PAPER

A High-Latitude Modular Autonomous Power, Control, and Communication System for Application to High-Frequency Surface Current Mapping Radars

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ABSTRACT

High-frequency, shore-based radars (HFR) collect hourly, real-time surface current data over broad areas of the coastal ocean and yield insights on time-varying circulation, predict oil spill trajectories, evaluate circulation models, and, in case of a spill, provide responders with real-time data on spill evolution. HFR requires 7.5 kWh/day of power, but the lack of power availability inhibits HFR use in Alaska. We developed a modular, autonomous remote power module (RPM) for Arctic environments. The RPM design facilitates setup and transport to remote sites using small vehicles, and it contains subsystems for power generation, satellite communications, and power performance monitoring. The subsystems are powered by a battery bank (with a 5-day power reserve) charged primarily by wind and solar and secondarily by a biodiesel generator. The RPM is a stand-alone device for long-term deployments. It minimizes permit issues associated with diesel generators and logistics costs associated with refueling and maintenance. Performance data from a prototype RPM setup in Barrow, Alaska, in fall 2010 is provided. The system is designed for high latitudes but can be modified for remote coasts elsewhere.

Keywords: remote power, high-frequency radar, CODAR, arctic, power, wind, solar, generator, communications, instrument enclosures, ocean currents, battery banks

Introduction

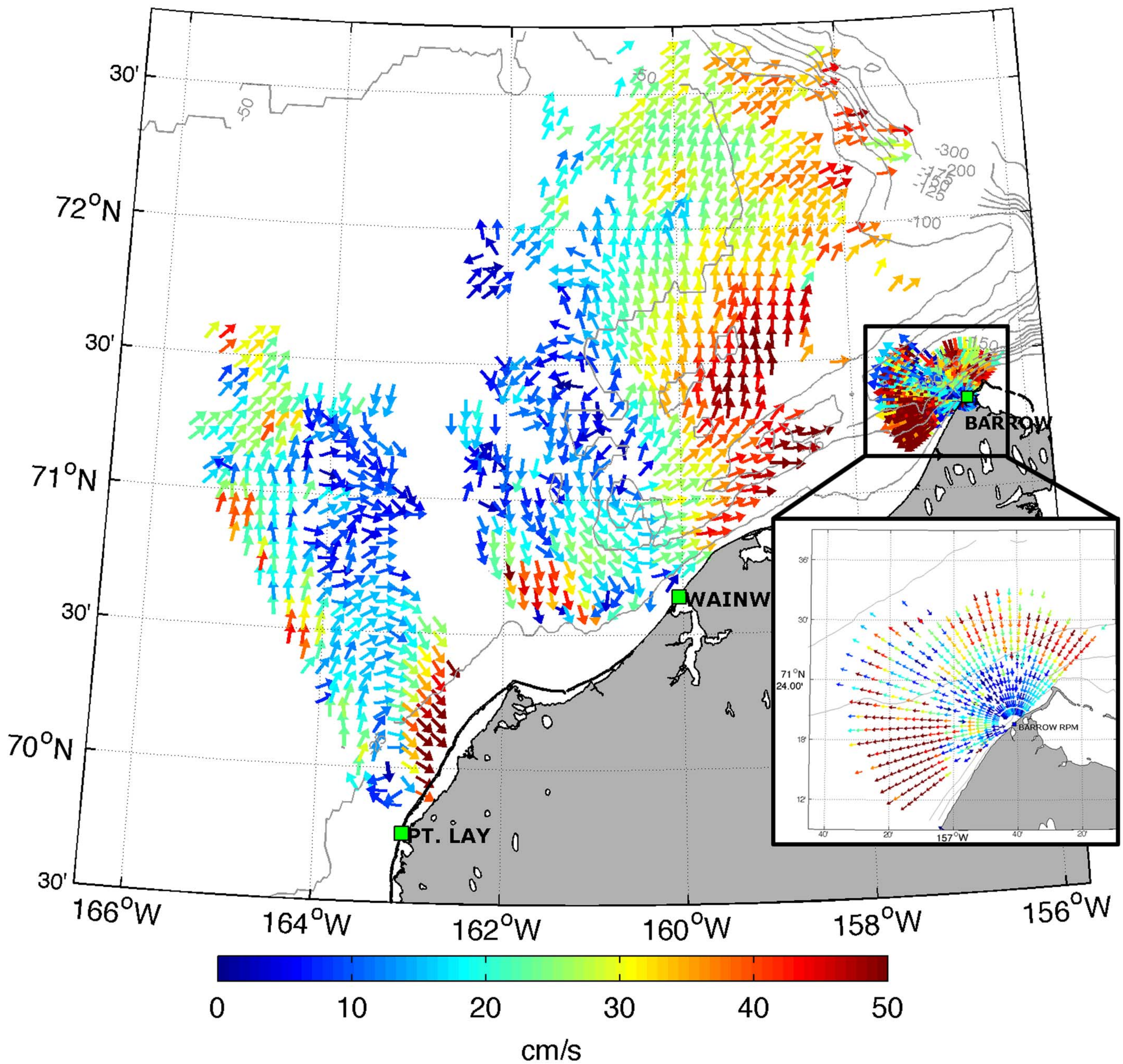
Shore-based, high-frequency radars (HFR) map surface currents in real time over the adjacent coastal ocean. As such, they can be applied to ocean circulation studies, real-time ocean forecasting, marine navigation, search and rescue operations, coastal zone and ecosystem-based management decisions, and real-time mapping of contaminant spills (Paduan & Rosenfeld, 1996; Coulliette et al., 2007; Ullman et al., 2006; Bassin et al., 2005; Abascal et al., 2009).

