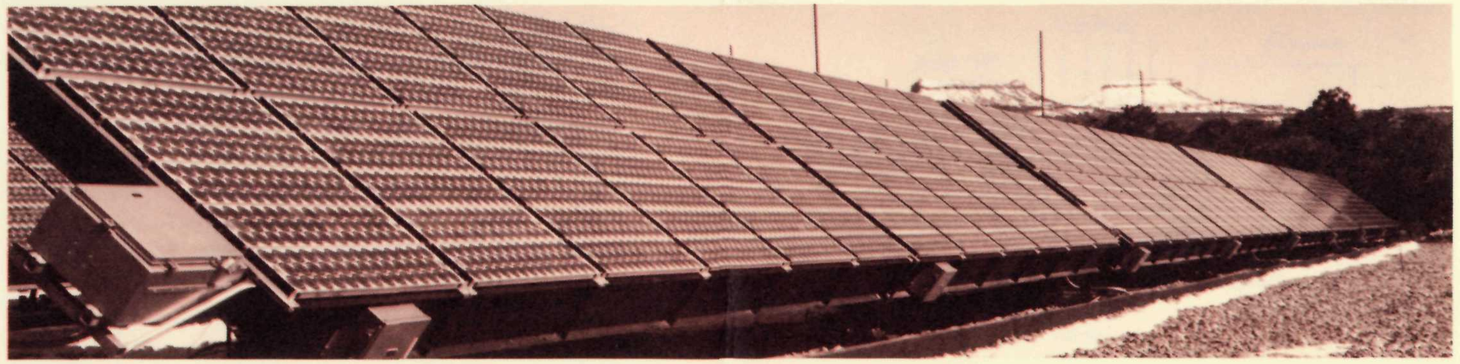

source and a form of storage. The diesel at NBNM drives the backup source, that is, the rotating generator, and the large, lead-acid battery provides energy storage. This battery has a rated capacity of over 750 kWh, although the maximum drawdown is limited to 600 kWh in order to increase its expected life. In further consideration of battery life, the drawdown in any one charge/discharge cycle is limited to 450 kWh, which is enough to operate the site for up to two days.

The cells in the battery are the familiar lead-acid type used in automobiles. Unlike car batteries, however, these cells are designed for "deep discharge" service. In addition to being a lot larger (each battery weighs over 2400 pounds), they have a number of unique characteristics. For example, each cell is equipped with a catalytic recombiner and an air-lift mixing pump. The catalytic device serves to recombine most of the hydrogen and oxygen that is produced during charge, particularly near full charge, and thereby to reduce the danger of explosion. The air-lift pump acts to mix the electrolyte within the cell and thus prevents the adverse effects that result from acid stratification during charging. Stratification is not a problem for automobile batteries, because the vehicle's motion ensures mixing.

The Array

The 100 kW(peak) PV array at NBNM is located on 1.3 acres just south of the Visitors' Center. Twelve rows of steel frames support glass-covered PV modules obtained from three different manufacturers. On the basis of power output, Motorola modules make up about half of the array, and ARCO Solar's (30%) and Spectrolab's (20%) modules constitute the remainder. Each module contains from 41 to 120 individual silicon cells.

Although the array frames have been provided with tilt adjustments to allow for maintenance and to accommodate summer and winter conditions, the frames were planned to remain year-round at a fixed angle of 30° (from horizontal). This angle yields the best overall average output for a site at the latitude (37.5°N) of NBNM.

For purposes of control, the array was divided into 48 separate electrical subfields of a little more than 2 kW(peak) each. Two 8- x 24-foot steel frames hold the modules that make up each subfield.

Power Processing Subsystem

The processing of electrical power from DC to AC is handled by two inverters. AC power for the majority of the NBNM loads is produced by a 40 kW/50 kVA single-phase main inverter; AC power for critical control, data, and alarm subsystems loads is produced by a 5 kVA UPS inverter. A dual-unit battery charger with a combined 40 kW rating is used to convert AC power from the diesel-powered generator to power for the DC bus. This charger incorporates a controlled ferroresonance power section, which has certain advantages in operating from a diesel-powered source. These advantages include a relatively pure 60 cycle AC current waveform and a near-unity power factor.

Control

An automatic control subsystem allows the PV system to operate for extended periods without intervention by NPS personnel. Its basic tasks are to control the battery charge when the battery is at or near full charge and to automatically initiate backup procedures when the battery state-of-charge drops to approximately 20% of full charge.

Near full charge, the controller will disconnect (shed) one or more of the 48 array subfields to prevent the occurrence of damaging overcharging. In contrast, when the battery charge drops to 20% of the full charge threshold, the automatic control will initiate a sequence that will start the backup diesel-powered generator. In the event that the diesel fails to start, the control will sound an alarm and shut down the main inverter, thereby dropping power to the site. However, the UPS inverter will continue to operate critical loads until the diesel can be started by NPS personnel.

