"Ivotuk Autonomous Research Platform"

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Systems Overview

Ivotuk is a small research site designed to support autonomous instrumentation that is powered 24 hours a day, 365 days a year. The Ivotuk site also allows for near real-time transfer of the scientific data to the researchers' home institution along with the capability of remotely monitoring some of the scientific equipment and the power system.

The power module arriving at Ivotuk

Location

Ivotuk, Alaska, lies at the southeastern edge of the National Petroleum Reserve on the North Slope, well in the interior of Alaska (68.5º N, 155.7º W).

Power Requirements and Instruments Powered by the System

Project Update: The information below describes the configuration and instrumentation through Summer 2008. Science funding has expired for the instrumentation supported by this system. Renewal funding requests are in process as of October 2008 and the site is currently available for new instrumentation. If no new use can be found for the power system, it is likely that it will be removed in 2011.

Power is primarily required for the operation of meteorological experiments and data acquisition instrumentation as well as for the satellite communications system, which is necessary for the transfer of data to researchers' home institutions.

The system supports the power and data transfer needs of research instrumentation for Dr. Walter Oechel's Global Change Research Group (GCRG) at San Diego State University and the data transfer needs of Dr. Larry Hinzman of the Water and Environmental Research Center (WERC) of the University of Alaska, Fairbanks.

GCRG's experiment consists of a suite of carbon flux and meteorological instruments. For more information on the specific instruments and data collected visit GCRG's web site at http://www.sci.sdsu.edu/GCRG/index.html. WERC maintains a meteorological tower at Ivotuk. For more information on those data and instruments please visit http://www.uaf.edu/water/.

A StarBand satellite system provides two-way, near real time Internet connectivity. A pair of RF transceivers supports the communications between the science instrumentation and the StarBand system. An iridium modem provides back-up communications.

Loads at Ivotuk are numerous and varied. The total average load on the system is 240 watts continuously. Power from the batteries is inverted to 120 VAC, stepped up to 240 VAC, and sent out to the primary instrument site. At the site, the AC power is rectified for use by the science equipment. This represents 150 watts of the total load. The remaining 90 watts is used for the communications gear, system controls, and efficiency losses.

Environmental Data

During the summer, overcast skies and frequent precipitation are the norm. In the winter, solar energy is available for at most a few hours a day. Wind speeds at the site are normally low to moderate.

Factor	Parameter
Wind speed	6 mph annual average
Solar insolation	Approx. $100 W/m^2$ annual average

Solution

Power System

A redundant diesel generator power system was initially selected to power the site. The autonomous power supply was built by Northern Power Systems (NPS). Two Lister Petter 6.5 kilowatt diesel generators run alternately to charge a 24 VDC, 720 amp hour, absorbed glass mat battery bank. The nominal 24 VDC is then inverted to 120 VAC by an Outback FX 2024 inverter. A step-up transformer is used to double the AC voltage to reduce line loss. From there, power is distributed to the components in the module itself, as well as to an instrument site located about 1,200 ft away. At the instrument site, the 230 VAC is rectified and regulated, supplying 24 VDC and 12 VDC to the instruments. Power system status and control are provided by a local programmed logic computer (PLC) communicating with the proprietary Excel-based *Remote View* software package.

The power system silhouetted against a fantastic show of aurora.

All of this, along with the communications equipment, is housed in a modular refrigeration enclosure set on a rugged, aluminum I-beam frame. NPS tried to incorporate redundancy throughout the system design to provide the highest level of reliability. Environmental control consists of integrated heating and ventilation subsystems. The heating system includes two diesel-fired Espar engine coolant heaters and a DC electrical resistance heater. There is no waste heat recovery system incorporated for the engine-driven generators. The ventilation system includes fans and louvers in various key locations throughout the module. The 18-ft-long module weighs in at a hefty 18,000 lbs. To deploy the unit, an LC130 "Hercules" aircraft was chartered. It was set in position with a large, off-road fork lift and came online in August 2003.

Complementing the *Remote View* program is a web-based system monitor that allows easier check-up of nearly every aspect of the complete system including the communications link. Personnel at SRI International worked together to create the electronics package and programming that allows one to see very detailed information on how the unit is performing (see http://transport.sri.com/ivotuk/). Data are sent out via a Starband satellite link to the server based in California, as well as to researchers' home institutions. Archived data allow one to note any trends in system performance over time. This is how deterioration of the battery capacity was detected after only a year of operation.