HFR has been applied in a variety of settings worldwide and is presently considered a standard ocean surface current measuring technology. Indeed there is an extensive HFR network operating continuously along the coastline of many of the contiguous United States (http://hfradar.ndbc.noaa.gov). HFR determines surface currents by analyzing and processing the Doppler spectrum of backscattered radar waves (Barrick et al., 1985). The cross-spectra of the backscattered radar waves include dominant first-order peaks, which arise by Bragg scattering from ocean waves at half the wavelength of the radar wave. In the absence of ambient noise and ocean currents the backscattered signal appears as delta functions in the spectra. Spectral broadening occurs due to currents in the field of view of the radar, which also measures the bearing and range of the sea echo. A single site HFR obtains radial velocities only, but by combining data from two overlapping radar masks horizontal currents are obtained. As an example, Figure 1 is an instantaneous map of surface currents from Alaska's Chukchi Sea as determined by three long-range (~4 MHz) HFRs.

With the exception of a single system located in Baja California, all other HFR systems of which we are aware obtain power from the onshore power grid. This dependency has severely limited HFR application in Alaska because vast stretches of the coastline are remote and uninhabited. Where power is available, the site location may not yield the optimal radar mask for sampling ocean currents. The gap in surface current measurements (Figure 1) results from the

FIGURE 1

Ocean surface current measurements over the Northeast Chukchi Sea derived from three land-based HFR stations in Barrow, Wainwright, and Point Lay. The data were collected on September 20, 2010 at 0600 UTC. Contours of bottom depths are in meters. The inset map shows the single high-resolution HFR powered by the RPM.



suboptimal location of HFR stations due to the reliance on the local power grid. This limitation led us to develop the remote power module (RPM), whose design and performance are described herein. Remote HFR users in Arctic and subarctic Alaska must also consider difficult and costly logistics, demanding environmental conditions, such as high winds, subfreezing temperatures, salt-laden maritime air and icing, inquisitive, and potentially disruptive, wildlife (rodents, foxes, and bears), and, finally, site permit requirements.

Design

Overview

The RPM is a fully automated, hybrid (solar, wind, and diesel) power station designed for Arctic and sub-Arctic maritime environments. It is a remotely deployable platform with a compact footprint congruent with permitting requirements in many coastal areas. A rugged, durable, and climate-controlled shelter houses HFR electronics, communications equipment, and electrical system components of the power plant. The assembled RPM-HFR (operating at 25 MHz) is shown in Figure 2.

The guiding principles behind our RPM design are that it be portable, flexible, and capable of providing sufficient and redundant power needed for the HFR, communications, and system self-monitoring components.

Portability requires that the system be deployable at remote sites without expensive logistic support. In particular, we required that no component be heavier (or bulkier) than two people can carry. Potential Alaskan settings include those within or near remote villages (all of which are served by commercial air cargo carriers) or on remote islands or coasts accessible by vessel. We employ system components that are <200 lbs and sized for accommodation in skiffs, trailer-equipped four-wheelers, or snow machines with a cargo sled—typical means of transport in rural Alaska.

Flexibility requires that a system can be optimized on a site-specific basis that takes into account regulatory constraints and the availability of renewable energy. Our design includes comprehensive power monitoring to provide key information for scaling the system components for future application to different sites. The RPM collects power source and sink data from key points in the system as well as wind speed, solar radiation, and indoor/outdoor temperatures. In aggregate, these data permit (1) assessing system performance, (2) anticipating and/or troubleshooting major system component failures, (3) heat budget handling, and (4) accurate scaling of system power generation and storage. The last point allows optimizing future deployments based on mission requirements and the power density of site-specific renewable energy resources. We can remotely control the data logger and its control circuitry (dump loads, exhaust fans, and generator operation). This allows us to conduct periodic generator condition checks and/or to start the generator remotely to maintain battery charge if renewables are unavailable.

FIGURE 2

The complete RPM in operation in Barrow, Alaska, during a 35-mph wind event on September 25, 2010.