Status

Solar PV was first used at NBNM on a test basis in February 1980. Following this test, work proceeded on completing the installation and checkout of the automatic control system, which became operational in May of that year. This, in turn, was followed by a period of acceptance testing, before the formal dedication on June 7, 1980. This date marked the beginning of routine operation. The performance of the system was scheduled to be monitored in detail by engineers at MIT Lincoln Laboratory for a number of years. These data were expected to suggest numerous improvements to systems of this type, so that in the future the NPS can make use of clean, quiet solar PV energy at other remote sites.

For further information, please write to: U.S. Department of Energy, Office of Solar Electric Technology, Forrestal Building, 1000 Independence Ave., S.W., Washington, D.C. 20585.

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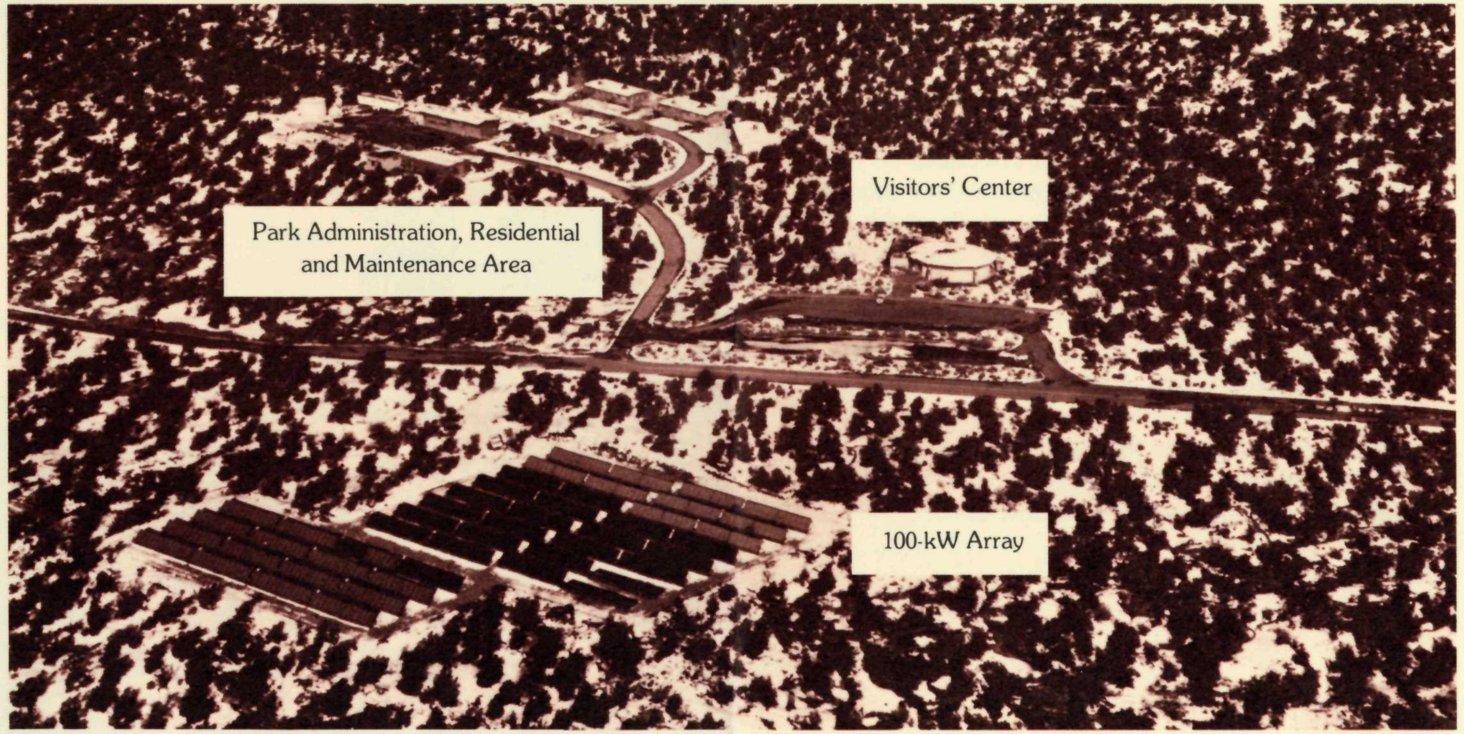
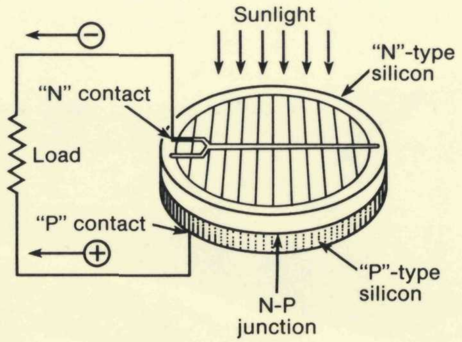
Introduction

MIT Lincoln Laboratory, under the sponsorship of the Department of Energy (DOE) and in collaboration with the National Park Service (NPS) of the Department of the Interior, in 1976 began to look for a National Park or Monument that would be a suitable site for the field test of a large, solar photovoltaic (PV) electric power system. After 63 remote sites were examined, the Natural Bridges National Monument (NBNM) in southeastern Utah was chosen. The factors influencing this decision included NBNM's remoteness from the public utility grid, its abundance of sunshine, the size and diversity of its electric loads, and its accessibility to the visiting public. After its dedication in June 1980, visitors were able to view the largest PV power system in the world.

