project, showing that it was both possible and within the capabilities of the students. Second, they designed the system, addressing the necessary technical questions and cost issues and observing important environmental constraints. Third, they assembled the generating system and tested it thoroughly, using a hydrology laboratory on campus. Fourth, they documented the design and created an operations guide to be used during installation on site and during normal operation. Finally, they included a datalogging capability to help the customer plan energy use effectively.

Problem Statement

The CFWRS needs more electrical energy for a planned expanded use of the Taylor Ranch research and teaching facility. The terrain, vegetation, and cost prevent a cost-effective expansion of the solar capability to this level. Environmental considerations unique to the location eliminate thermal generation as an option. However, the site does have significant hydropower potential.

The task is twofold: determine if the hydropower potential is sufficient to meet expected electrical needs and, if so, design and install a system to do so within approximately a year. The system should be less expensive than installing comparable solar generation. All environmental constraints must be strictly met, considering the unique pristine wilderness location. Everything must fit into a light airplane for transportation to the site, either whole or in modules that technicians can assemble on-site. The design should allow for reasonable future expansion of the system.

Feasibility Study

A feasibility study comprised the lion's share of the first semester of what was a two-semester design project. The following results led to the decision to proceed with a design.

<u>Which of the three streams should be tapped?</u> Environmental restrictions preclude tapping the two larger streams. Only Pioneer Creek, the source of on-site drinking water, is available.

<u>Is there sufficient energy available?</u> The feasibility study found the estimated load to be 2.6kW peak and 8.7kWh energy consumption per day. Environmental restrictions essentially mandate using the existing water diversion method and hardware. From there, the water descends a vertical head of approximately 30 meters to a generation site optimal for the terrain and customer location. Minimum stream flow occurs in late autumn, but allowable diversion is sufficient to sustain approximately 360W of continuous electrical generation. To gain the necessary flow, an existing 1½-inch pipe must be replaced with 4-inch pipe. With battery storage, the peak power requirements and overall energy demand can be met. A reasonable amount of expansion of the generating system can occur by adding storage in the form of additional deep-cycle batteries.

