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A Solar Photovoltaic Power System for Use in Antarctica

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Abstract

A solar photovoltaic power system was designed and built at the NASA Lewis Research Center as part of the NASA/NSF Antarctic Space Analog Program. The system was installed at a remote field camp at Lake Hoare in the Dry Valleys, and provided a six-person field team with electrical power for personal computers and printers, lab equipment, lighting, and a small microwave oven. The system consists of three silicon photovoltaic sub-arrays delivering a total of 1.5 kWe peak power, three lead-acid gel battery modules supplying 2.4 kWh, and an electrical distribution system which delivers 120 Vac and 12 Vdc to the user. The system was modularized for ease of deployment and operation. Previously the camp has been powered by diesel generators, which have proven to be both noisy and polluting. The NSF, in an effort to reduce their dependence on diesel fuel from both an environmental and cost standpoint, is interested in the use of alternate forms of energy, such as solar power. Such a power system also will provide NASA with important data on system level deployment and operation in a remote location by a minimally trained crew, as well as validate initial integration concepts.

Introduction

The remote and hostile nature of the Antarctic environment presents NASA with an opportunity to test and verify proposed approaches to planetary surface systems and operational techniques for future planetary missions. The U.S. Antarctic Program, sponsored by the National Science

Foundation, could in turn benefit from systems that would increase efficiency, reduce cost, and minimize environmental impact.

In support of the NASA/NSF Antarctic Space Analog Program, begun in December 1990, the NASA Lewis Research Center (LeRC) became involved in the design and construction of a solar photovoltaic power system for use at a remote site camp at Lake Hoare in the Dry Valley region of Antarctica.

The camp supports a small team of researchers during the austral summer. Power is required to operate laboratory equipment, lights, personal computers and printers, and a small microwave oven. In the past, power has been supplied to the camp by diesel generators. Although the generators have proven to be a reliable power source, there are some drawbacks which must be addressed. From both an economical and environmental standpoint, the NSF would like to reduce their dependence on generators due to the high cost of transporting diesel fuel and the possibility of fuel spills. Also, the noise and exhaust fumes produced by the generators have been unpleasant for the researchers living at the site.

At the request of the researchers and under the auspices of the NASA/NSF Antarctic Space Analog Committee, NASA LeRC initiated a study to look at the feasibility of using solar power at the Lake Hoare site. In May 1991, NASA LeRC was given the authority to design and build the system. The system was installed and used on the ice during October and November, 1992.

Requirements

Since the power consumption at the site was largely unknown, the system power requirements were based on the past experience of the team at the site. It was determined that the initial system should provide a baseline 0.5 kWe from a solar array and 2.4 kWh energy storage. It was also requested that both ac and dc power be made available to the site. An ac distribution system was in place at the site; however, provisions for dc distribution were required.

Since the system was to be installed by the field team, with minimal training and under adverse weather conditions, a simple design was preferred. In particular, it was recommended that the number of bolted and hardwired connections to be made at the site be kept to a minimum, and that the system components be easily manipulated while wearing heavy gloves. Finally, volume and mass constraints imposed by the NSF for shipping purposes had to be met.

Environmental Factors

In addition to the power requirements for the system, various environmental factors were taken into account in the design. The photovoltaic array area was dependent on the insolation at the site. The anticipated solar flux at Lake Hoare during the period of operation (late October through November) was determined through the use of a computer code developed by Gary Clow of the U.S. Geological Survey (1). The code calculates the instantaneous and average solar flux on a horizontal surface for one diurnal period based on data gathered at an automated meteorological station at Lake Hoare. Based on this code, the average daily flux on a normal surface was found to range from approximately 350 to 950 W/m^2. This flux includes shadowing effects from surrounding mountains and glaciers as well as atmospheric attenuation.

Ambient temperature was also a consideration in the design, both from the standpoint of battery lifetime and array output voltage. Expected temperatures in the region for the period of operation ranged from -15 °C to 0 °C. Finally, the sub-array structures were designed to withstand winter winds of 25 m/s, which would allow the sub-arrays to remain outdoors during the winter, if desired. Typical summer winds range from 0 to 8 m/s (2).

