· Article ·
Advances in Polar Science
doi: 10.13679/j.advps.2020.0008
September 2020 Vol. 31 No. 3: 156-166

Hybrid energy module for remote environmental observations, experiments, and communications

Misha B. KRASSOVSKI[1*], Jeffery S. RIGGS[2], Chris TAVINO[3], Stan D. WULLSCHLEGER[1] & Susan L. HEINZ[1]

[1] Environmental Sciences Division, Climate Change Science Institute, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6290, USA;
[2] Integrated Operations Support Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6290, USA;
[3] Laboratory Modernization Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6290, USA

Received 5 March 2020; accepted 19 May 2020; published online 20 September 2020

Abstract Increased concerns about climate change have led to a significant expansion of monitoring, observational, and experimental sites in remote areas of the world. Meanwhile, advances in technology and availability of low-power equipment have allowed increasingly sophisticated measurements with a wide variety of instruments. However, the deployment and use of these technologies in remote locations is often restricted not only by harsh environmental conditions, but also by the availability of electrical power and communication options. In some cases, research stations and military installations can provide power for scientific equipment, data acquisition, storage, and transmission. Clustering of research sites near existing infrastructure has had the unintended consequence of limiting a spatial understanding of large geographic regions. Fortunately, the modern market offers many power and communication solutions, but most of them are oriented toward large industrial applications. Use of those solutions to power a research site is limited because of their cost and need for significant modification for the specific research purposes. Each study has its own unique power requirements and needs for proper instrumentation. A power and communication solution for a vast majority of implementations with or without modification would be of considerable benefit. This article describes design of a universal, scalable hybrid energy module for the Next-Generation Ecosystem Experiments Arctic project (https://ngee-arctic.ornl.gov/). Two modules were built, and the authors describe their implementation and findings over a 2-year period at a remote field site on the Seward Peninsula in western Alaska, USA.

Keywords **solar energy, wind energy, communications, power sources, alternative energy, NGEE Arctic**

Citation: Krassovski M B, Riggs J S, Tavino C, et al. Hybrid energy module for remote environmental observations, experiments, and communications. Adv Polar Sci, 2020, 31(3): 156-166, doi: 10.13679/j.advps.2020.0008

1 Introduction

Increasing the understanding of high-latitude regions of the world in a changing climate requires coordinated investigations that target improved process knowledge and model representation of important land-atmosphere feedbacks. Many projects have tackled this challenge in past decades, and there is an emerging national and international effort to coordinate these activities. However, there are many challenges to overcome if the community is to collaborate on large, interdisciplinary studies in remote areas of the Arctic. Some of those challenges are caused by isolation from infrastructure (e.g., roads, power and communication lines), which is why these studies and experiments are relatively rare and provide limited data.

* Corresponding author, ORCID: 0000-0001-6166-0289, E-mail: krassovskimb@ornl.gov

The lack of data is a serious limitation not only for field researchers but also for modeling communities (Kane and Stuefer, 2015; Cable et al., 2016; Crépin et al., 2017). The small number of available measurements and their uneven space distribution restrict the ability to create grid-based products that are necessary for model validation and calibration (Fisher et al., 2018).

The Next-Generation Ecosystem Experiments Arctic (NGEE Arctic) project seeks to address the technical and logistical challenges posed by the remote nature of the areas of study by quantifying the physical, chemical, and biological behavior of terrestrial ecosystems in Alaska. The project also focuses on high-latitude ecosystems underlain by carbon-rich permafrost that is vulnerable to thaw in a warm climate. One of the NGEE Arctic research sites is located in the tussock tundra of the Seward Peninsula (64°51′39.71″N, 163°41′58.30″W), about 3.8 km south of Council, Alaska (Figure 1), and 92 km northeast of Nome, Alaska. As this site had no access to power or communication lines a system had to be designed, constructed and deployed that could reliably provide power and data acquisition capabilities. The following requirements for a power source were selected during instrumentation planning for the Council site: it had to be movable, easy to reproduce, modular, scalable, and made from commercially available parts. The energy module that was built using these requirements uses solar and, optionally, wind energy, to generate the power for instrumentation in remote areas in which line power is not available. The frame-based design used to build the module provided the following features of this system:

(1) The system was designed with scalability in mind; the power and communication capabilities can scale up or down depending on the application and adapt to different power needs.

(2) Power sources (solar panels and wind turbines) can be easily mounted in different ways and quantities to obtain the power necessary for a given application.

(3) Strong, rigid construction deployable in harsh environments can withstand winter and icing conditions and be strong enough for deployment using a helicopter.

(4) Instrumentation can be mounted on the module itself; for medium and large stations, standard towers could be added for instruments and sensors.

(5) Specially fabricated parts are not needed. All parts are commercially available and offered in various sizes, which simplifies scalability of the whole system.

(6) The frame-based design allows for the use of different materials for different environments and module sizes. For example, for milder locations and small modules, the aluminum pipes could be substituted by PVC pipes.

(7) Small- and medium-size stations can be set up easily and the entire module is transportable, albeit larger units may require additional design criteria focusing on weight.

(8) All components (e.g., solar panels, regulators, batteries) are colocated, which significantly reduces and simplifies wiring and maintenance. Furthermore, the system takes less space at the experimental site because of the simplified design.