Natural Bridges National Monument is situated at an elevation of 1980 meters (6500 feet) in the high, semi-arid country of southeastern Utah. A moderate climate and generally clear skies make NBNM an excellent location for a solar energy system. In the past, the headquarters area of the 7600-acre monument had obtained all of its electrical energy from a large, diesel-powered generator that operated continuously. After the solar PV power system began operating, the diesel was relegated to a backup role. This PV system offers a clean, quiet, safe, nonpolluting way to convert solar energy into electrical energy.

Before the PV system began operating, the site consumed up to 200,000 kWh of electric power annually, with a peak demand ranging from 10 to 40 kW. However, a portion of this energy was wasted as a consequence of the operational requirements placed on the diesel. Since the advent of solar PV power and the implementation of conservation measures, the site requires less than 150,000 kWh annually, and more than 90% of that comes from solar energy. As in the past, most heating and cooking needs continue to be met by a combination of liquefied petroleum gas and firewood.





A Silicon Solar Cell

How Does a Solar Cell Work?

The photovoltaic solar cells used in the NBNM project are made primarily of silicon, which, after oxygen, is the most abundant element in the earth's crust.

The front surface of the cell is coated with a thin grid of collector wires. These wires, together with a conductive back surface, provide the contact through which the power from the cell is delivered. The front surface is also covered with an anti-reflective coating.

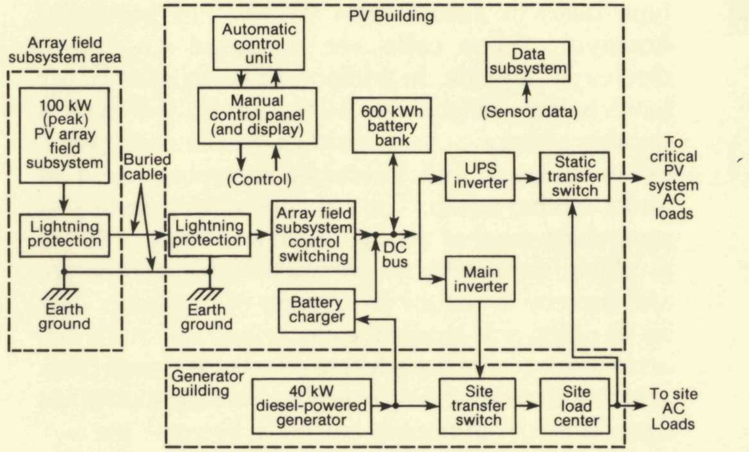
When sunlight shines on the cell, about 10% of the light energy is converted and released in the form of a flow of electrons, thereby establishing an electric current. Under ideal conditions, each 3-inch cell used at NBNM produces about one-half watt of power in the form of direct-current (DC) electricity.

System Description

In the NBNM system, there are about 256,000 2- and 3-inch silicon PV cells, each of which produces about 0.4 watt at noon on a clear day. These cells are connected in series/parallel strings and have a combined peak output that is nominally rated at 100 kW. Naturally, this value is reached only around noon, and the array's output is lower in the morning and afternoon.

The major components of the PV power system are shown in the accompanying diagram. Direct-current electrical power from the array is passed through lightning-protection devices and an underground cable to an array field switching subsystem. This subsystem allows portions of the array to be disconnected from the DC bus in the event that an excess of solar energy is available. Energy reaching the DC bus is either stored in a large, lead-acid battery or passed to one of two single-phase inverters. These devices convert the direct-current power into alternating current (AC), which is required by most appliances and other loads. While the uninterruptible power supply (UPS) inverter supplies critical PV system loads, the power for the site loads is supplied by the main inverter through a site transfer switch.

Backing up the PV system is a 40 kW/50 kVA diesel-powered generator. Power from this single-phase generator, when required, may be supplied either directly to the site through the transfer switch or to a 40 kW battery charger. Output from the charger goes to the DC bus in a manner analogous to that of power from the PV array.



Simplified PV Power System

The Storage System

Solar energy is not always available when needed (for example, at night). For this reason, a remote PV system like the one at Natural Bridges, which is not connected to a utility grid, must have a backup power