System Description

The power system consists of three photovoltaic sub-arrays, a field junction stand, three battery modules, an instrument and control rack (ICR), and two dc power supplies. Figure 1 shows one of the sub-arrays with the balance of the system components. Each of these will be discussed in turn in the following sections. In order to minimize the number of hardwire connections to be made at the site, the modules were pre-wired before shipping and connections between modules were made with plug-type connectors. This design approach not only made for easier installation, but also reduced the risk of electric shock by protecting the field team from exposure to potentially hot wires. The only hardwired connection made was between the power system and the existing ac distribution system at the site. The modular design approach also allowed for portability of the system from the drop site to the installation point.

Photovoltaic Sub-arrays

The basic component of a solar power generation system is the solar module. The modules used for this particular application are Siemens Solar Industries M55 solar modules, consisting of 36 single crystal silicon solar cells connected in series. Each module is rated at 53 W (3.05 A, 17.4 Vdc) at 25 °C and 1000 W/m^2 incident solar radiation. At an operating temperature of -15 °C, the expected cell performance is 62 W (3.2 A, 19.3 Vdc). Eight of the modules are integrated into a sub-array. The modules are electrically connected in series and terminated within a sub-array mounted fused disconnect. As a result, a single electrical connection is provided from each sub-array via this fused disconnect. Three individual sub-arrays are electrically connected in parallel at the field junction stand resulting in a full photovoltaic array.

Figures 2 and 3 show a sub-array when fully deployed, viewed from the front and back respectively. The sub-array structures are designed to be easily and quickly deployed without the use of tools and to be structurally rigid to withstand harsh environmental conditions. The sub-array structures are constructed of aluminum with stainless steel components used for fasteners, hinges and miscellaneous hardware. This material selection allows for reduced structural weight and corrosion resistance. The four inner modules are mounted on a rotating sub-array base. The remaining four modules are mounted on two hinged, fold-out wings of two modules each. For shipping and storage purposes, each end pair of modules folds in on the inner modules. Figures 4 and 5 show the sub-array in its stowed configuration. To deploy the modules, the wings are folded out and a hinged support arm is lowered and mated with a support tongue on the wing. The connection is secured with a locking pin. Each sub-array has four hinged legs which fold upward for shipping. When deployed, the legs provide a large stable base and a location from which to secure the structure to the ground.

The solar modules are angled at 70° from the horizontal. This angle provides the best average output power for the 10° to 30° range of solar elevation angles experienced at the site during the period of operation. In order to track the circumpolar movement of the sun, the sub-arrays are designed to be manually rotated. Each sub-array is to be turned every six hours by depressing a foot lever on the rotating base of the sub-array and turning the sub-array 90°. A locking mechanism in the base secures the sub-arrays from inadvertently being turned by wind gusts or other means. Manual tracking was chosen over automatic tracking due to reliability concerns associated with complex mechanisms in harsh environmental conditions. Since the sub-arrays are not designed to track continuously, the power output of the sub-arrays will show a cosine variation. At the minimum, the power output from the array will be approximately 0.5 kWe, while at the peak, the array will provide approximately 1.5 kWe.

Battery Modules

Batteries are required on the electrical bus to provide stabilization during current surges and also to provide power during shadow periods. The battery storage system consists of 10 sealed lead-acid gel-electrolyte batteries connected in series to provide a nominal 120 Vdc on discharge. The cell capacity is rated at 80 AH at the 20 hour discharge rate at room temperature. The batteries chosen for this system are Dynasty GC12V80 batteries manufactured by Johnson Controls.

The system is designed to provide 2.4 kWh of storage. At room temperature the system is capable of delivering 9.6 kWh at the 20 hour discharge rate. Providing the required 2.4 kWh results in operation at 25% depth-of-discharge (DOD). However, the battery capacity must be derated for low temperature operation at-15 °C to 0 °C. At -15 °C, the cell capacity is reduced to 48 AH, which is 60% of the room temperature capacity; therefore, the DOD is effectively increased to 42%.

The batteries are configured into three modules: two consisting of three batteries each and one consisting of four batteries. A three-battery module is shown in Figure 6. The batteries within each module are connected in series to provide a nominal 36 Vdc and 48 Vdc, respectively. The modules are further connected in series to achieve the 120 Vdc battery subsystem.

The battery module enclosure is made of aluminum to minimize weight. A layer of styrofoam between the enclosure walls and the batteries provides thermal insulation. Connections between modules are made via Supercon connectors installed through the walls of the enclosures. These connectors were chosen for the inherent safety feature of shrouded contacts so as to minimize the risk of electrical shock.