Faced with mounting fuel efficiency issues and the loss of battery capacity, the diesel generator/battery system was augmented with a wind turbine and photovoltaic (PV) system. The primary renewable energy component is the Proven WT600 wind turbine. It is a "downwind" style turbine (no tail) and is solidly built to hold up to adverse conditions. The tower is 20 ft tall and guyed with four 2 ft x 2 ft deadmen anchors placed 2 ft underground. The permanent magnet alternator puts out a wild 3-phase AC, which travels about 100 ft total before reaching the Proven controller. The controller box rectifies the 3-phase AC to a regulated 24 VDC to send to the batteries.

The Bureau of Land Management required the addition of a tower strobe light. An independent PV power system was chosen as the solution. Two 20-watt thin-film PV panels supply power to two beefy (1,200 cold cranking amps) starting batteries. An efficient, bright, 48 LED bulb minimizes the power draw. The light is enclosed in a weatherproof housing and mounted just below the top guy point on the mast. An insulated, plywood box with the top sloped at 45º was constructed to maximize the summer gain. The strobe timer and the charge controller were pre-wired in a weatherproof box, which is mounted to the outside of the battery box. A simple toggle switch for turning the light on and off completes the package. The charging circuit is active all of the time, although there is little or no input for at least four months of the year. The batteries have ample power to sustain several days (weeks) of operation in overcast weather.

For the PV component of the primary system, four 110-watt Evergreen PV panels are mounted vertically on an array pointing true south at approximately a 70º angle. This orientation gives up some production in the summer but takes good advantage of the transitional sun angles throughout the season. It also gets a bit more reflected light from the snow-covered surface (8 months of the year) and sheds snow more readily than a flatter angle. The panels themselves are mounted 2 ft above grade, which allows the snow to slide off without accumulating at the base of the panels.

The 440-watt Evergreen PV array is wired in series for 48 volts nominal output. The power is converted to 24 VDC nominal by an Outback MX60 charge controller. This is a maximum power point tracking (MPPT) controller, which can significantly increase the real output of the PV array. The system has put out 510 watts maximum from the 440-watt array, so the advantages of MPPT technology are pretty obvious.

In the event that the batteries are full, the DC power can be diverted to an electrical resistance-type heater located in the equipment room. The Outback MX60 charge controller initiates the sequence for this diversion load. There is an auxiliary power supply that serves as the first point in a simple ladder logic circuit. Simply put, the auxiliary power output closes a relay, which then closes a contactor capable of handling the current to the heater. When battery voltage exceeds a pre-set point, power is diverted to the DC heater. When voltage drops below another pre-set point, the auxiliary power supply turns off, and the current is once again routed to the batteries. A second relay in the chain is opened or closed via a command from the SRI-developed data acquisition system (DAQ), which is sensing for AC voltage from the diesel generators. Obviously, the heater should not be on when the generators are running, as it will dramatically prolong the run cycle and cause unwanted heating (and subsequent venting) of the equipment room. This relay prevents this condition by opening the circuit if AC is present.

The parallel PLC developed by SRI also continuously monitors the system status, which is displayed on the web site and updated once every ten minutes. The advantages of being able to monitor system performance in near real time cannot be overstated. One can monitor system health, determine if any performance criteria are falling out of normal parameters, and even do a bit of troubleshooting when problems arise. It should be noted that this functionality could have been incorporated via the original PLC supplied by NPS. However, to do so would have created a potential single point of failure that could take the entire system down. This system was designed with as much redundancy (and hence reliability) as possible.