Figure 1 View of Council site.

In this article, the authors describe this system, along with data communication capabilities, and highlight how the system is currently used in the context of the NGEE Arctic project. Portability, power requirements, and year-round operation of the system are analyzed, especially throughout the winter when solar radiation becomes a critical system limitation. While the system has worked as designed and as planned, lessons learned are presented and discussed so as to continually optimize system design and deployment criteria.

2 Power calculations

The first task in designing the energy module was to calculate the power requirements for the whole system, which determined the sizes and number of solar panels and battery banks that dictate the general size of the module.

To calculate the size of the solar panels, the following parameters were used:

(1) Power ratings of all components (e.g., instruments, sensors, heaters)

(2) Number of hours per day when equipment would run

(3) Average number of sun hours

Device power consumption (*DP*) can be obtained from a specification or directly from a manufacturer. The required number of hours per day for the device to run (*Dh*) were calculated for each component because in some cases, different pieces of equipment might require different run times. For example, telemetric equipment will only be on for enough time to transmit parameters and then will be off until the next transmission time. The average daily sun hours (H_{avg}) in units of $kWh \cdot m^{-2}$ per day differ based on geographical location and are published by many sources; for example, for the United States, average daily sun hours can be found from maps produced by the National Renewable Energy Laboratory (Roberts, 2018) (Figure 2). Also, internal inefficiency of a charge controller and other internal losses (*IL*) must be considered. We estimated the efficiency as 85% and IL = 1.15. The final calculation can be made by using Eq. (1):

$$TP = ((DP_1 \times Dh_1) + (DP_2 \times Dh_2) + \cdots (DP_i \times Dh_i)) / H_{avg}) \times IL \tag{1}$$

The resulting number is the total power (*TP*) required to be produced by the solar panel (s). The number of panels can be calculated by dividing the *TP* by the panel power rating, which will allow for the choice in the number of panels best suited for a particular installation. Either many small panels or few big panels might be preferred.

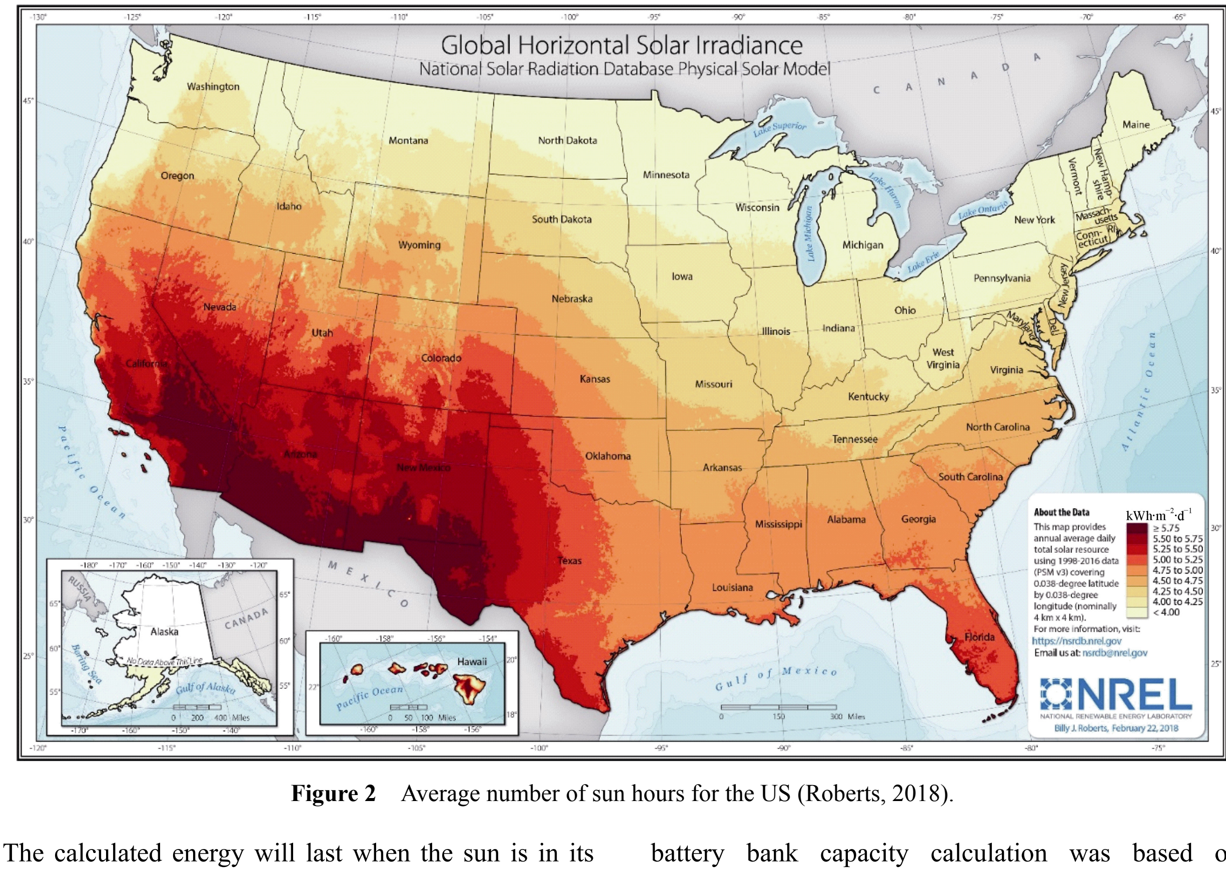

Figure 2 Average number of sun hours for the US (Roberts, 2018).

