MITRE TERRESTRIAL PHOTOVOLTAIC ENERGY SYSTEM

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SUMMARY

The MITRE Corporation is developing a complete terrestrial photovoltaic energy system employing computer control and battery and hydrogen storage systems. The solar array has been installed and operated to obtain some of the information necessary for the control system design.

INTRODUCTION

The MITRE photovoltaic energy system is designed to investigate terrestrial photovoltaic systems assuming that the solar cell costs will be reduced to an acceptable level in the future. The object of the MITRE photovoltaic program is:

1) to investigate and demonstrate the operation of the complete photovoltaic energy system with base- and peak-load capabilities,

2) to develop a dynamic energy management system to ensure that all available solar energy is utilized in the most efficient manner,

3) to study the effect of environment on the operating photovoltaic cells to ascertain their reliability and lifetime,

4) to provide a data base and test facility for evaluation of new photovoltaic cells and system concepts, and

5) to provide a test facility to study the optimum way to utilize the existing and new energy storage techniques and systems.

These objectives are being implemented by designing and constructing a system which will have the following operating characteristics:

1) solar energy collection system will be operated at all times to supply its maximum available power,

2) the demand load will be supplied on demand up to a specific limit continuously,

3) solar energy in excess of the load demand will be stored, and

4) the energy storage system will be designed to handle both base and peak loads.

Figure 1 shows schematically the photovoltaic energy system being constructed. It consists of a solar energy array of 1,000 watts peak capability. The output of the array will drive a power conditioning inverter changing the 24 volt dc output of the panels to 110 ac 60 Hz square wave for transmission. The square wave inverter was chosen to facilitate the battery charging. The energy storage system is employed as a shunt regulator to the solar array output. Excess energy available above that required by the load is put into the energy storage system, and when the load demand exceeds the output of the solar energy converter, energy is supplied from the energy storage system. The control for this is performed by a dynamic energy management system which is a minicomputer. In this way, the load demand can be satisfied at all times and the system can track the peak power point for the solar array.

Figure 2 shows the energy storage system. It consists of battery storage for short-term and peak power requirements, and an electrolysis hydrogen gas system fuel cell combination for base load and nighttime operation. The estimated energy utilization efficiencies, for power from the panels, for the three different operations are:

1) power directly to the load, 72% overall efficiency;

2) power to and from the battery storage system, overall efficiency of 42%; and

3) power to hydrogen to fuel cell, overall efficiency of 11%.

These are the anticipated efficiencies for the off-the-shelf components that have been purchased to assemble this system. A Nova 1200 jumbo minicomputer is employed as both a real time energy management system and as the data acquisition and data processing system. The computer has 16 K of core storage and 48 analog input channels with an A to D converter and eight D to A converter output channels to be used for system control.

Figure 3 is a picture of the solar array installed on the roof of the MITRE Washington operations. Of the twenty 50-watt peak panels, 17 are from the Solarex Corporation and one each from Spectrolab, Centerlab and Solar Power Corporation.

RESULTS

Figure 4 shows the normalized output power from a single 50-watt panel and from the entire array as a function of load resistance. For this set of data, the array consisted of five panels connected in series, and four of the series group connected in parallel. This was done to provide a higher output voltage. Two characteristics are observed. First, the width of the curve is expanded considerably as compared to the single panel: a sharp peak power point is no longer well defined for the full array. Second, the maximum for the full array, in this case, occurred at a substantially higher load resistance than for the single panel. This was due to a faulty panel in one of the series legs.

This type of characteristic change with the number of panels is significant when trying to design a computer control system. It implies that the computer control system must not operate on any absolute parameters for the tracking of the peak power but must depend only on differences, so that as the array changes its characteristic either due to aging failures or a change of panels, the control system continues to function in a satisfactory manner. A second important consideration in implementing this type of control system is that of system dynamics.

Figure 5 shows the transit response for the array as a function of time on a day when there were stratocumulus clouds at about 1,000 feet moving with velocities of 40 to 45 mph. It can be seen that the power experiences a 60% drop in a period of about one second. For a large power array, it does not appear practical to buffer the input with capacitor banks or with batteries, because if batteries were used, one would continually run into the problem of either having them overcharged, thereby reducing their life, or having the tendency to deplete them, again reducing their life. Thus, it would be desirable to operate the solar cell array directly into the power conditioning unit and into the load with a minimum of energy storage system inbetween. As an example, to reduce the transit from one second to several seconds would require, for the present system, a capacitor bank in the order of several farads. Therefore, for large power systems it appears impractical to consider conventional capacitors. A battery could be employed; but because of the size requirement and effects of transit on lifetime, it also does not appear desirable.