The system is designed to reduce operating costs by generating power from renewable energy. Reliance upon fossil fuel generators as the primary power source is costly due to frequent maintenance requirements, limited life expectancies, and logistics and fuel costs (Bryce, 2008). The RPM supplies the daily power requirements of 7.5 kWh/day of a typical CODAR Ocean Sensors Seasonde©, a high-speed satellite communications link, a small meteorological station, and power monitoring and control equipment. The RPM consists of three subsystems: (1) power generation, storage, and conversion; (2) the SeaSonde HFR; and (3) communications, control, and monitoring. Figure 3 provides an overview of the system. It uses off-the-shelf components that have low radio frequency interference so as to avoid contaminating the HFR signals. All electronic devices receive power from a battery bank through a 24-V DC distribution panel. Wind turbines, photovoltaic (PV) panels, and a backup generator recharge the batteries through the same panel.

Design redundancies protect many features of the system against spurious failures. For example, power is available from four wind turbines, three independent strings of PV cells, and the diesel (DC) generator (which can be started/stopped locally or remotely). Control of power hut temperature is by both thermostatically controlled exhaust fans and diversion loads inside and outside the hut. Monitoring points for voltage, current, temperature, and remotely controlled switches are distributed at key points throughout the system. Monitored data are stored in a data logger and sent hourly via a satellite communication link to the central station at the University of Alaska Fairbanks.

The system is designed to run as a stand-alone, hands-off operation. However, if needed, operational decisions developed from the monitored data can be relayed from the central station through the communications link and control module to remotely regulate diversion loads, exhaust fans, and/or the generator. All components, except the antennae, wind turbines, and solar panels, are housed within a modular hut, the "power hut." Power system electronics (the "power panel") are mounted to the wall inside the enclosure on a modular carry-up, bolt-on, quick connect assembly constructed for ease of system deployment and demobilization. We use prelabeled Molex and Anderson

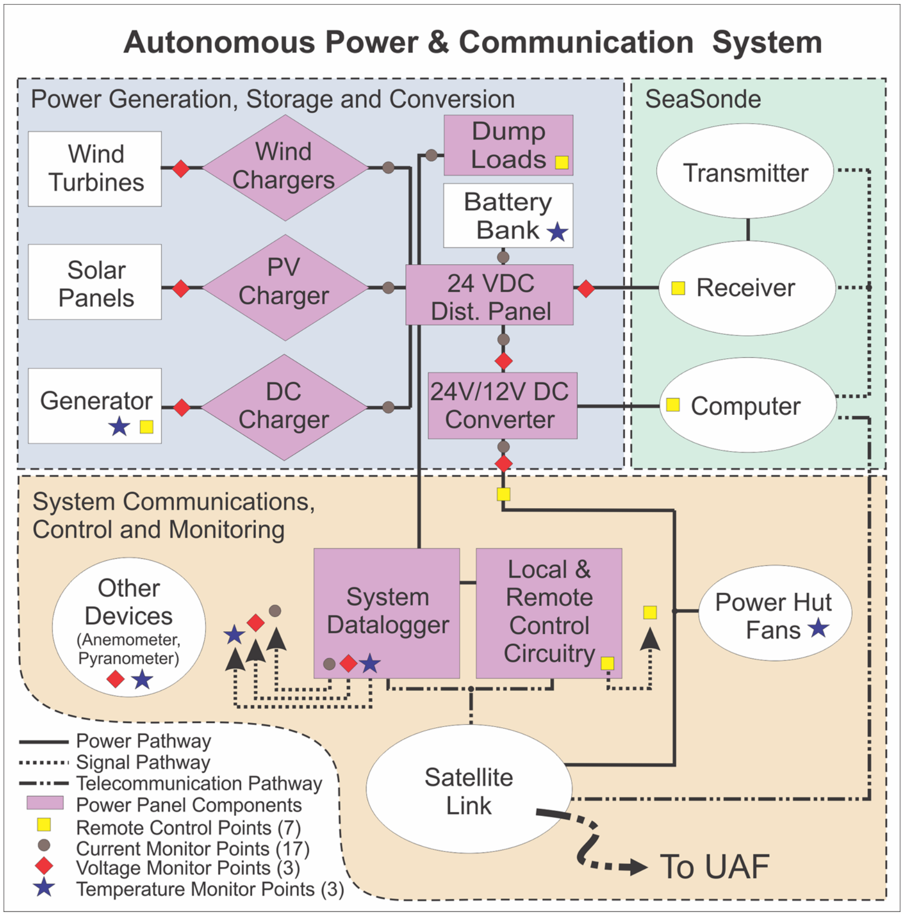


FIGURE 3

Overview of the autonomous power and communication system indicating the major subsystem breakdown and primary monitoring and control points. The three subsystems have different background shading. Purple-shaded components indicate components on the wall-mounted power panel. UAF, University of Alaska Fairbanks. (Color versions of figures available online at: http://www.ingentaconnect.com/content/mts/mtsj/2011/00000045/00000003.)

style connectors that allow the multitudes of sensor cables and delicate wiring connections in the RPM to be rapidly assembled in the field.