The calculated energy will last when the sun is in its peak hours, diminish on cloudy days, and totally dissipate at night. This means that energy must be stored to allow equipment to run during nonpeak performance hours. The battery bank capacity calculation was based on the following parameters:

(1) Power ratings for all components

(2) Number of hours per day when equipment should run

(3) Days of autonomy
(4) Temperature coefficient
(5) Maximum discharge rate
(6) Voltage of the whole system

DP and *Dh* are the same numbers used in solar panel calculations. Days of autonomy (*DA*) is the amount of hours desired for the system to run if there is no input from the panels, for example, if there are several cloudy, rainy days when there is minimum or no input from solar panels. This number depends on geographical location, particular preferences, and requirements for each case. The location will also dictate the temperature coefficient (*TC*). The chemical reactions that occur within batteries vary with temperature—colder temperatures have a negative effect on the battery bank capacity and its charging ability (Misra and Williamson, 1996). These variations cause a battery charged or maintained at standard voltages to be undercharged in cold environments and significantly reduces the lifetimes of battery banks. Battery lifetime is especially important for places with very low temperatures, such as the Arctic, and must be considered. Temperature coefficients are usually published by battery manufacturers. The *TC* used for the calculations must correspond to the coldest average temperature expected in the area, which occurs for at least a few days in a row. Maximum discharge rate or depth of discharge (*DoD*) is how deeply the battery bank will be allowed to discharge. Flooded lead acid batteries, sealed Absorbent Glass Mat batteries, and sealed gel batteries are all rated in terms of charge cycles. The further a battery is discharged, the fewer cycles that battery will be capable of completing, and the shorter the battery life will be. Voltage (*V*) of the system is a factor determined by the voltage required for most devices. In this case, scientific instrumentation and communication equipment required 24 V and 12 V. The authors decided to run the whole module on 24 V because internal losses involved in converting the voltage to 12 V were less than those from modifying the 12 V instrumentation to run directly from 24 V. By using all the numbers given, the final battery bank capacity (*Ah*) expressed in amp hours, can be calculated by Eq. (2):

$$Ah = \frac{\left(\dfrac{(DP_1 \times Dh_1) + (DP_2 + Dh_2) + \cdots + (DP_i + Dh_i))}{V}\right)}{DoD} \times IL \times DA \times TC \tag{2}$$

The calculated number allows for the choice in size and number of batteries required. Based on that calculation, the size of the enclosure(s) needed to protect the batteries from the environment is decided.

3 Mechanical design

With all the dimensions together (solar panels, battery enclosures), the general layout of the system was composed; then, the authors proceeded with mechanical design. Considering the harsh winter conditions in the area (high humidity, high wind), structural aluminum pipes grade 6063 were chosen (Davis, 1993). This material type is commonly referred as architectural alloy. Architectural alloy is designed as an extrusion alloy with relatively high tensile properties, excellent finishing characteristics, and high corrosion resistance. Resistance to corrosion is imperative because the proximity to the Bering Sea (~36 km away) and the presence of salt in the air form a very aggressive and humid setting. These pipes are widely available, have moderate costs, and come in different sizes. For this installation, standard 48 mm outside diameter (1½ in. iron pipe size) pipes were used. Pipes of this size can form a structure strong enough to withstand the weight of the battery banks and can be easily used with available structural fittings. The authors used Kee Klamp fittings, which are commonly used in the construction of handrails and barriers. They have high corrosion resistance, can support an axial load up to 907 kg (2000 lb) per set screw (Kee Safety, 2018), and are very easy to install. For small modules and conditions that have fewer restrictions, PVC pipes can be used. They are light, very easy to work with, and available in many sizes. Because the primary use of this module is in the Arctic region of Alaska, where the day length and sun time during winter months is very low, a wind turbine was added as an additional source of power. Detailed information about the area of deployment is presented in Figure 3. Most of the available small-scale (less than 1 kW) turbines have a cut-in wind speed around 3–5 $m \cdot s^{-1}$ and a nominal wind speed around 11–13 $m \cdot s^{-1}$. Figure 3 shows that even in the winter, the average wind speed for Nome, Alaska remains high enough to generate power and keep equipment running. In calm periods with no wind, days of autonomy were foreseen when general power requirements were calculated.

After evaluating many available wind turbines, the authors selected a Superwind 350 model that was designed for tough conditions, can withstand strong crosswinds, and has a good performance curve (Figure 4) (Superwind, 2016). This model has a regulator that does not require additional power. It works as soon as the turbine can provide a high enough current and can easily integrate with other equipment. A broadly accurate principle for wind turbine placement is the higher the better, although that is not always practical. For this construction, the turbine mounting pole was placed on a standard Rohn 25G 3 m tower (Rohn, 2015). The height of the tower plus the length of the mounting pole allowed the turbine to be positioned at a 5 m height and allowed convenient service access by lowering the pole. Rohn 25G is a triangle tower made with tubes that can mount it to the module frame. Figure 5 shows the general overview of the designed module.