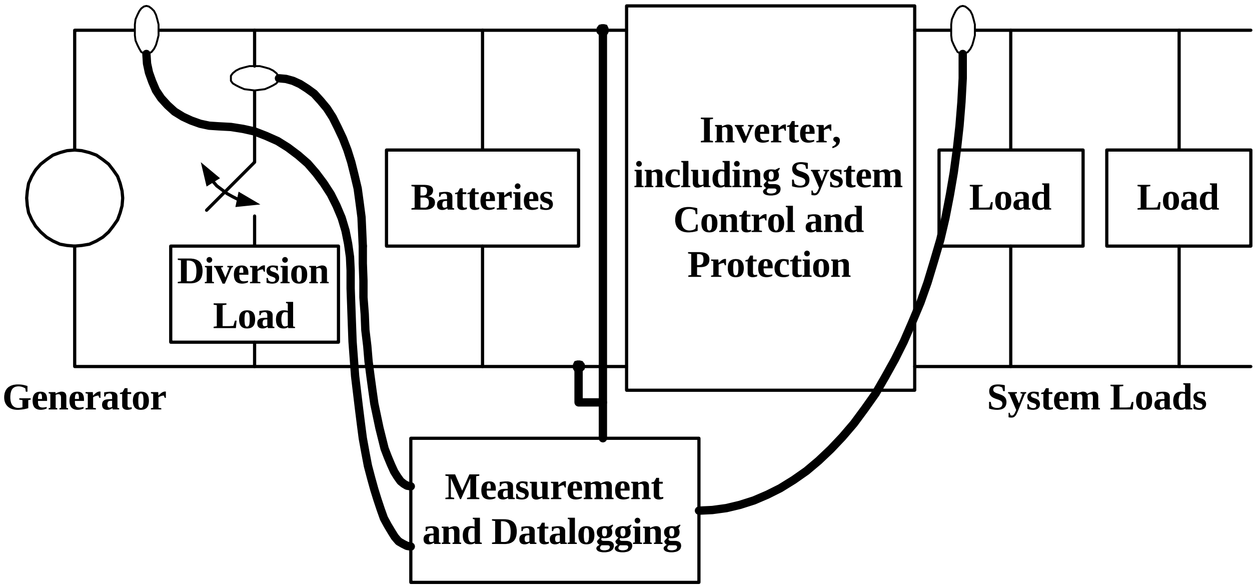

Figure 1. Diagram of Electrical System

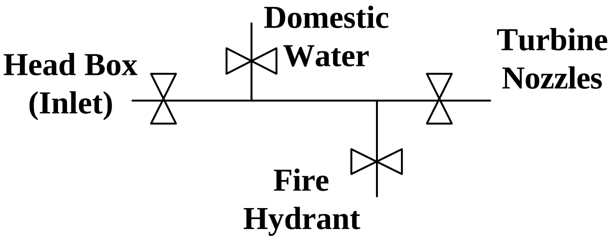

Figure 2. Improved Water Distribution System

Is construction within the capability of the design team? Yes, but only if the team purchases certain major subsystems as modules. A good example of this is the inverter (DC to AC converter). Acquiring the knowledge to design and build the inverter requires more time than the design team has, but one student has sufficient background to understand the interface specifications of a commercial inverter module well enough to complete a good system design around it. The same is true for the other students and other major subsystems, such as the generator, battery charge controller, and appropriate instruments.

What system configuration is recommended? An electrical diagram is shown in Figure 1. Major system components are in a general parallel arrangement as shown. Important functions include generation, energy storage in batteries, inversion to 120 Volts AC, a diversion load to dissipate any energy in excess of storage capability, appropriate real-time control and protection (provided within the inverter), and data measurement and logging.

What site improvement must be done? Laying new water pipe, wiring additional buildings (interior fixtures and exterior underground cable and circuit protection), and building a small "powerhouse". State regulations require that licensed workers perform certain construction tasks, for example, electrical wiring. The design team specified these to meet building codes and in a technical format appropriate for university physical plant technicians. Adding the water wheel and a needed fire hydrant produces the expanded plumbing system shown in Figure 2.

What will it cost? Parts and components total about $6000, not including installation, transportation, and constructing the powerhouse. This is considerably less than a comparable solar installation.

Summary of Technical Issues

A discussion of the technical issues of this project appears in reference [1]. A brief summary of the issues and design is given as follows.

Operating voltage. The load consists of computers and laboratory equipment, lights, a radio for communication with the main campus, and a few small household appliances. These all operate on 120VAC. Therefore, the system voltage is 120VAC. A working voltage for the batteries is 24VDC. This is a compromise between minimizing the number of batteries and minimizing the losses in distribution and conversion.

Battery storage. Eight 12V lead acid batteries provide 10.5kWh of storage. This is a nice compromise among the factors of energy storage capability, weight and volume (delivery is by light airplane), expected battery life, and total cost. Ventilated plastic containers hold the batteries. These contain any possible liquid spills but allow escaping hydrogen gas to dissipate.

Generator output. The team selected a 600W unit at 24VDC. The unit contains a four-nozzle turbine and an electric machine remarkably similar to an automobile alternator. Nearly all the research work on site will be performed during the months of peak stream flow. 600W allows for a doubling of the expected load and is compatible with the peak capacity of the 4-inch pipe. The cost difference for the larger unit is minimal.

Inverter selection. The team selected a 4kW true sine wave inverter (Trace SW402) with on-board load and storage control. The computer and instrumentation portion of the load favors a true sine wave converter. The 4kW rating allows for expansion. Selecting a unit of this nature is also pedagogical good sense. Though designing such an inverter is a nice full-year project alone for a group of good students, the goal in this project is to design and build the generation system. Keeping this goal foremost requires such choices.

Charge control. Diversion of excess power to a load resistor provides a more reliable solution to the problem of overcharging the batteries than cycling the generator on and off. For flexibility and ease of interface, a Trace C-40 controller was selected.

System protection. Much of the system protection is already internal to the inverter or specified by the inverter manufacturer. However, to prevent generator overspeed, no breaker or fuse isolates the generator from the batteries. A 100A distribution panel designed for commercial installations serves the load and 15A breakers protect each cabin.