Power Requirements and Integration

The average electrical load is nearly constant at ~310 W or 7.5 kWh/day with ~70% of the power consumed by the HFR. The HFR electrical supply is connected through a low-voltage disconnect relay that disconnects the radar if the battery bank experiences a low voltage condition. Power is restored to the HFR when the battery bank voltage returns to its normal condition. This feature allows us to protect against complete battery discharge while still leaving sufficient battery capacity to power the communications and monitoring systems for remote troubleshooting.

The DC distribution panel allows easy integration of additional wind or PV sources without a costly redesign of the power system. Future modifications can therefore be accommodated by simply adding a modular subpanel with the required components.

Foundation

The RPM is supported by a compact multipoint foundation 16 feet wide by 20 feet long. This trussed aluminum frame, with 12 vertically adjustable feet, is assembled quickly over uneven surfaces and unstable soils. A wooden deck is affixed to the foundation with a 4-foot cantilevered overhang, which forms the solar array attachment. The raised array prevents snow accumulation on the solar panels and inhibits potentially disruptive wildlife visits (Ross & Royer, 1999).

Shelter

The power hut is an 8 feet × 12 feet, 10-feet-high walk-in freezer composed of 30 foam and aluminum sections secured together by a system of cam locks. No single section weighs more than 75 lbs. The hut's modular structure has individual locking panels akin to the stress skin buildings used successfully in the U.S. Antarctic Program. The 4-inch thick walls, floor, and roof provide an R-34 insulation rating. It is partitioned into two rooms: one for the electronics and one for the generator and fuel. The hut size provides a safe and comfortable working environment and, if harsh conditions occur, emergency shelter for personnel visiting the site.

Battery Bank

Power is stored in a 2,745 A h (24-h discharge rate) battery bank consisting of three strings of 12 individual Concorde Sun Extender PVX-9150T 2 V cells. Each 24-V string of 12 batteries is fused to protect the battery bank from individual cell failure while still retaining the overall battery bank integrity. These robust cells have a long life cycle, little self-discharge, and can withstand extreme temperature excursions (−40°C to +72°C).

Each cell weighs 94 lbs and is easily integrated into the battery bank by prefabricated intercell connectors. The batteries are sealed valve, regulated lead acid units and thus exempt from DOT Hazardous Material Regulations and IATA Dangerous Goods Regulation. This feature minimizes shipping costs for both deployments and demobilizations.

If the batteries are initially fully charged and if we apply a 10% derating factor to account for fluctuating temperatures and performance degradation over time, then the battery bank has sufficient capacity to provide ~5–6 days of power. By this time, the batteries will be 50% discharged, and recharging is required. The loss of an individual string of batteries would reduce the capacity of the bank by roughly one and a half days. We note, however, that a battery bank sized to provide 10 days of unassisted power fits easily within the dimensions of the power hut.

Our analysis of long-term wind records collected at coastal sites in Alaska suggests that calm conditions typically prevail for <3 days at many potential HFR sites. For deployments that require maximum dependability and that must also be modular and portable, reliability scales directly to battery bank size. We anticipate that most power generation problems will be identified by monitoring current and voltage at the points indicated in Figure 3 or be identified during routine site inspections. With this in mind, a 5-day battery bank should allow adequate time to identify problems in the power generation subsystems and implement on-site repairs without curtailing data collection. However, battery bank capacity could be changed in accordance with mission goals, site location, logistics costs, etc.

Wind Power

Wind is the primary power source in Arctic Alaska, and it is provided by four Ampair 600-24 wind turbines. The turbines, mounted on towers at each hut corner, collectively generate up to 2.4 kW. The four turbines are sized to supply 100% of the system power when the wind speed exceeds 11 mph (~5.5 m s^{-1}). The marine grade turbines are small, lightweight, and quiet with overspeed governing automatically controlled by blade pitch adjustments. We chose the Ampair turbine because of its robust construction and good performance in high winds. The turbine's glass reinforced polyester blades have snow-shedding characteristics, making it an excellent choice for high-latitude maritime environments. Based on the manufacturer's specifications, the turbines were expected to generate 3.4 kWh/day at ~5.5 m s^{-1} wind speed. These criteria were met throughout our test deployment in Barrow, Alaska, between September and December 2010.

The Ampair wind turbine generates three-phase AC power that is converted to DC by the Ampair charge controller and supplied to the battery bank. The controllers utilize a four-stage charging algorithm (bulk, pulse width modulated absorption, float, and equalization) and diversion load control. When the battery bank becomes fully charged, the diversion load control prevents overcharging by diverting the unneeded power to a pair of resistive heating elements (the diversion load). A voltage and current monitoring point was placed at the output of each turbine charge controller and at the diversion loads to monitor turbine performance and facilitate remote diagnosis of turbine failures.