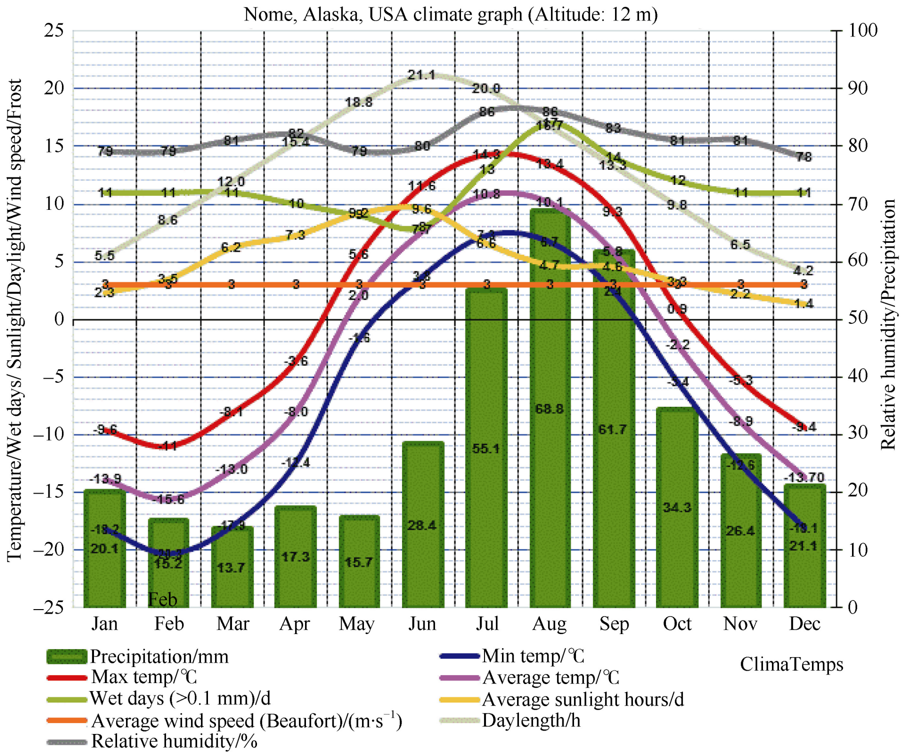

Figure 3 Nome, Alaska annual averages (World Climate and Temperature, 2019).

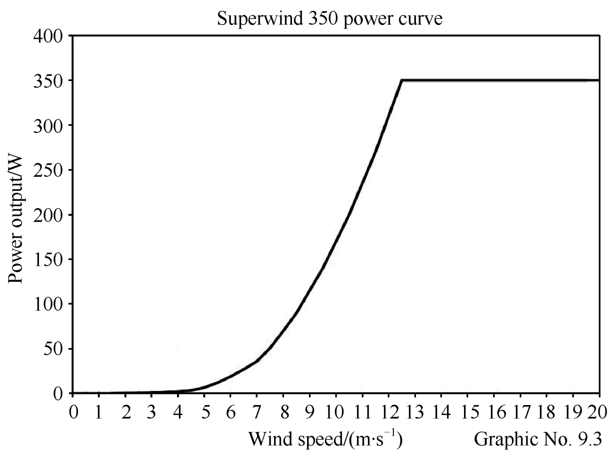

Figure 4 Superwind 350 power curve.

4 Electrical design

The electrical design of the module is depicted on Figure 6 and was based on the following commercially available components:

(1) The Morningstar TriStar TS-60 solar charge controller limits the rate at which an electric current is added to or drawn from electric batteries. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifespan. It also has Modbus communication capabilities (Morningstar Corporation, 2017) and can be integrated with other monitoring equipment.

(2) The Superwind charge controller plays the same role as the solar charge controller but is based on the wind turbine input. When the batteries have reached their maximum charging voltage, the circuit automatically diverts the wind turbine's surplus power to the diversion resistor block or dump resistor. Because this module was intended to function in a low-temperature location, the authors placed two dump resistors in battery boxes, to utilize an excessive amount of electricity possibly produced by the wind turbine to heat the battery boxes and keep the batteries warm. Notably, after one of these modules was deployed, a third resistor had to be added and was placed outside. With several consecutive days of wind more than 6 m·s^{-1}, the temperature inside the boxes reached up to 50 ℃. To prevent overheating, datalogger redirects the current to the third resistor (it was introduced later) when the inside temperature is more than 25 ℃.

(3) The Campbell Scientific CR6 datalogger monitors solar charger parameters, collects environmental information from outside sensors (temperature, humidity, wind speed, wind direction), and, as previously mentioned, helps prevent the batteries from overheating.

(4) A 24–12 V converter provides 12 V power for environmental sensors specific to this particular implementation.