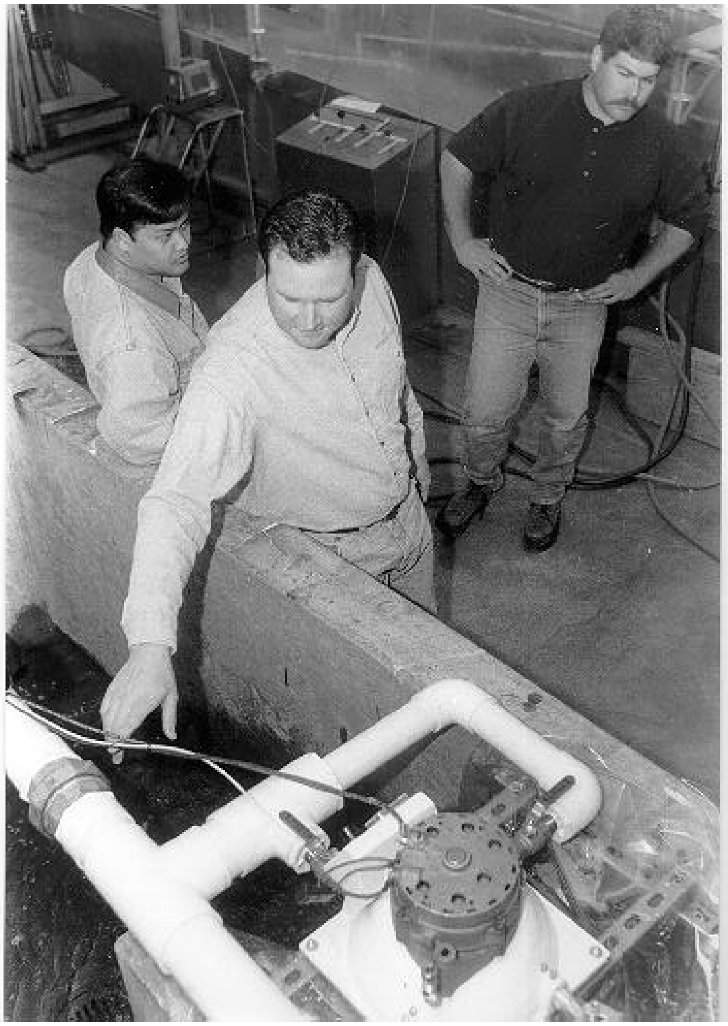

Figure 3. Ben Seitz (center) conducts tests in the Civil Engineering Hydraulics Lab. Other team members are Cesar Salire (left) and Gary .Harwood.

Wire size. Wire size conforms to the National Electrical Code (NEC) and the inverter manufacturer's recommendations. AWG12 wire forms the distribution network to the cabins, a heavier wire than nominal for the 15A loads due to the voltage drop expected on some long runs.

System grounding. Meets requirements of the (NEC) [3] and IEEE Standard 142-1992.[4]

Datalogging. Landis and Gyr donated a datalogger to monitor the following: generator current, diversion current, inverter output voltage and current, and battery voltage. The datalogger calculates and stores kWh generated and consumed and load profile. A laptop computer easily retrieves the data and formats it using ordinary spreadsheet software.

Testing

The students built the working generator-inverter system in the Civil Engineering Hydraulics Laboratory on the main University campus. That laboratory has the equipment to simulate the field conditions of water flow and pressure. Details of tests performed in that laboratory (and on-site) are given in reference [1]. The system performed within specifications. The design team prepared it for movement to the field site. After testing was completed, the students wrote their final report and graduated. In Figures 3 and 4, students are shown with the equipment.


Figure 4. Cesar Salire with inverter and control panel

Installation

CFWRS workers and, when required by regulations, university physical plant technicians, did the installation work. Ben Seitz, one of the students and Prof. Jim Peterson, the first author of this paper, supervised the installation and testing.

As part of the project's deliverables, the design team prepared wiring and installation plans. This process provided the students with a realistic experience in communicating their design to technicians, who then performed the work to specifications and code.

Installation took place in six phases in 1997. First, the wiring inside the cabins was done in May. Second, the trenches were concurrently excavated for 4-inch pipe and for wire between cabins in early summer. Third, pipe and wire was laid in June. Fourth, a powerhouse, a cabin 2m x 3m x 2.5m tall, was built in July. Fifth, the generator and electrical controls and equipment were flown to the site as modules and installed in August. Finally, the system was tested on site. By October, the system was in full operation.

An aerial view of the site is shown in Figure 5. Arrows are drawn to indicate the intake and powerhouse locations. The loads are in the cabins, which are distinguished by their light-colored roofs. One cabin is not shown, being off the photo about 50 meters to the left of the word "powerhouse." The end of a grass airstrip is immediately below the word "powerhouse." An intake box, a 1m x 2m enclosure designed as a covered settling tank is shown with the diversion dam in Figure 6. From the intake box, a 4-inch PVC pipe directs the water down the hill to the generator in the powerhouse. Instruments and batteries inside the powerhouse are shown in Figure 7. The generator is at floor level, just outside the left edge of the photo. A 12-inch