Wind Turbine Masts

The turbines are mounted atop 18-feet rigid poles with two support members. This design allows raising and lowering the turbines easily in all but the most severe winds using a gin pole, ratcheting rope puller, and three people: one rope puller and two to stabilize the turbine while lowering/raising. The design also allows for a compact footprint for the four turbines as compared to a guyed tower. The rigid poles reduce collision threats by migrating birds due to their higher visibility. Both of these features are important in terms of site permit requirements. The masts are manufactured with a multipurpose sleeve design, which reduces the overall length and weight of the towers prior to assembly.

As part of the tower engineering design, we determined the tower resonance conditions through finite element analysis. The basic three-dimensional node and beam model used for the analysis assumes concentric 2-inch schedule-80 external members with 1.5-inch schedule-40 internal members. The model analysis considered the cross-sectional area of each member, the second moment of inertia in each dimension, the material's modulus of elasticity, the material's Poisson's ratio, and the weight/density of the material.

We computed the first five eigenmodes of the turbine towers using a dynamic vibration analysis solver based on the Raleigh-Ritz subspace iteration method. These modes define the response of the system when excited by the rotating turbines. The Ampair 600 turbines rotate between 250 and 1,000 rpm for wind speeds between 3.0 and 11 m s^{-1} and turbine rpm asymptotes for wind speeds >11 m s^{-1} due to blade pitch governor operation. The first eigenfrequency is at

27.6 Hz (or equivalently at 1,656 rpm), but the turbine-induced tower frequencies are substantially less than this frequency. Therefore, we do not expect to see resonant frequencies excited by the wind turbine and tower structure to cause excessive strain and premature equipment failure.

Solar Power

The system is equipped with nine 200-W solar panels fastened to the south side of the module via cantilevered supports. This 1.8-kW PV array provides additional charging power during the 24 h of sunshine present at high latitudes during summer months. The arrays are mounted on frames tilted at a 55° angle to take advantage of low sun angles. To optimize the charging efficiency of the system, we incorporated a solar charge controller that uses maximum power point tracking and a DC-DC converter circuit designed to extract the most power available from the PV array.

Multifuel Generator Power

The generator, a standard two cylinder, 600 cc, liquid-cooled Kubota engine, has an extensive engineering and industrial usage history. It powers a 24-V DC alternator, with a rated output of 170 A, which enables rapid, temperature-compensated, four-stage charging to the battery bank should renewable resources be absent for extended periods. The generator is remotely configurable, fully automated (ignition, warm-up, and shut down), with service intervals after every 500 run-time hours. The fuel delivery system can be configured for either diesel or biodiesel fuels. We placed a 15-gal fuel tank inside a secondary spill containment structure in the hut. This volume is sufficient for our application because the generator is simply a backup power supply during extended periods of calm winds or low-light conditions.

The Kubota generator automatically starts based upon a programmable low-voltage battery condition and/or a preset number of ampere-hours consumed from the battery bank and turns off based on a number of programmed charging algorithms. To conserve fuel, the generator will not recharge the battery bank to full capacity (Chastain, 2006); this task is left to the wind turbines during periods when wind speeds exceed 5.5 m s^{-1}. Given the anticipated level of available renewable energy and to conserve fuel, we elected to start the generator when the battery bank had discharged 50% of its available capacity and run it until the battery bank was recharged to 80% capacity. The 15 gal of diesel fuel stored onsite supports 60 run-time hours for the generator or nearly seven charging cycles as described above. Generator monitoring by the data logger includes run-time hours, generator voltage, and DC current output from the alternator.

Communications

We use the HughesNet communications system for data transfer between the RPM (and HFR) and the central station in Fairbanks. Typical file sizes for the HFR data and RPM system health information combined are 36 Mb/day. In addition to data transfers, remote terminal sessions allow for periodic system checks and modifications to the HFR and power delivery system. HughesNet is the most appropriate and cost-effective satellite-based Internet service operating in Alaska at the communication speeds needed (256 kbps uplink) for the project. As deployed, our communication system utilizes a small percentage of the total bandwidth available to a subscriber. Excess bandwidth may be very attractive to other potential users of the RPM who may have data transfer needs in remote environments.

The HughesNet system is easily installed, can be monitored remotely, and offers static IP addresses for easy remote logins via port-forwarding protocols. The HughesNet modem and a four-port Ethernet router integrate seamlessly with the HFR Macintosh computers and the datalogger. Based on the manufacturer's recommendation and their results in a variety of environmental settings, our system utilized a 1-m diameter antenna with a 2-W transmitter. All communication equipment power supplies can be remotely cycled in case of software hang-ups.

In the case of high-latitude work, above 78° latitude, HughesNet style geostationary satellite communications would not be appropriate due to line of sight issues. At such high latitudes, the additional cost and slower performance of Iridium systems, like OpenPort (128 kbps) or Iridium link (2,400 bps) may be justified.