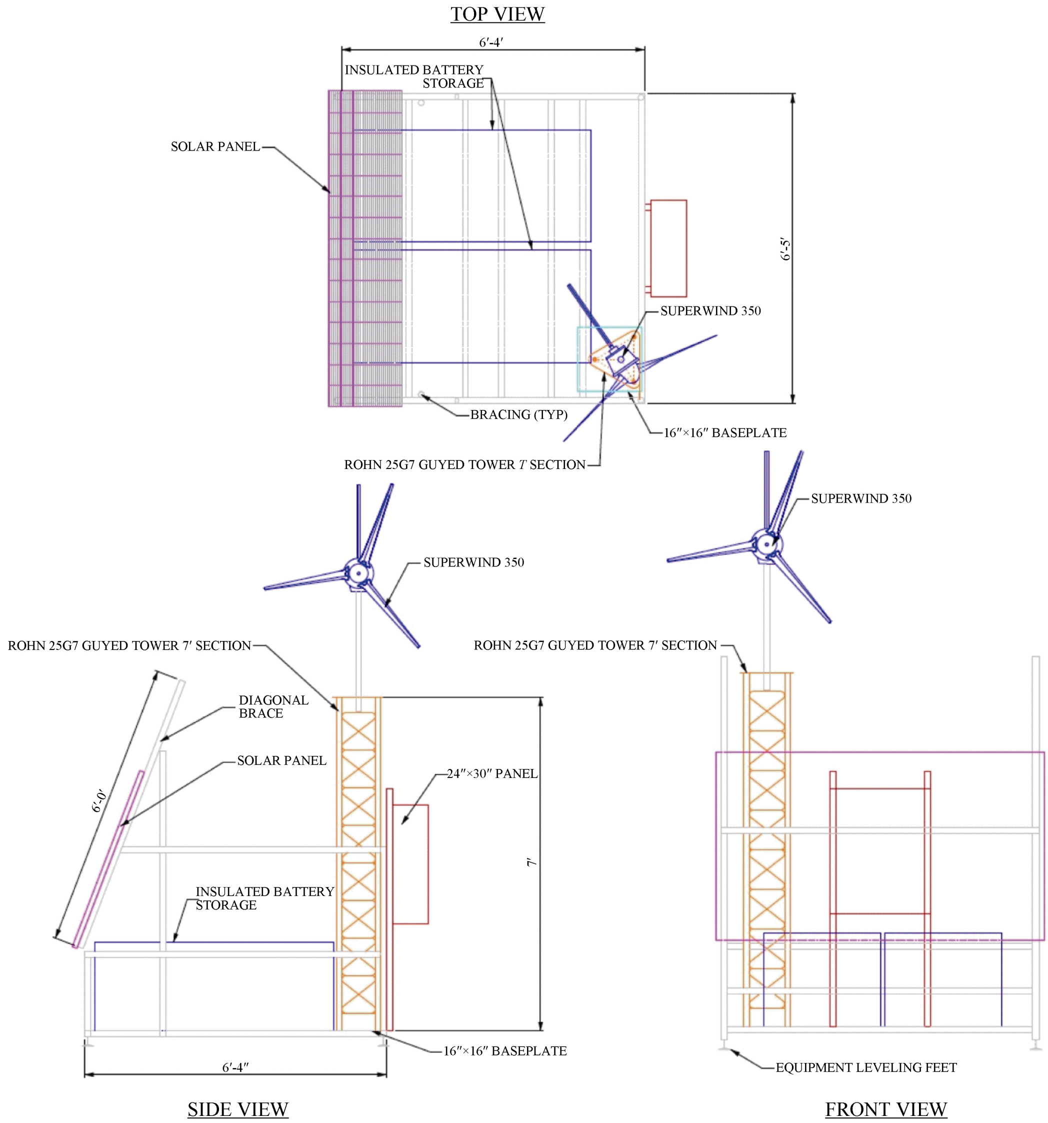

Figure 5 Module with mounted wind turbine.

(5) An Ethernet switch is used for communication equipment connections (remote monitoring and telemetry transmission). It is also specific to this particular installation.

5 Communications and data collection

Communication capabilities were one of the major components foreseen in the initial design for this installation. Monitoring the functional parameters of the modular and the environmental conditions around the communication equipment is imperative for diagnostics, not only for the module itself but also for scientific instrumentation that receives power from it. Monitoring can also provide valuable input for future improvements and upgrades. After communication capabilities of the installation area were surveyed, the closest place to set up internet access was found in a settlement ~19.75 km away in a straight line southeast of the experimental site (White Mountain, Alaska). Modern communication equipment can communicate point to point for distances more than 40 km in the line of sight, but in this case, a nearby mountain ridge (~9.75 km away in a straight line) blocked the line of sight. Therefore, an additional module was set up on the top of the ridge and was used as a repeater to pass the signal from the site to White Mountain. Figure 7 shows the signal path between all communication points. The satellite link at White Mountain was the only available internet access option in that region; it was slow, had low bandwidth, and was expensive. The individual experiments generate large amounts of data, up to 4 MB per hour in the case of the eddy covariance station, so the satellite link is only used for control and monitoring functions. The data is transferred from the site only to the server at White Mountain and retrieved from there manually. White Mountain is a village easily accessible year-round by scheduled flights from

