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DOE/LeRC PHOTOVOLTAIC SYSTEMS TEST FACILITY

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THE DOE/LeRC PHOTOVOLTAIC SYSTEMS TEST FACILITY*

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ABSTRACT

The DOE/LeRC Photovoltaic Systems Test Facility was designed and built and is being operated by the NASA Lewis Research Center, Cleveland, Ohio, as a national facility to serve the needs of the entire DOE National Photovoltaic Program. The objective of the facility is to provide a place where photovoltaic systems may be assembled and electrically configured, without specific physical configuration, for operation and testing to evaluate their performance and characteristics. The facility as a "breadboard" system allows investigation of operational characteristics and checkout of components, subsystems and systems before they are mounted in field experiments or demonstrations. The facility as currently configured consists of 10 kW (peak) of solar arrays built up from modules from several manufacturers, two inverter test stations, a battery storage system, interface with local load and the utility grid, and instrumentation and controls necessary to make a flexible operating facility. Expansion to 30 kW (peak) is planned for 1978. Test results and operating experience are summarized to show the variety of work that can be done with this facility.

INTRODUCTION

The DOE/LeRC Photovoltaic Systems Test Facility (STF) located at the Lewis Research Center (LeRC) Cleveland, Ohio provides a vital support capability to the overall DOE National Photovoltaic Program. As a "breadboard" system, it allows preliminary investigation and checkout of components, subsystems and complete photovoltaic systems before installation in actual service. The STF also permits the assessment of candidate photovoltaic systems and design concepts, and can be used to determine optimum system configurations and operating modes.

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This report describes the STF and its capabilities. More detail can be found in reference 1. Some results of recent facility operation are presented to illustrate the type of information this facility can provide.

FACILITY DESCRIPTION

The elements of a photovoltaic power system are shown in figure 1. The Systems Test Facility includes these elements as well as an instrumentation and data acquisition system. Figure 2 is an aerial photograph of the STF which shows the array field, the energy storage building, and the control room that houses power conditioning and distribution equipment and the instrumentation and data acquisition system. All wiring between major areas is by underground conduit.

Array field. - Figure 3 is a photograph of the STF array field. The array field consists of 240 4 by 8-foot solar cell panels mounted on support frames whose tilt angle can be varied from 5° to 85° . There are eight rows of 30 panels each. These frames and the wiring to them are capable of 40 kW (peak) operation. Each solar cell panel can be equipped with modules of nearly any design. The present array consists of two rows utilizing modules from three manufacturers. These two rows have an installed peak power rating (at 1000 W/m^2 , 28° C) of 10 kW. Additional modules are planned for installation in 1978 to bring the field to an installed peak power of 30 kW.

The modules may be interconnected electrically in various configurations. Two wires per half panel are provided to connect the array to solar array busbars in the control room through a switch, an insolation diode and a fuse. Series strings consisting of one or more half panels of modules terminate at a positive and negative bus in the control room. The output voltage of the solar array can be changed by reconfiguring the

array interconnection in the field or in the control room. The array can also be electrically split into several independent arrays. To add to the flexibility of this system, a power patch cabinet is planned for the control room. This will allow rapid reconfiguration of the array by use of simple power patchcords.

Energy storage equipment. - Many photovoltaic power systems require on-site energy storage. The STF presently has 48 kWh of lead-acid storage batteries with expansion to higher voltage and increased capacity planned for 1978. The battery cells are of a deep-discharge-cycle-duty type, with lead-antimony positive plate grids and calcium alloy negative plate grids. The batteries are housed in a building immediately adjacent to the control room. The building is provided with forced air ventilation and a safety alarm which is triggered by loss of ventilation. Plastic acid-resistant trays are also provided to contain accidental acid spills. Room is available in the building to expand the on-site storage to as high as 500 kWh.

Power conditioning equipment. - The STF is a flexible power system and can be interfaced with virtually any type of AC or DC power conditioning equipment. At present two test stations are available in the control room which may be used for inverter operation or the testing of DC systems containing components such as battery charge regulators, maximum power trackers, DC to DC converters, etc. For the safe operation of those systems in which the batteries are an integral part, a test station has been established in the energy storage building.

Power distribution equipment. - Both AC and DC power may be transmitted through the system by a fused and instrumented distribution system. The interface with an electric utility is achieved through proper matching transformers and circuit breakers which allow load sharing and two-way power flow with the utility.

Various electrical loads are available for use as part of a system test. These include up to 20 kW of resistive load that may be used for AC or DC and a 3-phase AC programmable load bank presently being installed with up to 30 kW resistive, 30 kVAR capacitive and 15 kVAR inductive elements. Also available are programmable power supplies capable of up to 39 kW of DC power.