Monitoring and Control System

Near real-time monitoring and remote control of the system is accomplished by integrating a Campbell Scientific data logger with a multiplexor and a relay driver. Measurements of power, current, voltage, ambient and indoor temperatures, wind velocity, and solar radiation are logged and then transmitted via satellite communications to Fairbanks for performance evaluations and/or control adjustments.

Implementation

The design, assembly, and initial testing phase of the RPM began in the summer of 2009 in Fairbanks, Alaska. Various configurations of the hut, turbines, and PV array were considered, with the end result representing a balance amongst portability, robust engineering, and permit considerations for the test site in Barrow, Alaska. Final tests on the power panel electronics and integration with the engine controller were completed in June 2010 and deployment in Barrow began in late August 2010.

For transport, the RPM was and packed into several dozen crates (each less than 200 lbs) and loaded into a single 20-feet steel shipping container. The container was trucked from Fairbanks to Prudhoe Bay (475 miles) and then barged the 200 miles between Prudhoe Bay and Barrow. The total weight of all RPM components was 2,721 kg (~6,000 lbs, 3,400 lbs of which were batteries). Use of a bulk container to ship the RPM to major destinations for unloading prior to transporting the smaller packages to field sites is probably the most efficient method for coastal Alaska. Once in Barrow, it took four people 4 days to set up the RPM. Two people spent two additional days installing and calibrating the HFR.

Results

We deemed the September to December 2010 full system test of the RPM in Barrow, Alaska, to be highly successful insofar as the RPM powered the HFR, communications, and data logger for the duration of the experiment without the need for a single generator start-up in spite of considerable variability in solar insolation, wind speed, and ambient air temperature (Figure 4) throughout the duration of the test. Figure 5 shows corresponding time series of battery bank voltage and solar panel and wind turbine current production. As evident from these figures, winds were the dominant energy source (93% of total power produced by the system) with solar power effectively negligible after the first week of October. Average battery voltage over the test period was 26.9 V DC, and with the exception of the last week in November, the battery bank voltage exceeded 25 V DC during this 3-month period.

The RPM endured four storms with steady winds exceeding 15 m s^{-1} (~30 kts) during the field test. Two

FIGURE 4

Time series of RPM solar insolation (top), wind speed (middle), and ambient air temperature (bottom) during the 2010 RPM test phase in Barrow, Alaska.

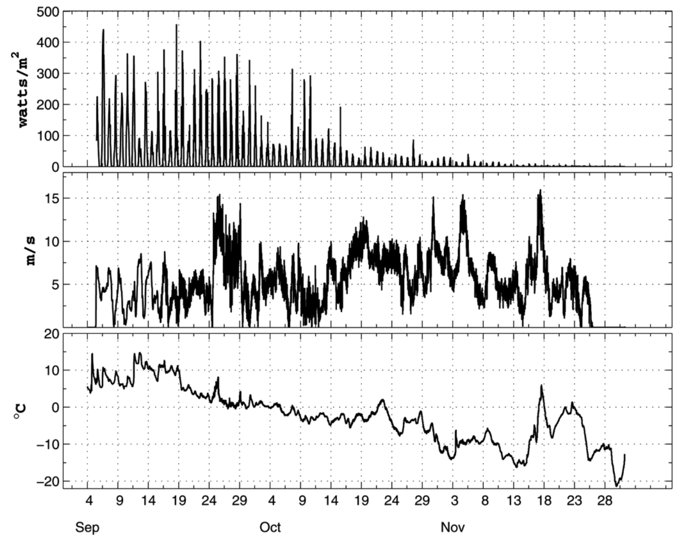
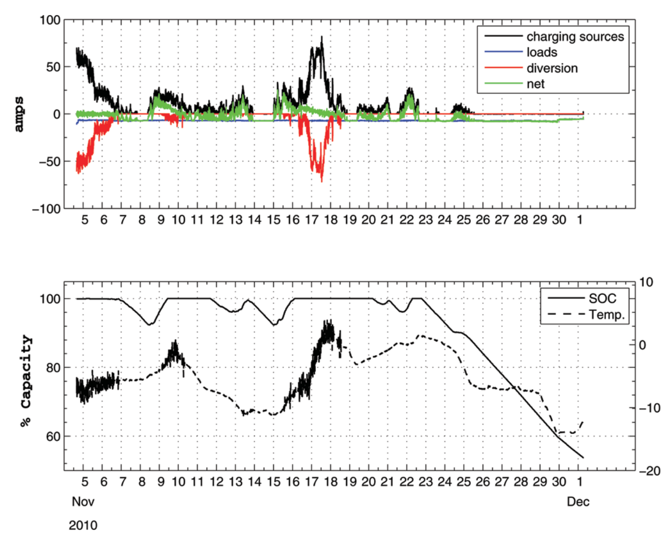


FIGURE 5

Time series of series of battery bank voltage (top), solar panel current production (middle), and wind turbine current production (bottom) during the 2010 RPM test phase in Barrow, Alaska.



mid-October storms were accompanied by 20 m s^{-1} (~40 kts) gusts, below freezing temperatures, and extreme icing conditions. The November 17th storm caused a storm surge that piled sea ice on the coast up to a height of 8 m. Observations of the RPM by team members during these events indicated that all components operated flawlessly and remained intact.