Field Junction Stand

The field junction stand serves as the electrical junction point for the sub-arrays. At this junction, the individual sub-arrays are electrically connected in parallel and the array output power routed to the ICR. The sub-array/field junction connection is made via Hubbell twistlock connectors to eliminate the need for a hardwired connection to be made in the field. For each sub-array, there is an associated non-fused disconnect box (max. rating 250 Vdc and 30 A) mounted on the stand, which isolates the sub-array from the rest of the bus for servicing. The output of each disconnect box is fed to a terminal strip in a weatherproof junction box. A #10 AWG cable is hardwired into the junction box and delivers power from the array to the ICR.

Instrument and Control Rack

The ICR is a single-site structure used to provide main power bus interconnects, circuit protection, battery charge/discharge control, ac/dc supply connections, and data display and acquisition.

The photovoltaic array and battery power connections are made at the ICR. The array connection is made via a Hubbell twistlock plug and receptacle. The battery connection is made via a Supercon connection. Two 2-pole, 250 Vdc, 15 Adc circuit breakers connect the array and battery to the main bus. Battery state-of-charge is regulated through the use of a battery charge controller (BCC), manufactured by Photocomm, Inc., and mounted on the side of the ICR. The BCC uses a series regulator to control the battery charge/discharge state. Circuit protection for the BCC is provided through the use of 10 A, time-delay fusing.

A utility-type ac inverter is built into the ICR. The inverter, also manufactured by Photocomm, Inc., generates a quasi-sine output, 117 Vac(trms), 60 Hz from the main bus high voltage dc. The inverter is rated at 1.6 kVA, continuous duty. In terms of its circuit configuration, the inverter is directly wired to the main bus (i.e. battery). This allows the inverter to pull from the high current capacity of the battery during motor start-ups and other instances requiring high in-rush currents for very short periods of time. The inverter will operate through a range of dc input voltages. The typical dc input voltage is 125 ±15 V.

Two dc output connections are made through 3-pin receptacles. These receptacles provide a connection between the high voltage dc bus and the dc-dc power supplies. These receptacles are energized by a 2-pole, 250 Vdc, 15 Adc circuit breaker.

An ac power connection is provided by a special twistlock plug and receptacle. The receptacle, mounted on the ICR, is energized with the 117 Vac(trms), 60 Hz, quasi-sine output from the inverter, which is hardwired to this receptacle. A three-conductor, #10 AWG cable with a mating plug was provided to the user. This cable was hardwired into a double-throw disconnect to connect the photovoltaic system ac power into the existing on-site ac distribution system.

DC power supplies

In order to provide the user with 12 Vdc power, dc-to-dc converters were designed into a power supply package which provides dual outputs for a total of 72 W. These power supplies use Vicor Mega/Master Module single output dc-dc converters to convert a 150 ± 50 Vdc input to a 12 Vdc output at a conversion efficiency of 80 to 90%. Short circuit protection and current limitation are designed into the converter. Each supply uses two Vicor modules which provide 4 Adc and 2 Adc current capability to the user at 12 Vdc. A terminal strip allows the user to connect to the outputs of the dc-dc supply. Each output is independently fused with time delay fuses. The high voltage dc input is also protected with a 1.25 A, time delay fuse.

Results

The system was installed at the Lake Hoare site in October 1992 and operated through the duration of the field season, approximately five weeks. Favorable comments were received on the reliability of the power and on the simplicity of the design. Installation and deployment proceeded without problems.

Preliminary analysis of the system data shows that the array output voltage approached 180 Vdc, which was higher than expected, most likely due to lower than anticipated ambient temperatures (approximately -22 °C). This array output voltage exceeded the rated voltage of a gas discharge tube and metal oxide varistor in the BCC, causing them to fail. These devices are factory-installed standard equipment in the BCC and serve to protect the system from very high, short duration voltage/current spikes resulting from lightening strikes. The failure of these devices, which are not necessary for Antarctic applications, did not affect the operation or performance of the system. Also, during periods of full sun and light loading, a relay in the BCC was observed to rapidly open and close, again because the system was producing more power than was originally anticipated. This problem was solved in the field by off-pointing one of the sub-arrays when full power was not required. Additional system data was returned to NASA LeRC and is currently being analyzed. The BCC was also returned to LeRC for up-grade to accommodate the higher voltages.