Autonomous Research Platform Specifications

System Overview	
System type	Off-grid diesel generator/battery system plus a wind turbine/PV hybrid system
Location	Ivotuk, Alaska
Production	173 DC kWh per month average
Diesel Generator Unit	
Generators	2 Lister Petter 6.5 kW generators running in alternate succession
Peak kW rating	6.5 kW
Average kWh per month	Varies with required run time
Wind Turbine	
Turbine	Proven WT600
Rotor diameter	2.55 m
Wind turbine controller	Proven ECM 600; rectifies wild 3-phase AC to regulated 24 VDC
Tower	20-ft. tower guyed with four 2 ft. x 2 ft. plywood deadmen and four “Manta-Ray” earth anchors; 8 guy cables total
Peak kW rating and wind speed	600 W at 12 m/s (25 mph)
Average kW per month	58 to 150 kW, depending on site
Photovoltaics	
Modules	4 Evergreen PV panels, 110 W
Array	440 W STC, 48 VDC nominal output
Array disconnect	20 amp breaker in ECM 600
Array installation	Vertically mounted 2 ft. above ground, pointing true South at 70^{o}
Peak W rating and solar insolation	440 W (510 W observed at controller)
Average kWh per month	Too soon to tell
Balance of System	
Inverter	Outback FX2024, 24 VDC nominal input, 120 VAC nominal output
PV charge controller	Outback MX60, 48 VDC nominal input, 24 VDC nominal output
Transformer	120/240 step-up
System status and control	Local PLC running *Remote View* software
Heating system	2 diesel-fired Espar engine coolant heaters and a DC electrical resistance heater
Ventilation system	Fans and louvers in key locations throughout the module
Energy Storage	
Batteries	Deka “Unigy II,” AGM type
Battery pack	24 VDC, 720 Ah
Battery/inverter disconnect	Two 70-amp breakers

Communications System

The remote location of this research platform requires a wireless communications system to bring back the measurement data, permit remote configuration changes, and report power system status. A StarBand Model 360 satellite system was chosen, based on the need for two-way communications and over 10-MB of daily uplink traffic. The Internet access offered by the StarBand system is a useful feature.

Originally intended for home Web surfing, the StarBand system offers significantly higher downlink speeds compared to the uplink. Typically, a short URL request would download a large Webpage. We have been experiencing downlink speeds averaging 630 kbps and uplink speeds averaging 65 kbps.

Because the StarBand system was designed for home use, two precautions were designed into our implementation to improve the system's reliability. The Equipment Room ambient temperature is maintained between 45 and 100 °F, to simulate a home environment. Two StarBand Model 360 modems are connected to the single front end low noise receiver and transmitter; the modems are alternately powered to provide backup functionality, should components fail or parameters drift. To date, we have not needed the backup modem for the Ivotuk system, though we did see an infantile failure on an earlier single modem deployment at Sag River, Alaska. A 1.2-m diameter dish antenna is needed to provide sufficient signal strength for sites in Alaska, due to the larger path loss at high latitudes. The elevation angle to the satellite is only 10.5°. The nearly vertical positioning of the offset feed dish helps to shed any snow and ice that might build up and degrade performance.

The StarBand networking software for the Model 360 modems required a Windows operating system. We used Windows 2000 Professional. An alternately-powered pair of rack-mounted personal computers offers backup functionality for the data processing and communications functionality. The primary computer has remained functional and there has been no need for the backup computer. The new StarBand Model 480-series of modems do not require a Windows-based platform support higher data rates. We currently plan to retrofit the Ivotuk system with these newer modems during the next annual maintenance trip in August 2005.

The module after installation of wind and solar components.

The control for the switching of backup modems and computers and for powering a Webcam and statistical multiplexers is accomplished through a Network Power Switch connected on a serial port to an Iridium data transceiver. The 2400-bps Iridium link offers two-way communications to the switch to toggle power to the various elements, allowing for the switching in of backup elements or for rebooting the computers. This independent data link offers some system recovery ability, if there is a failure in a StarBand modem or a lock up of the computer.

The personal computer offers Network Address Translation (NAT) through an Internet Connection Sharing Ethernet configuration. This allows additional network devices to reside on a local network sharing the single StarBand connection. The Webcam, a serial link converter, and a data acquisition system benefit from this functionality.

To bring researcher data from the tower back to the StarBand system located at the power shelter, we implemented a wireless point-to-point data link using a pair of FreeWave 900-MHz ISM-band transceivers. The transceivers cost less than an armored data cable, they are quicker to deploy and less likely to be damaged by wildlife. The data link supports traffic to 115.2-kbps and is fed by a pair of statistical multiplexers to carry four separate serial streams over the single wireless link.

A second FreeWave point-to-multipoint network was added in August 2004 to provide a communications link for WERC's research towers. A serial to Ethernet network interface allows two-way data transfers and control of the data loggers at the remote towers. Access to this network of research towers is available from any computer on the Internet, with proper login permissions.