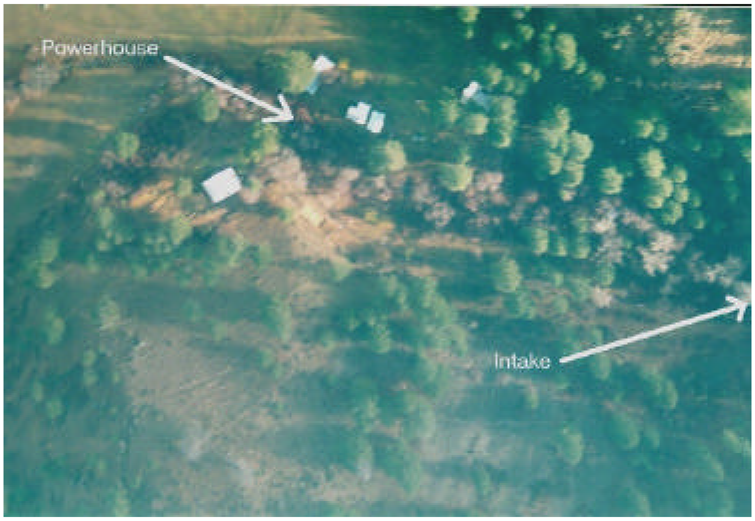

Figure 5. Aerial view of Taylor Ranch site.
Scale: 200 meters from left to right edge of photo.

outlet pipe collects the water from the generator and discharges that water back into the same creek as it flows past the powerhouse.

Figure 6. Diversion dam and covered intake box

Operation

The system began full operation in October 1997. It has remained reliably in operation since that time. Datalogging for more than a full year has shown it to be performing as designed.

Nonetheless, prudent energy management remains necessary to guarantee sufficient energy for research tasks. The design team specified instrumentation to enable the site caretaker to quickly assess the energy storage state of the system, providing the CFWRS researchers with timely information about electric power available for their work. Though the system cannot support (and was never designed to support) a typical load of residential electric conveniences, this information permits prudent use of some conveniences. To date, careful planning and supervision has insured that the system meets the expanded electrical energy needs of the research facility.

The University President formally announced a significantly expanded mission for the Taylor Ranch research and teaching facility in early 1998.

Conclusions

The College of Forestry, Wildlife, and Range Sciences at the University of Idaho needed a reliable source of electrical energy to support an expansion in the teaching and research mission of its Taylor Ranch facility. This research station is in a remote wilderness location, 400 km from the main campus, without access to the electric utility grid. As a capstone senior undergraduate engineering project, a design team of three students investigated the feasibility of harnessing available hydropower on the site. They found the project to be reasonable and within their capability. They designed a system, carefully addressing technical issues and very stringent environmental constraints. They built and tested it in the lab and wrote specifications and instructions for its installation and operation. The system has since been installed and has contributed

Figure 7. Inside the powerhouse

to an expanded mission for the research facility.

Acknowledgements

The students of the design team are, as mentioned in the paper, Ben Seitz, Gary Harwood, and Cesar Salire. Their technical paper on the topic is reference [1]. The College of Forestry, Wildlife, and Range Sciences (CFWRS) at the University of Idaho funded this project. Dr. Edwin Krumpe, Professor of Wildlife and Recreation Management represented the CFWRS. The photograph shown in Figure 3 was purchased from the Moscow-Pullman Daily News, Pullman, Washington.

Bibliography

[1] B. Seitz, C. Salire, G. Harwood, J. Peterson, and H. Hess, "Taylor Ranch Micro-Hydroelectric Generation System," Proceedings of the 30th North American Power Symposium, Cleveland, Ohio, 19 October 1998, pp. 7-13.

[2] B. Seitz, C. Salire, and G. Harwood, "A Feasibility Study for Installing a Hydroelectric Generating Facility at Taylor Ranch Research Facility," University of Idaho Internal Report, 1996.

[3] National Fire Protection Association (NFPA), 1996 National Electric Code (NEC).(Quincy, MA: NFPA, 1995).

[4] Power Systems Engineering Committee of the IEEE Industry Applications Society, "IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (The Green Book)," IEEE Standard 142-1992, Fifth Edition, (New York: IEEE Press, 1992).

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James Peterson received his PhD in Electrical Engineering from Iowa State University, then following several years working in industry, joined the UI Department of Electrical Engineering where he teaches courses in Design Projects, Digital Filtering, Circuits, and Control Systems, among others. His interests include signal processing, system identification, and feedback control. He currently is involved with research on voice characterizations and compression applications.

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