Summary

A solar photovoltaic power system was designed and built at the NASA Lewis Research Center for use at a remote Antarctic field site. The system was installed and operated beyond performance predictions at Lake Hoare in the Dry Valleys in October/November 1992. Favorable comments were received from the field team, especially with regard to reliability and simplicity. Data analysis is currently underway at NASA LeRC.

Acknowledgments

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1. Clow, Gary D., Personal Communication, U.S. Geological Survey, Menlo Park, California.

2. Clow, G. D., McKay, C.P., Simmons, G.M., and Wharton, R.A., "Climatological Observations and Predicted Sublimation Rates at Lake Hoare, Antarctica," Journal of Climate, Vol.1, No.7, July 1988.

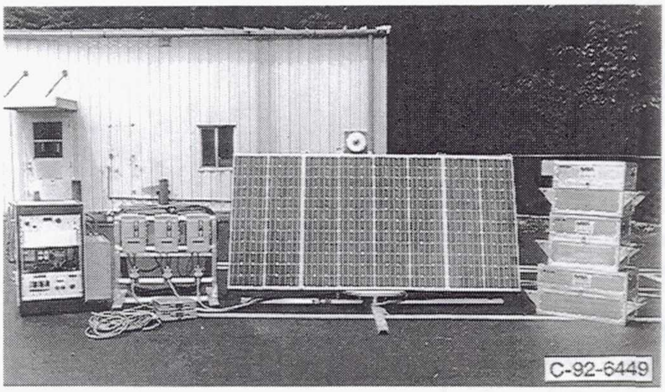

Figure 1.—Solar photovoltaic power system.

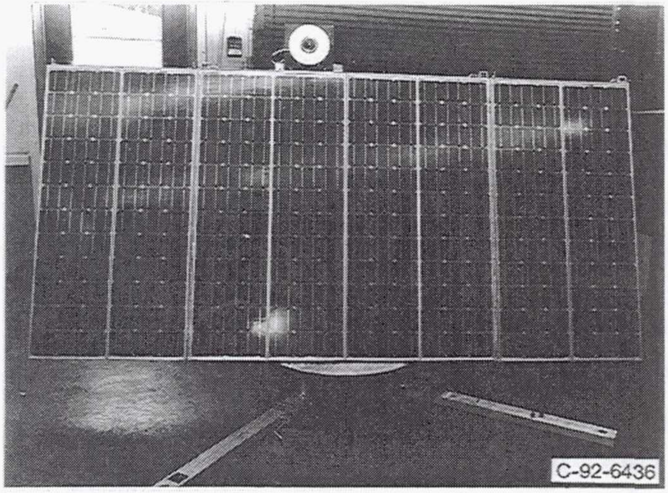

Figure 2.—Deployed sub-array (front view).

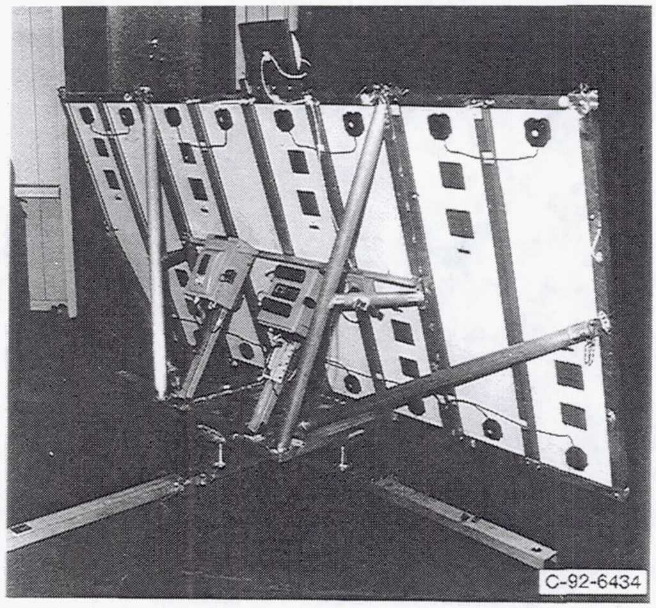

Figure 3.—Deployed sub-array (rear view).