Power system and computer parameters and status data are transported over the Internet using established Internet mail handling protocols. The Transport Net server receives, processes, and archives this data, which appears on the system status web pages. The research data transport utilizes store-and-forward protocols to ensure that its data transfers are equally reliable. If the communications link is temporarily unavailable or heavily loaded, the files remain stored on the computer at Ivotuk for later delivery when the communications link is restored.

Successes

This system has several attractive features, the most obvious of which is the ability to monitor what is going on from afar. In addition to being able to monitor system status, the *Remote View* program allows the operator to interact with the unit and change set points, locking-out functions, etc. from anywhere with Internet connectivity. This functionality also allows operator intervention whenever a problem begins to manifest. It does not compensate for fundamental design flaws, however.

The renewable energy enhancements made on the Ivotuk power and telemetry system have dramatically increased system performance. Thus far, it appears that the fuel supply may be stretched out to the extent that an annual maintenance and refueling interval is achievable – even with the current degraded battery bank. The replacement of the battery bank next year will definitely make a once-per-year visit possible. By adding alternative power inputs, the reliability of the system has already been markedly enhanced.

Being able to see how the system is performing on a daily basis will allow conclusions to be based on real data rather than assumptions, which has often been the case with autonomous systems in the past. This is cutting-edge technology, and there have admittedly been some painful lessons learned along the way. However, there is no doubt that this system will continue to evolve and point the way toward better, smaller, more easily deployed, and less costly systems in the future.

Lessons Learned

Diesel Generator

First and foremost is the fuel efficiency issue of the generator. The generator unit was supposed to run unattended for a full year at a 200-watt rated output. Between the drawing board and the implementation, the actual power requirement is an average of 240 watts continuously. This does not sound like much, but when you add it up, it comes to 5,760 watt hours a day, or 2,102 kilowatt hours a year. That is a fair bit of electricity, and it takes a large volume of diesel fuel to produce it. Also, the thermal inefficiency of the unit resulted in a tremendous number of run cycles on the Espar heaters, which are fired off of diesel fuel. Basically, the module could only run for about seven months before travel to the site for refueling was necessary.

To understand why this condition occurred, the conflicting requirements of the generators and the battery bank must be understood. Diesel generators run best under a full load at which the efficiency (still only about 30% conversion efficiency) and the longevity of the engine are greatest. If a diesel generator is run under low loads for extended periods of time, they are far less efficient in burning fuel. Incomplete combustion and dramatically increased emissions result in heavy deposits in the exhaust system and oftentimes cause premature cylinder wear, sticking piston rings, and a host of other problems. Cold weather exacerbates these conditions markedly. Batteries, on the other hand, demand long periods of low-current input at the end of a charge cycle.

In the Ivotuk module, the generator would run at its maximum efficiency for a relatively brief period of time and then drop off fairly rapidly at the end to avoid excessive fuel consumption and possible engine damage. A longer run cycle would be better for the batteries but bad for the engine. A shorter run cycle would be better for the engines but bad for the batteries. The compromise ultimately settled on was fairly bad for both components. The fact that the battery bank was rather undersized at 720 amp hours at 24 VDC only made the problem worse, because the generators had to cycle more frequently and thus ran under a low load for a greater percentage of the time. Here was a system crying out for renewable energy input.

Battery Performance

As stated above, system monitoring over the course of the year indicated that the battery performance was deteriorating. However, it was not fully understood at that time how critical the situation was, the extent of damage to the battery bank, and that the battery bank was failing due to the fundamental design flaw mentioned earlier. Progressive discharge testing performed on-site by NPS personnel revealed that one cell was severely compromised with fully half of the cells performing well below acceptable standards. Basically, the battery bank would reach a point in the discharge cycle where it would collapse and voltage would plummet. Running several deep discharge/charge cycles restored a bit of capacity, but it was clear that the problem would have to be addressed more comprehensively. Unfortunately, shipping out an entirely new battery bank within a few days was out of the question. Instead, a single cell was located to replace the most severely compromised cell in the stack. The parameters were also reset to favor battery longevity over fuel efficiency and long-term generator performance. A major component of the field maintenance next year will be to replace the existing battery bank with a new and adequately sized stack capable of handling the rigors of this application.

Further Reading

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