Instrumentation and data acquisition system. - The Instrumentation and Data Acquisition System includes transducers for measuring electrical parameters (voltage, current, power, reactive power), temperatures, weather parameters (wind speed, wind direction, air

temperature), insolation, and any special user instrumentation. The electrical transducers are designed to handle nonsinusoidal as well as sinusoidal waveforms. Both instantaneous and integral readings of electrical parameters can be made for use in power and energy balance calculations. As will be noted on the block diagram (fig. 4) the instrument signals may be routed to various locations in the facility by use of patchboards. Real time data acquisition equipment include oscilloscopes, analog chart recorders, analog tape recording, and a microprocessor-minicomputer based data acquisition and display system with facility hardcopy. Further specialized processing including frequency spectrum analysis is available using the LeRC central computing facility.

Current-voltage traces of individual strings and grouping of strings up to and including the total field can be made using a technique developed at LeRC. A simplified block diagram is shown in figure 5. In operation, switches S1 and S2 are closed and the array short-circuit current is obtained. When switch S1 is opened, the array current charges the capacitor (C1) to near open-circuit voltage. The constant current source continues the charging past open-circuit voltage. In the process the IV trace has been swept and may be recorded by use of an X-Y recorder or other data acquisition system. The circuit is reset by opening switch S2 and discharging the capacitor by closing switch S3.

The operational status of the individual strings in the field are monitored by use of a light panel that indicates which strings are furnishing voltage. The light panel is used for failure detection and to verify fault isolation.

In addition to installed thermocouples, the temperature of the array or other system components can be monitored by infrared scanners.

SAFETY CONSIDERATIONS

General LeRC safety procedures with regard to both AC and DC circuits of comparable current and voltage are applied to the STF. The solar array field is regarded as a DC substation and is enclosed on all four sides by an 8-foot-high chain-link fence. The steel solar cell panel mounting frames are connected to array field ground through a buried copper cable network and ground rods. Frame grounding is for limiting damage from lightning and for personnel safety.

As mentioned earlier each series string of the array is connected to the solar array busbar through disconnect switches. These switches are opened and tagged with a

warning when work is being done on panels within the series strings. A master switch to isolate all array DC power from the control room wiring is also provided. This switch is opened and tagged when work is being done on the DC lines within the control room.

Safety procedures for maintenance and inspection of the solar array have been set up. The preferred method is to do work involving physical contact with the array at night when the array is not producing power. Alternate methods for daylight work have also been approved which include isolating the portion of the array to be worked on with the switches mentioned above and shorting the output terminals of the panel.

EXAMPLES OF STF TESTING

Results from STF include test data and operating experience acquired on the facility and experimental packages. No attempt will be made to cover all the test results obtained, but rather the intent is to give the reader a feeling for the type of work being done and some of the more significant results from this facility.

Array performance. - The STF array and associated data system provide a means for obtaining long term operating history under a variety of environmental conditions. One of these conditions is snow fall. The array output was found to increase up to 6% due to reflection from a snow field in front of the array. Conversely a 1/4 inch layer of snow on the array can reduce the output by up to 90%. The depth of snow accumulation and percent of module coverage is a function of the snow type, wind conditions, module surface, and panel tilt. From the preliminary data obtained, panel tilt angles greater than 40° are desired to facilitate self cleaning of the array.

There was no observable damage to the STF array during the blizzard of Jan. 26-27, 1978 (the most intense blizzard in the area for decades during which winds up to 82 mph were recorded). Even during this blizzard the array produced about 20% of its normal peak power.

The modules have been exposed to the Cleveland environment for periods ranging from 17 to 24 months. The deterioration of the array has been monitored by physical inspection and electrical measurement. Degradation of the electrical output of the array of approximately 13% occurred during the first 14 months of array operation. At this point the array was washed resulting in a recovery of about 6%. In the ten-month period since washing a further power decrease of about 13% has been experienced.

Delamination has been noted in a majority of the modules. The major delamination has been around the edges of the modules with only a small portion showing delamination over the cells. Cracked and/or hot cells have been noted in approximately 20 modules (approx. 2% of installation). This cracking has occurred since initial installation and seems to be more pronounced in the last 6 months. Only two modules have failed to an open condition.

Inverter testing. - Test stations for inverters have been established in the STF for inverter testing in a photovoltaic system. Two initial systems were assembled with commercially available inverters. The first used a single-phase, stand-alone 5-kVA self-commutated inverter with battery storage and a local load. The second system had a single-phase 8 kW line-commutated inverter, transformer-coupled to a load bank and to the local electric utility distribution network.