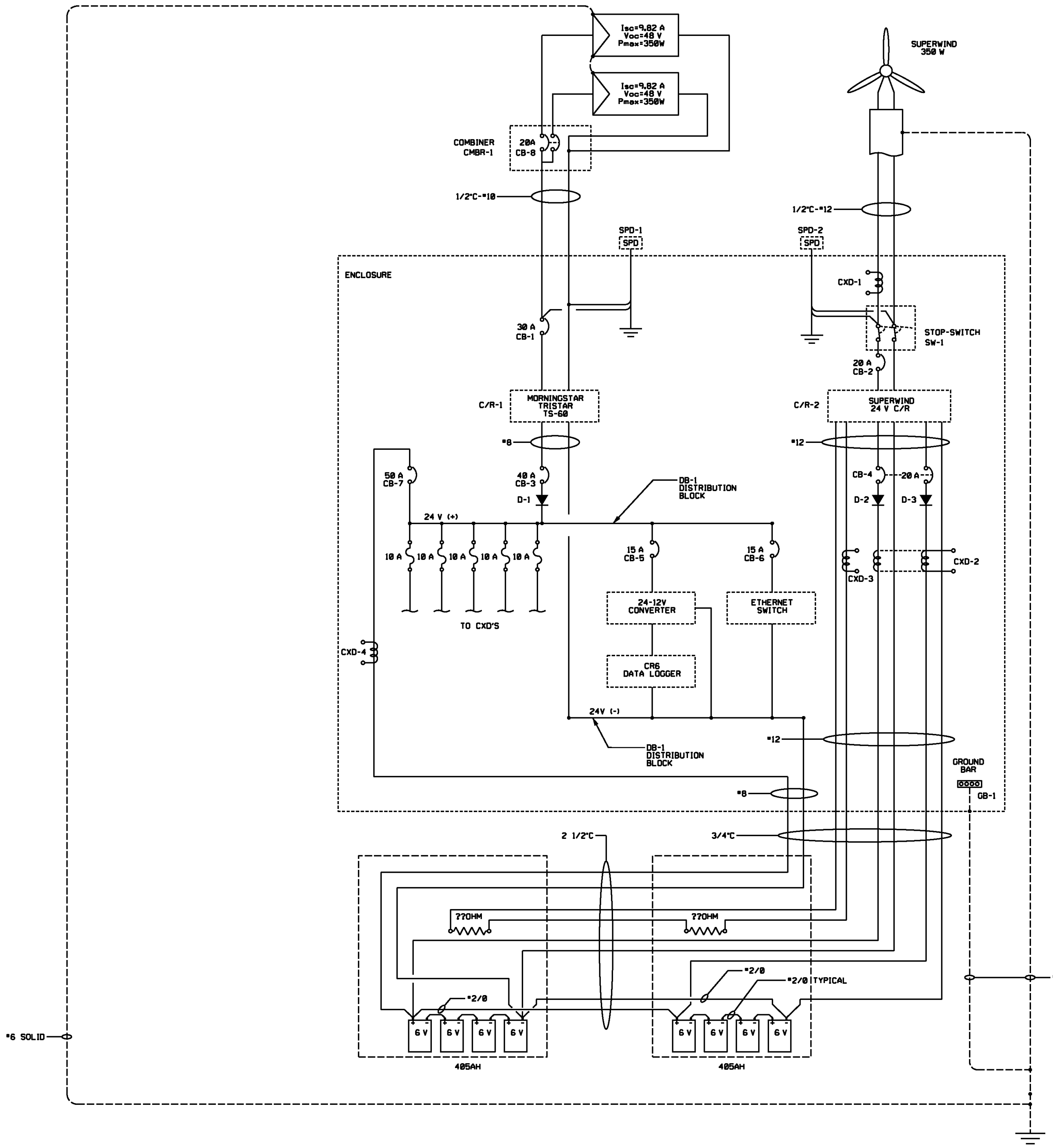

Figure 6 Power system diagram.

Nome, Alaska. It has an airport utility building, where the server was installed (Figure 8). Since all modules and instruments had Campbell Scientific dataloggers, LoggerNet server software was deployed, which enabled automated data collection and real-time access to telemetry from computers (Figure 9) and mobile devices. Ubiquiti PowerBeam PBE 5AC 620 dishes were used for communication between the site module, repeater module, and server at White Mountain. This communication capability and the ability to constantly monitor performance of the modules and data collection processes allowed the authors to not only generate scientific data sets of excellent quality, but also create data sets combined from telemetry and environmental data. These data sets can be used to study correlations between module performance and environmental conditions, which allowed the authors to