Thus, the decision was made to design the control system to regulate the output from the solar array to a percent or two for transients of this type with no energy storage before the power conditioner. In order to sample the voltage and current, make the necessary computations and provide correction signals to maintain an output voltage within the desired range, the computer must sample the system parameters at least once every ten milliseconds. Thus, the computer makes two samples, makes a decision, and provides the necessary correction in a period of about 20 milliseconds. A more rapid time would be desirable, but because of the quantity of data that must be extracted and the time required to make the necessary multiplications and computations, it did not appear practical; in fact, severe limitations were encountered in trying to operate the computer at these very high sample rates to provide the necessary information for regulation. One of the consequences of this was that all ac power measurements are performed externally using analog multipliers (Hall effect units), since the time required to do internal mulitiplications proved prohibitive.

Figure 6 shows the components of the MITRE solar energy test facility which will be used to provide the data for analyzing the performance of the photovoltaic energy system. It consists of the computer; a solar monitor which contains direct and total radiation instruments; a UV radiometer; calibrated solar cells for making solar measurements with respect to the photovoltaic characteristics; meteorological information consisting of air temperature, humidity, wind speed and direction; a dust monitor to obtain information on dust buildup; thermocouples for measuring panel temperatures and cell temperatures; and electrical instruments for measuring ac voltages, currents and powers in the system. In addition, we are taking photographics of the solar cell panels in order to ascertain any change in their observable physical characteristics.

The information to be supplied to the computer from the photovoltaic system will be from all the critical points in Figures 1 and 2. We will measure both ac and dc power at all critical points in the system and information with regard to hydrogen generation and storage in the storage system. A count of the number of channels of information necessary to provide a detailed analysis of the operation of the system, along with the solar and meteorological data, shows that we will be monitoring about 42 parameters for the system. The data processing system is designed to provide integration of all power data over specified periods, so that the data retained in the system will represent integrals over these periods. This was necessary because the data acquisition rate of 100 samples per second on 42 channels would very rapidly overtax the storage capability of the system and provide a flux of data beyond our capability to handle and analyze.

CONCLUSION

The present status of the system is that the solar array has been installed on the roof of the MITRE facilities for a period of several months. It has been operated into a load and battery storage system without computer control for a limited period of time. We are in the process of completing the installation and developing the software for the system control. The exposure of the panels and the limited operation over the past several months has shown some degradation in the panels, and it has shown that care must be execercised in connecting panels from different manufacturers into a common array. Our results to date also indicate that any control system should operate on differences rather than absolute values. It is anticipated that the full system will be in operation using the computer control within a period of a few months.