The self-commutated inverter was a standard unit designed for uninterruptable power service. Its operation with the array and battery system demonstrated the feasibility of such systems, although this unit was not well suited for photovoltaic application due to its high no-load losses (approx. 30%). Further work on this class of inverter will be done in STF with the testing of a 10 kVA self-commutated unit specifically designed for photovoltaic application (3).

The line-commutated unit was designed for use with wind-powered generators and modified for photovoltaic operation with the addition of input shunt capacitance, input series inductance, and open and closed loop maximum power controllers. The input capacitor was found necessary for both this inverter and the self-commutated unit to operate directly from the solar array with no battery back-up. Tests performed on this system determined the effects of varying input capacitors, inductors, array voltage, and array current levels on inverter efficiency and power factor. The necessary capacitor was found to be relatively small (2500 μ F). Improved efficiency and power factor resulted from increasing series inductances from 5 to 20 mH. The efficiency varied from 76 to 88% over the test range (15 to 75% of rated power) with the maximum at about half the maximum power rating. The power factor increased with both increasing input voltage and increasing current from 36 to 72% with a projected maximum of 77% at rated power (2).

DC systems. - Many of the near-term applications of photovoltaic systems are total DC systems. The STF is being used to support these systems from concept

testing through breadboard testing to the checking out of the physical hardware and diagnosis of any operational problems experienced. An example of this type of effort is testing of components for photovoltaic village power systems now being designed for installation at Schuchuli, Arizona, USA and Tangaye, Upper Volta, Africa.

The major result of this testing is operating experience with these systems which is leading to modifications and improvements to the systems. System development and debugging can take place much faster and more conveniently in STF than is possible in the field. Further, design deficiencies, uncertainties, overdesign and underdesign can be determined before the system is delivered to the field. Confidence in the delivered system can thereby be enhanced. Some of the areas being investigated include:

- Motor starting from the array with and without batteries
- Battery charge regulation using both dissipative electronic loads and array string switching
- Use of pilot cells to determine battery state of charge
- Use of load shedding at high depth of discharge
- Field acquisition of data by small low-power microprocessor-based data systems

Much of the information obtained in these conceptual investigations is reflected in the final designs of these systems.

CONCLUSIONS

The Systems Test Facility is providing a means to experiment with photovoltaic systems, subsystems, and components in an actual operating environment. Both quantitative and operational data may be acquired from the concept thru breadboard to final hardware stage of development. The knowledge gained in this facility is being and will continue to be used to improve the design and operation of photovoltaic systems.

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ELEMENTS OF PHOTOVOLTAIC POWER SYSTEM

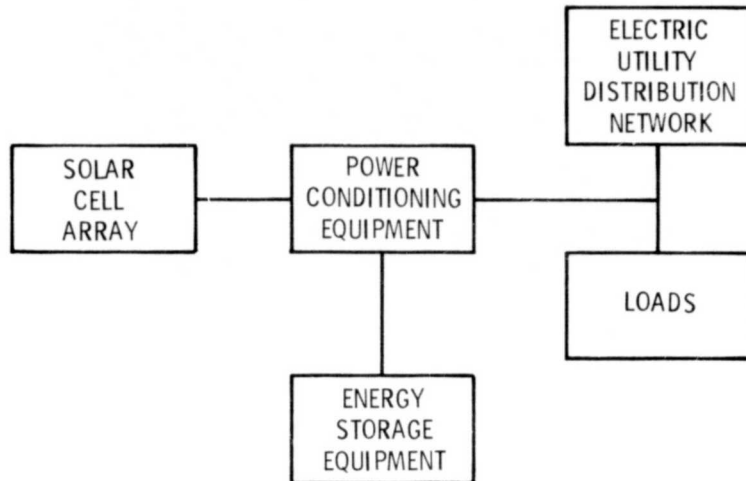


Figure 1.

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DOE/LeRC PHOTOVOLTAIC SYSTEMS TEST FACILITY

AERIAL VIEW

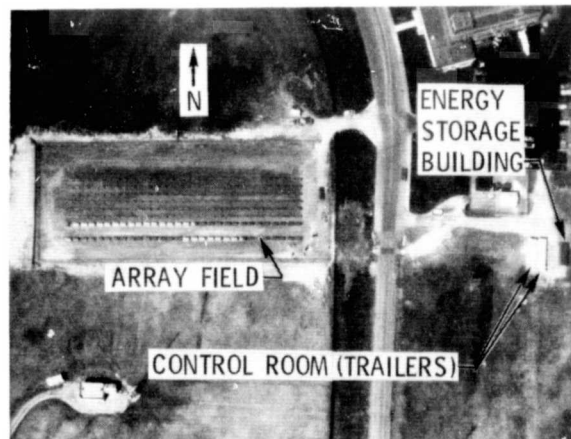


Figure 2.