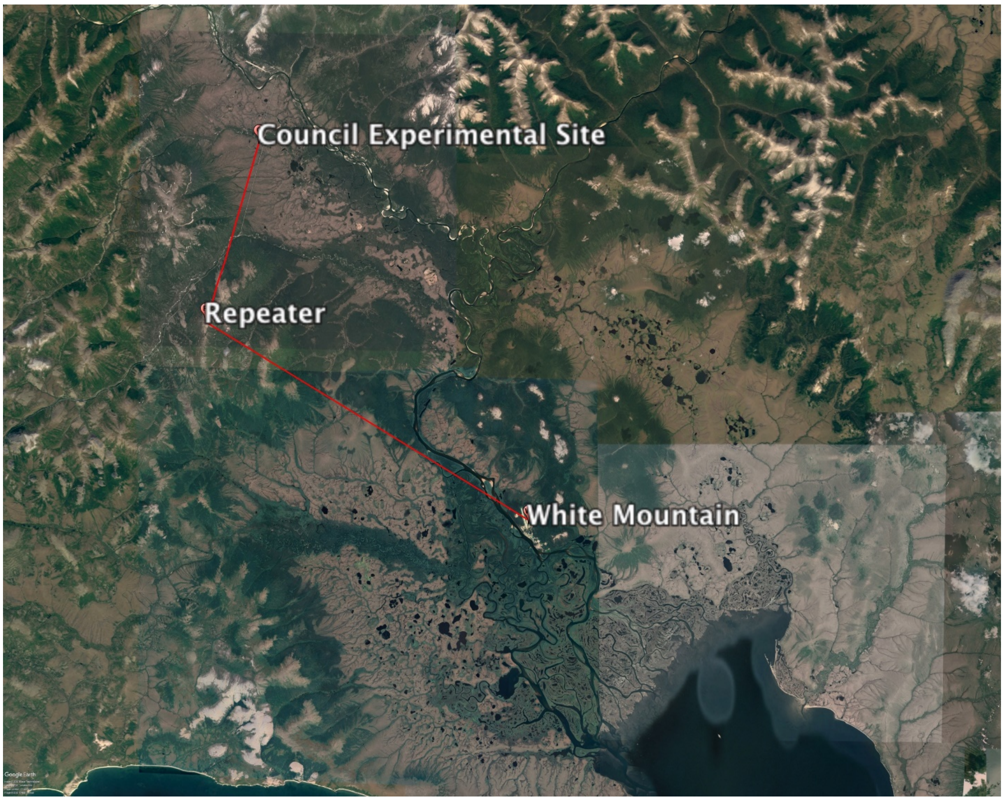

Figure 7 Communication signal path.

Figure 8 Data collection and access server at White Mountain, Alaska.

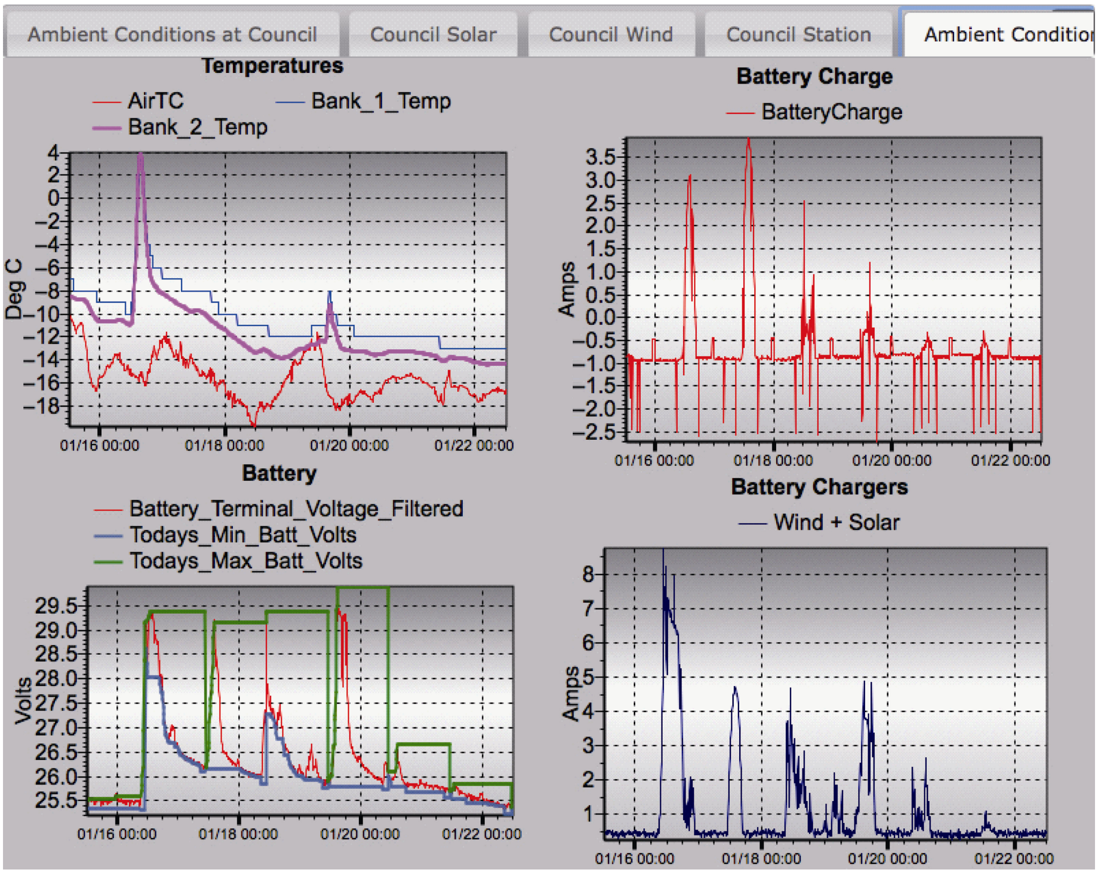

Figure 9 LoggerNet real-time monitoring and CONTROL software.

Figure 10 Council experimental site module.

make some improvements in the hardware as discussed in Section 6.