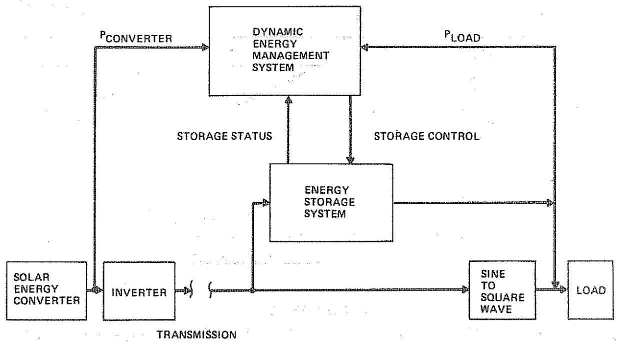

FIGURE 1
PHOTOVOLTAIC ENERGY SYSTEM

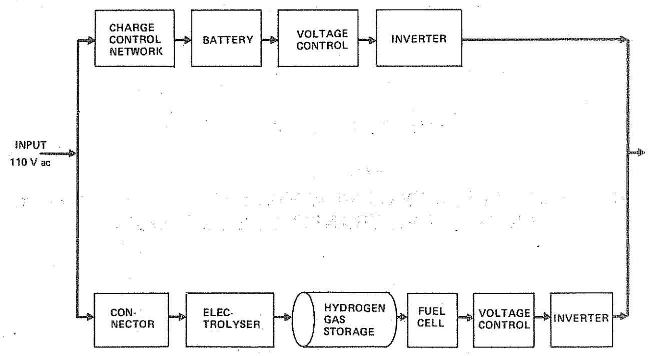

FIGURE 2
ENERGY STORAGE SYSTEM

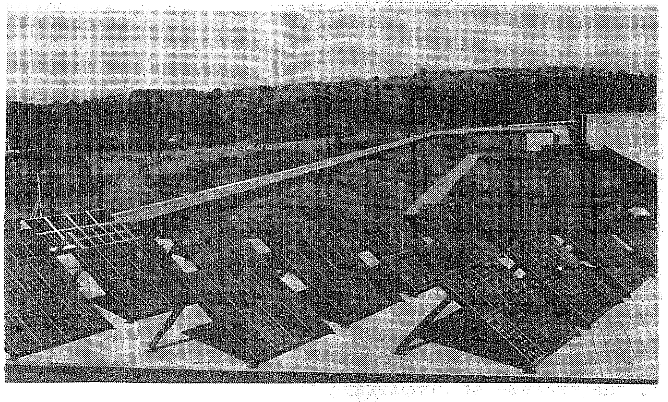

FIGURE 3
PHOTOGRAPH OF SOLAR CELL ARRAY INSTALLED ON THE ROOF OF THE MITRE WASHINGTON OPERATIONS

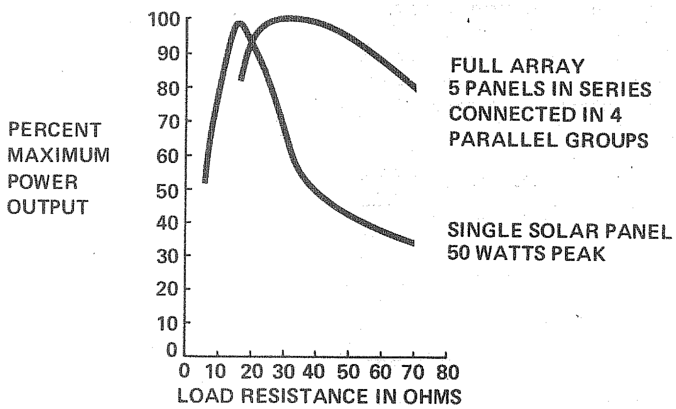

FIGURE 4
NORMALIZED POWER AS A FUNCTION OF LOAD RESISTANCE

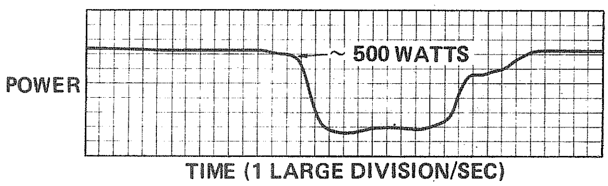

FIGURE 5
STRATOCUMULUS CLOUDS 40-45 MPH DEC. 3, 1974 11:00 a.m.
TYPICAL POWER TRANSIT DUE TO CLOUDS

1) DATA ACQUISITION AND CONTROL SYSTEM
   DATA GENERAL NOVA 1200 JUMBO COMPUTER:
   - 16,384 WORD CORE STORAGE,
   - A/D CONVERTER WITH 48 ANALOG INPUT CHANNELS,
   - EIGHT D/A CONVERTERS OUTPUT CHANNELS,
   - TELETYPE KEYBOARD/PRINTER,
   - THREE TAPE CASSETTE STORAGE SYSTEM.
2) SOLAR MONITOR
   - DIRECT RADIATION (EPPLEY PYRHELIOMETER),
   - TOTAL (WHOLE SKY) RADIATION (EPPLEY PRECISION PYRANOMETER),
   - ULTRAVIOLET RADIOMETER (EPPLEY),
   - CALIBRATED STANDARD SOLAR CELLS (CENTERLAB).
3) METEOROLOGICAL MONITOR
   - AIR TEMPERATURE } MOTOR-ASPIRATED SHIELD
   - RELATIVE HUMIDITY, }
   - WIND SPEED AND DIRECTION,
   - DUST.
4) TEMPERATURE MONITOR
   - FOUR CHANNEL THERMOCOUPLE UNIT
5) ELECTRICAL MEASUREMENTS
   - HIGH ACCURACY (.005%) DVM,
   - HALL EFFECT VOLTAGE, CURRENT, POWER AND WATT-HOUR MONITORS FOR SINUSOIDAL AND NON-SINUSOIDAL WAVE FORMS.
6) VISUAL RECORDING
   - 35 MM NIKKON CAMERA WITH 55 MM MACRO LENS FOR CLOSE-UP PHOTOGRAPHY,
   - COMPLETE IN-HOUSE PHOTO SERVICES AND LABORATORY.
7) SUPPORT EQUIPMENT
   - EIGHT CHANNEL STRIP CHART RECORDER,
   - FLUKE 515A PORTABLE CALIBRATOR,
   - IN-HOUSE ELECTRONIC SHOP CAPABLE OF DESIGN AND FABRICATION OF ELECTRONIC EQUIPMENT.

FIGURE 6
MITRE SOLAR ENERGY TEST FACILITY COMPONENTS