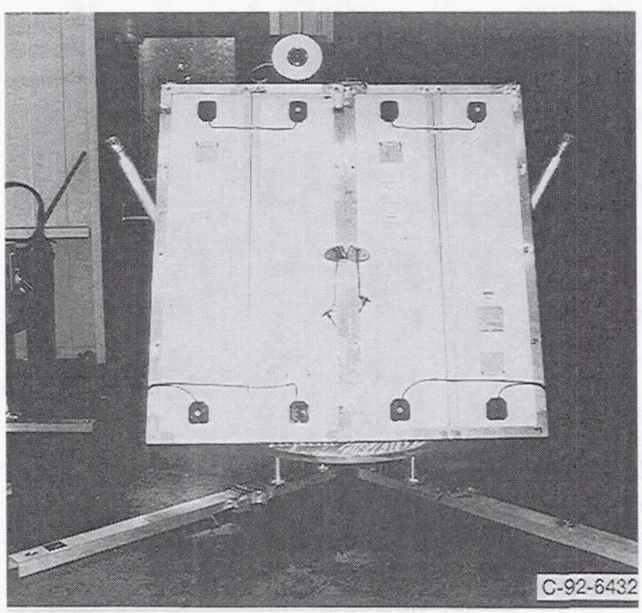

Figure 4.—Sub-array in stowed configuration (front view).

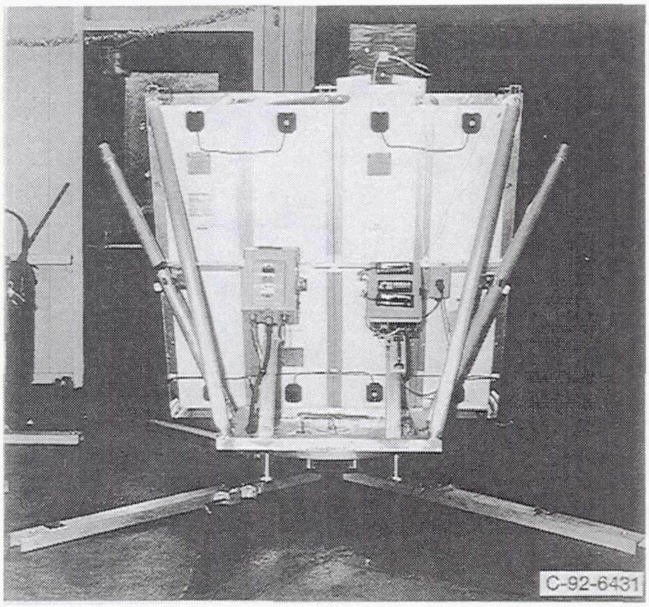

Figure 5.—Sub-array in stowed configuration (rear view).

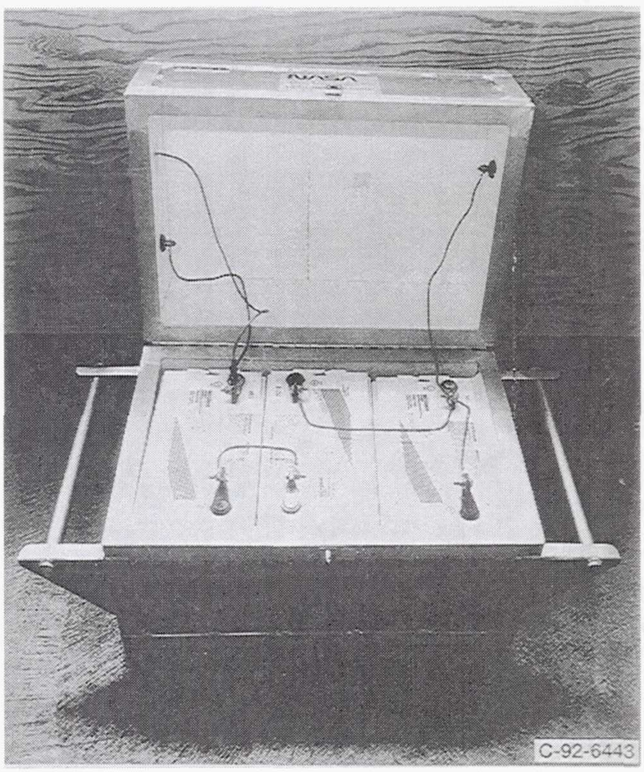

Figure 6.—Battery module.

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13. ABSTRACT *(Maximum 200 words)*

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