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DOE/LeRC PHOTOVOLTAIC SYSTEMS TEST FACILITY

ARRAY FIELD

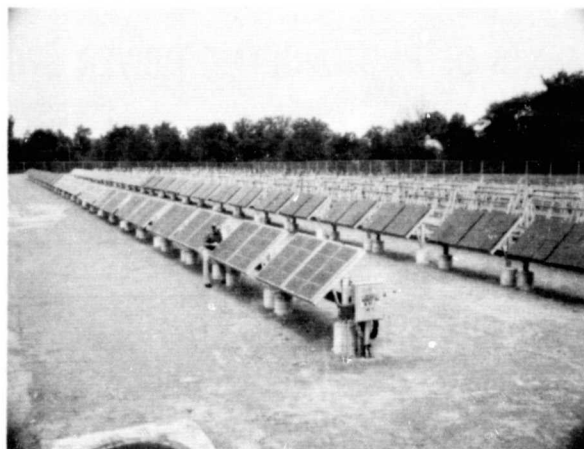


Figure 3.

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STF DATA ACQUISITION AND REDUCTION SYSTEM

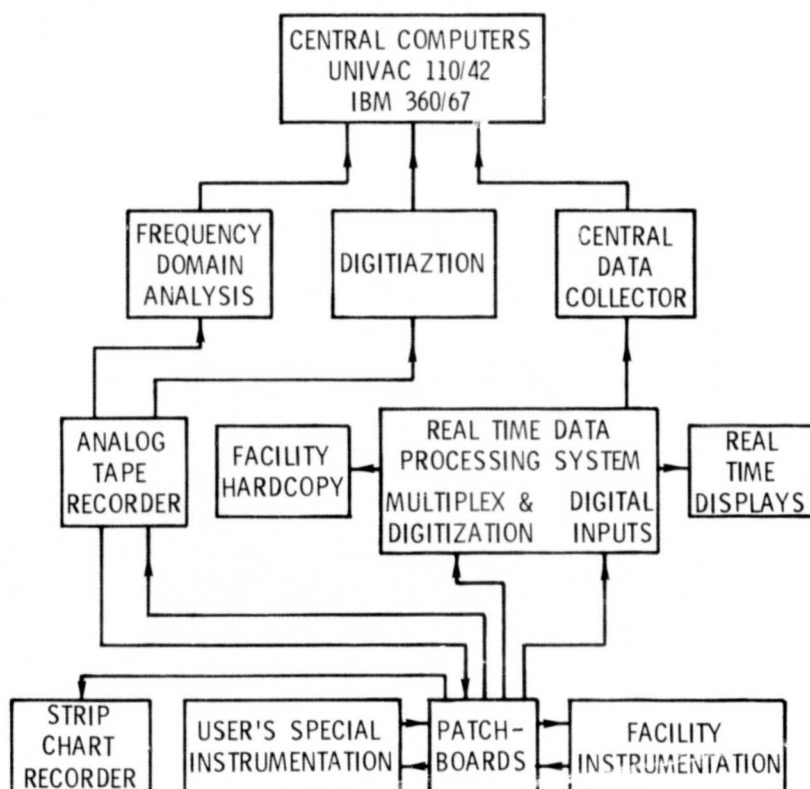


Figure 4.

IV CURVE TRACER

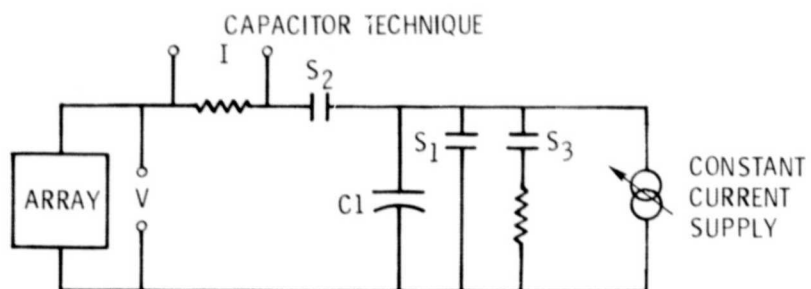


Figure 5.

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