A particularly useful result from the test is that we developed a power production curve from the Ampair 600 wind turbines under a variety of conditions representative of an Arctic maritime environment (Figure 6). Such data are notoriously difficult to obtain due to the lack of standardized practices for their determination (Gipe, 2004). Note that wind power production is negligible for wind speeds <3 m s^{-1} and then rises gradually from 3 to ~4.5 m s^{-1}. Wind power increases linearly between 4.5 and 11 m s^{-1} and then very slowly at higher wind speeds due to the overspeed control mechanism that reliably engaged at speeds >11 m s^{-1}. All of these observations agree with the manufacturer's specifications.

The deepest discharge of the battery bank occurred during the last week of November when ambient air temperature dropped below −5° C and winds were light and variable (Figure 7). Battery bank voltage decreased to 24.3 V DC, the lowest point of discharge during the experiment. Following the ampere-hour counting method to determine battery bank state of charge (Pillar et al. 2001), we find that, by December 1, the battery bank had discharged 47% of its available capacity over this 8-day period that lacked both sunlight and wind. The generator did not turn on at this time because the bank's SOC had not dropped below 50%. This is a useful finding for it suggests that we sized the battery bank conservatively. Following this period, we winterized the RPM after first fully recharging the battery bank with the generator.

The top of Figure 7 also highlights how the system operates and how some of the system status data can be used to gauge the operation in real-time. The top of the figure shows the steady current draw (negative) by the instrumentation (HFR, HughesNet, and data logger). The charging current (positive) reflects production by the wind turbines, which varies considerably over this portion of the record. This curve is mirrored by the diversion loads, which convert the excess power

FIGURE 6

Wind turbine power production versus wind speed for the four Ampair 600 wind turbines deployed at the Barrow field site over the course of the 3-month deployment.

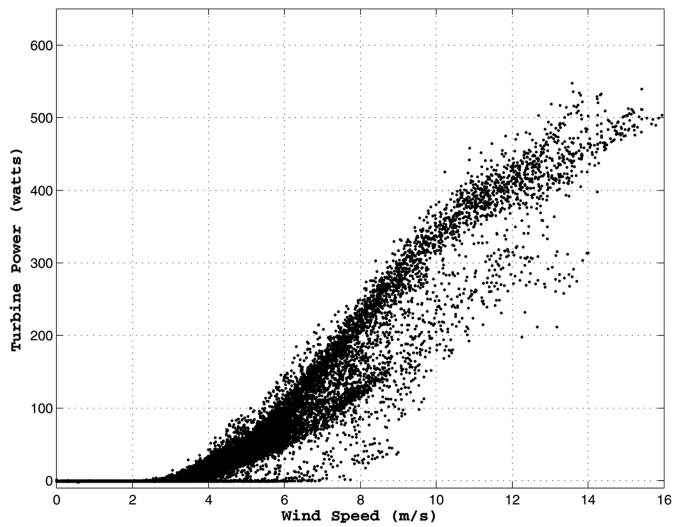
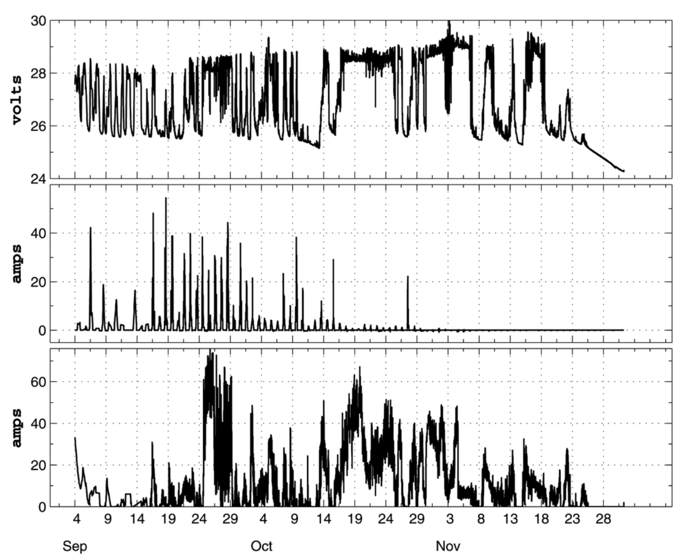


FIGURE 7

Time series from November 2010 of individual charging sources/sinks (top) and battery state-of-charge (SOC) and air temperature (bottom).



into heat, while maintaining sufficient current to power the steady (and negative) instrumentation load.

