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THE PHOTOVOLTAIC POWER SYSTEM AT NATURAL BRIDGES NATIONAL MONUMENT* +

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The 100-kWp photovoltaic (PV) power system implemented by MIT Lincoln Laboratory under U.S. Department of Energy sponsorship serves a small self-sufficient community, isolated from the utility grid, at the Natural Bridges National Monument (NBNM) in southeastern Utah. This power system is providing information important to the successful operation of future systems: namely, data leading to improved models for system sizing and design as well as reliability, maintenance and performance data on critical PV system components. The park is visited by over 80,000 people per year and thus offers an excellent opportunity to educate the public on renewable energy sources and energy usage. The PV system is operated by the park staff.

Figure 1 shows a block diagram of the system which has been in operation since May 1980. The 100-kWp array area is located approximately 1200 feet south of the PV equipment building on an inconspicuous south-facing hillside. The flat-plate, glass-covered modules are mounted in twelve rows, each containing eight 8 X 24-foot frames. Although the tilt angles can be adjusted, the frames are set at a fixed 40° tilt to favor the winter season and to facilitate snow shedding. Power is transmitted to the PV building with buried cables from each of the 48 subarrays.

Automatic control for the system is implemented with a microprocessor which is primarily used to monitor and manage the battery state of charge. Control of battery charging current and voltage is implemented by shedding subarrays with mercury-relay switches. The controller also monitors battery state of charge by integrating the battery current and starts the backup diesel-powered generator and battery charger if the state of charge reaches a predefined lower limit or if periodic battery equalization is required.

The system incorporates electrical storage since it must provide power 24 hours per day and is not served by a utility grid. Thus this system will provide operational experience with a large lead-acid storage battery (600 kWhrs 3520 Ah) pertinent to the design of future systems incorporating storage for load leveling or stand-alone requirements. The battery uses a calcium additive in the lead plates to minimize the production of hydrogen gas during charging; its cells are also equipped with catalytic recombiners to further reduce the explosion hazard. These measures also limit water loss and therefore reduce maintenance. The battery is sized to provide about two days of storage in cloudy weather.

Two inverters are used in the system. The first is a 5-kVA uninterruptible power source (UPS) inverter used to isolate the control system from load-induced voltage variations on the main inverter. The main inverter, with a capacity of 50 kVA, is several times larger than the average site load in order to provide adequate starting current for large (2-3 HP) AC motors.

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During the initial checkout of the system, four inverter-related problems were encountered: 1) overload of the main inverter at turnon due to initial core saturation in a large power distribution transformer, 2) radio noise emanating from the main inverter, 3) sensitivity of the inverter control circuitry to radio frequency (450 MHz) energy from a nearby radiotelephone, and 4) malfunction of the small UPS inverter resulting from the very low resistive source impedance in the large battery. These problems were solved with: 1) a resistive starter to limit initial current, 2) power-line filtering, 3) RF filtering, and 4) a small series resistor.

In designing the system, considerable effort was expended to reduce overhead loads and to meet the year-round energy needs with a minimum of diesel-powered generator operation. As a consequence, the average site AC load, including PV overhead, is about 12-17 kW. The PV building requires approximately 1 kW for fans and evaporative coolers in the summer season. In winter, waste heat from the inverter is circulated to heat the building and the corresponding load is less. In addition, the UPS AC load is about 800 watts year-round. Averaged over a year, the backup generator is projected to supply less than 15% of the total energy consumption.

In Fig. 2 the estimated load power profile, at the DC bus assuming constant 24-hour demand, is shown based on 1979 actual load data adjusted for inverter losses and overhead loads. This load is artificially high, due to the previous practice of base loading the generator with extra lights and winter season heaters for proper diesel load. Also shown is the maximum available array power, which is what might be collected if a maximum-power-point tracker were used to extract the full output from the array. This is, of course, an upper bound on the available energy. A more realistic profile is shown by the expected collectable power which estimates what this system can supply during the year. With these load estimates, a net energy deficiency during December and January will have to be made up by diesel operation. With conservation measures in effect, the projected deficits in the winter season will be less than is suggested by Fig. 2.

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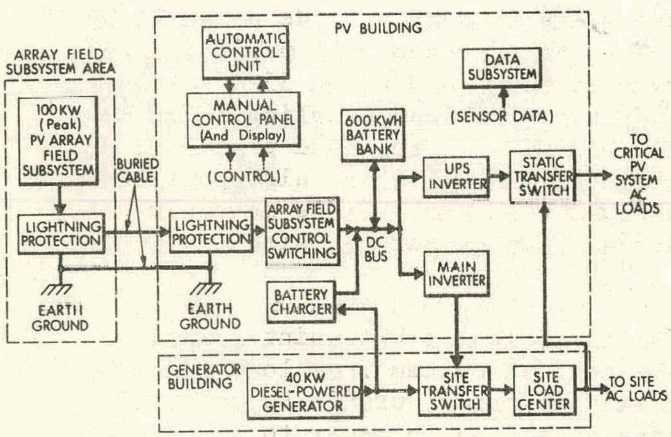

Fig. 1. Simplified PV power system.

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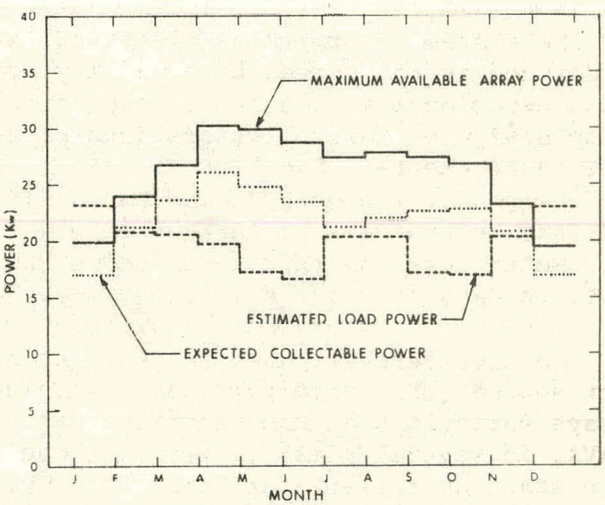

Fig. 2. Load requirements compared to available array power.