6 Implementation and lessons learned

As mentioned, in Section 1, the module was designed for the NGEE Arctic project with known instruments and capabilities. Two modules were built. The first module was set up at an experimental site located in the tussock tundra of the Seward Peninsula. This first module provided power for methodological and eddy covariance stations and communication equipment. Both stations and communication equipment required about 60 W of power and ran year-round. Heat exchange had to be prevented to preserve the permafrost and prevent sinking. Therefore, the module was elevated about 1 m from the ground and set up on stainless steel poles. The poles were thermo-insulated and penetrated 1 m into the ground, using the permafrost as their foundation (Figure 10). The second module was set up at the top of a nearby mountain and served as a repeater to pass telemetry and collect data to White Mountain, Alaska, where internet connectivity was available. It provided power for communication antennas and basic meteorological sensors (temperature, humidity, wind speed and direction). The total power consumption for the second module was about 30 W and most of it was used by the antennas (Figure 11).

Both modules were set up in June 2018 and proved their reliability and functionality through the winters of 2018/2019 and 2019/2020. During these periods, the performance of both modules was observed, and two modifications were added:

Figure 11 Repeater module.

(1) External resistor for power dump—As mentioned in Section 4, the authors used two dump resistors, placed them in battery boxes, and used excess electricity to heat the battery boxes. Because of significant amounts of wind, so much extra electricity was produced by the repeater (module on the top of the mountain) that the temperature inside the boxes sometimes rose above 50 ℃. The authors added a solid-state relay, outside dump resistor, and programmed datalogger to turn on the outside resistor if temperature inside the boxes rose above 25 ℃.

(2) Ability to turn loads on/off remotely—Initially, all instrumentation that received power from the experimental site module was hard-wired and could not be turned off and on remotely, so that ability was added based on two factors. First, all instruments used on the site were controlled by dataloggers and, like any other computer, they sometimes needed to be rebooted. Second, in the winter period of very little sun and wind, noncritical instrumentation was turned off, to save the electricity of the batteries, by adding solid-state relays controlled by the datalogger program.

The meteorological data collected by both modules is available as a public data set (doi: 10.5440/1529604) and can be accessed at the NGEE Arctic website (http://ngee-arctic.ornl.gov).

7 Conclusions

New climate change studies and research will require more work and observations in remote locations where no infrastructure exists. The demand for data from isolated regions with extreme conditions is growing and needs reliable setups for instrumentation, sensors, and data acquisition systems, which all require reliable alternative power sources based on solar and wind energy. Here, the authors share their experience of and lessons from designing such a system in the form of scalable power modules that are used in the extreme Arctic environment of Alaska. The authors hope this research will benefit other studies and researchers facing difficulties of powering equipment in other remote and harsh locations.

Acknowledgments This research is supported by the US Department of Energy, Office of Science, Biological and Environmental Research (BER) and conducted at Oak Ridge National Laboratory (ORNL), managed by UT–Battelle, LLC, for the US Department of Energy under contract DE-AC05-00OR22725. This paper has been authored by UT–Battelle, LLC, under contract no. DE-AC05-00OR22725 with the US Department of Energy. The publisher, by accepting the article for publication, acknowledges that the United States Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this paper, or allow others to do so, for United States Government purposes. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan, last access: 13 June 2018).

References

Cable W L, Romanovsky V E, Jorgenson M T. 2016. Scaling-up permafrost thermal measurements in western Alaska using an ecotype approach. Cryosphere, 10(5): 2517-2532, doi: 10.5194/tc-10-2517- 2016.

Crépin A S, Karcher M, Gascard J C. 2017. Arctic Climate Change, Economy and Society (ACCESS): integrated perspectives. Ambio, 46(S3): 341-354, doi: 10.1007/s13280-017-0953-3.

Davis J R. 1993. Aluminum and aluminum alloys. Ohio: Materials Park, ASM International.

Fisher J B, Hayes D J, Schwalm C R, et al. 2018. Missing pieces to modeling the Arctic-Boreal puzzle. Environ Res Lett, 13(2): 020202, doi: 10.1088/1748-9326/aa9d9a.

Kane D L, Stuefer S L. 2015. Reflecting on the status of precipitation data collection in Alaska: a case study. Hydrol Res, 46(4): 478-493, doi: 10.2166/nh.2014.023.

Kee Safety. 2018. Kee Klamp technical specifications. https://www.keesafety.com/products/kee_klamp#techdetails.

Misra S S, Williamson A J. 1996. On temperature compensation for lead acid batteries in float service: Its impact on performance and life. Proceedings of Intelec'96−International Telecommunications Energy Conference, Boston, MA, USA. IEEE, 25-32, doi: 10.1109/INTLEC.1996.572374.

Morningstar Corporation. 2017. TriStar solar charging system controller: installation, operation and maintenance manual. https://2n1s7w3qw84d2ysnx3ia2bct-wpengine.netdna-ssl.com/wp-content/uploads/2014/02/150V-TS-MPPT-Operators-Manual.pdf.

Roberts B J. 2018. Global horizontal solar irradiance. National renewable energy laboratory. https://www.nrel.gov/gis/assets/images/solar-annual-ghi-2018-usa-scale-01.jpg.

Rohn Products. 2015. Product catalog No. 3. http://www.rohnnet.com/files/2015_Rohn_Full_Catalog.pdf.

Superwind. 2016. Superwind 350 12 V & 24 V manual. North, central, & South American regions. https://www.superwind.com/wp-content/ uploads/2018/05/Superwind350-Manual-12V-24V-09-01-2016-Final.pdf.

World Climate and Temperature. 2019. Climate graphs for Nome, Alaska. http://www.nome.climatemps.com/graph.php.