Problems Encountered

Although we regard this initial test as successful, there were several minor problems encountered that were quickly resolved. These are worth mentioning in the event that readers wish to develop similar systems. In the second week of the test, two critical flaws were discovered in the Hughes Net system. First, the high latency (the amount of time it takes a packet of data to travel across a network, roughly 0.5 seconds) associated with satellite-based communications at 71°N caused the Campbell Scientific datalogger to lock up its Ethernet-based IP communications. Campbell Scientific remedied this problem with a firmware upgrade (version 20). Second, a faulty Hughes Net modem power supply caused a board level failure on the modem resulting in a 10-day a loss of communications with the RPM. A replacement modem was found, but it took almost 2 weeks to replace the faulty modem with a new one. This fault underscores the need to have spares of critical system components on site and provide a "back-door" communications platform. The latter can be addressed by installing an Iridium modem directly connected to the data logger.

During preliminary testing of the data logging hardware and software systems in Fairbanks, no significant wind events occurred. Consequently, we decided that hourly averages of system variables would suffice for transmission to Fairbanks for efficient system diagnostics. Almost immediately after leaving the Barrow field site, multiple wind events with wind speeds >6 m s^{-1} indicated that hourly averages of critical system status variables resulted in the data logger recording "out of range" errors on differential voltage measurements. This is a consequence of the pulse-like nature of wind power production and the lack of adequate settling time on the data logger. As a result, many of the hourly averages of solar and wind power production data collected in September had large gaps. We remedied this problem in early October when we installed a new modem by reprogramming the data logger to store raw voltages every 10 s and transmit this high-resolution data to Fairbanks for postprocessing.

The resistor diversion load wires comprised a final failure point, which was not noticed until the end of the test when we demobilized the RPM. The wiring harnesses that connect the diversion loads to their current measuring shunts were made of heat resistive wire with a tolerance of 105°C. However, we suspect that during some of the prolonged wind events, temperatures inside the diversion load enclosures exceeded this temperature limit and melted the insulation. All of the wiring inside the diversion load enclosures has been replaced with high-temperature wire commonly found inside of toaster ovens and electric heaters.

Discussion

The successful deployment of the RPM for a 3-month field test in the Arctic indicates that such a system can power HFR (and similar systems) entirely by renewable sources. Our results suggest that that many coastal Alaskan sites from the high Arctic, along the Bering Sea coast, the Aleutian Islands, and the Gulf of Alaska are suitable for future deployments of HFR powered by the RPM.

Although this version of the RPM performed quite well, we will incorporate several modifications to improve functionality and deployment speed. For example, we will replace the deck lumber of the RPM with aluminum I beams and grated catwalks. Prefabricated structural I beams with welded attachment points for the turbines will minimize rotting and make the units more suitable for multiple deployments (since lumber can only accept so many lag bolts).

A second improvement would be to include an Iridium phone "back-door" communications platform so that telemetering system status data can occur even if the Hughes Net satellite service fails. Although the Iridium data link is much slower (2,400 bps as compared to 256 kbps) it suffices for transmission of system diagnostics and for remote control of the RPM.

During the 2010 field test, excessive wind power was generated and thus diverted to the heater dump loads to prevent overcharging of the batteries This indicates that the RPM could support additional sensors. For example, we are in discussions with the United States Coast Guard (USCG) to support Very High Frequency (VHF) transceivers used for maintaining communication and position with vessels at sea. In addition, the Marine Exchange of Alaska has expressed an interest in colocating a marine automatic identification system transceiver on the RPM platform. (We have tested these transceivers for radio frequency interference, and they do not seem to be a problem in the 162-MHz band). We are also investigating the potential of using the RPM platform to host air quality recorders, a sea-ice tracking radar, and additional meteorological sensors.

The RPM is currently demobilized for the winter. We will be preparing manuals that include design schematics, operating and maintenance instructions, and troubleshooting guides. We are also using the RPM performance data collected during the Barrow test to develop an empirical model useful for accurately sizing similar renewable energy systems based on available environmental data. An additional year of testing, incorporating our design improvements will be conducted in the summer of 2011 at Barrow. The results from these efforts will be accessible by those interested from the project Website (http://www.ims.uaf.edu/artlab/RPM.html).

The RPM as herein described was designed for use in Arctic and sub-Arctic environments. By adjusting the number of wind turbines and/or PV panels, this technology may be directly applied to other locations guided by suitable meteorological information (wind speeds, solar insolation, and air temperatures). If applied to warmer climates, care should be exercised to avoid excessive internal heating of the power hut due to high air temperatures. In such cases, solid-state thermo-electric air conditioners may be used to cool the interior of the power hut. Units with operating specifications appropriate for HFR typically consume an additional 100 W, which can be accommodated by the RPM as long as the available renewable energy resources suffice.

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