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DEVELOPMENT OF THE SMALL COMMUNITY SOLAR POWER SYSTEM

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ABSTRACT

This paper presents the status of the Small Community Solar Thermal Power Experiment (SCSE Program). Current activities on the Phase II single/module development effort are presented, together with plans for the Phase III 1 MW_e demonstration plant. A description of the various subsystems and components is given with particular emphasis on the unmanned microprocessor-based plant control subsystem. Latest performance figures are given for the 1 MW_e plant, based on 56 power modules, each consisting of a G.E. 12m Low Cost Concentrator, a FACC cavity receiver, a Barber-Nichols Organic Rankine power conversion subsystem and a ground-mounted solid-state rectifier. Overall plant efficiency at rated conditions is 15.8 percent. Advanced glass concentrator designs yield 20 percent overall efficiencies.

INTRODUCTION

The Aeronutronic Division of Ford Aerospace & Communications Corp. (FACC) has been under contract (1) to JPL since 27 December 1979 for Phase II development of the Small Community Solar Thermal Power Experiment (SCSE). This program is the first experiment (FE-1) in the Engineering Experiment series of the Parabolic Dish Project managed by JPL for the U.S. Department of Energy (DOE). The EE-1 concept is classified as a Point-Focusing Distributed Receiver (PFDR) system with Distributed Generation. It is a modular system, comprised of multiple power modules interconnected by a conventional electrical system, with provision for utility grid-connected operation. During Phase II, a single power module is being fabricated and subsequently will be tested at the JPL Parabolic Dish Test Site (PDTS) at Edwards AFB, California. In the follow-on phase (Phase III), a complete 1 MW_e plant, composed of approximately 56 power modules, will be fabricated and installed for test at a site to be selected by DOE.

Each power module, as shown in Figure 1, is comprised of a parabolic dish concentrator with a Power Conversion Assembly (PCA) mounted at its focus. The PCA shown in Figure 2 consists of a cavity receiver and a Power Conversion Sub-system (PCS) comprised of an organic Rankine cycle (ORC) engine and a high-speed, direct-coupled permanent magnet alternator; a solid-state rectifier is located at the ground. Maximum gross weight of the PCA is 680 kg (1500 lb.); over-all length is 2.38 m (7.8 ft.) and maximum diameter is 1.124 m (3.7 ft.). The PCA and its associated support structure block approximately 1 percent of the incoming solar power.

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(1) Contract No. 955637

PROGRAM STATUS

The SCSE master schedule is shown in Figure 3; a Preliminary Design Review (PDR) was successfully completed on 27 June 1980 and the System Design Review (SDR) is scheduled for 28 January 1981. As currently planned, the PCA will be shipped to the Edwards PDTS by mid 1981, after thorough testing of the receiver at Aeronutronic and subsequent testing of the combined PCS and receiver - on electrical heat - at the Barber-Nichols facility. The Plant Control Subsystem and associated electrical interface equipment will also be tested at Aeronutronic, then delivered to the PDTS for integration (with the PCA and the General Electric Low Cost Concentrator [LCC]) into a functioning EE-1 power module. The hardware will be tested under field conditions for 5 months under the existing contract; the intent of the field test operation is to verify the EE-1 design as a prerequisite to fabrication/installation/demonstation of the complete 1 MW_e EE-1 plant during Phase III of the SCSE program.

A second power conversion unit is being procured from Barber-Nichols for the parallel Design Maturity Testing (DMT) program. This unit will be in continuous operation at the Barber-Nichols facility - driven by an electrically heated boiler - primarily to ascertain long-term durability on all power conversion components. The test rig will also simulate the effect of engine attitude orientation - in real time - and achieve accelerated life testing. The lessons learned from the DMT program will be incorporated into the PDTS test unit as required, either in the form of hardware replacements, changed operating procedures, revised maintenance procedures, etc.

SYSTEM DESCRIPTION

The LCC, the ORC-PCS and the FACC receiver are presented in detail elsewhere in this Program Review and will not be repeated here. The Energy Transport Subsystem (ETS) and Plant Control Subsystem are also important elements of the EE-1 system, however, and are discussed below.

Energy Transport Subsystem (ETS)

The ETS is comprised of 1) a conventional dc electric system which interconnects each power module, 2) central static dc-to-ac inverter(s) for power conditioning and voltage/load control and, 3) associated equipments for grid interfacing and synchronization. The system is designed to operate at 600 volts, interfacing with a 4800 volt (typical) utility distribution line. Facility power is used to drive the individual concentrators, PCS accessories and the control room; an uninterruptable power supply (UPS) is provided for power when the grid is out and self-generated power is not sufficient to operate the system. A load bank is also provided to dissipate stored energy during grid out/concentrator de-track operation. The major benefit of the dc approach is that it permits the speed of the ORC engines to be varied with the change in solar insolation in order to achieve high part-load efficiency and hence high annualized performance. In addition, the use of the central inverter(s) for voltage/load control eliminates any need for individual field control of the alternators, as discussed below. Finally, grid synchronization in frequency and phase is much easier, since an ac system would require synchronization of each engine whereas this system is accommodated at the central point of grid contact.

The ETS is being modified for the Phase II tests at the JPL-PDTS to accommodate certain differences in the grid interface and existing JPL equipment at the site as well as the fact that only a single module will be tested. However, basic principles of the Phase III design will be demonstrated

Plant Control Subsystem

The SCSE plant control subsystem is being designed for automatic, totally remote (unattended) operation. Manual control capability will be provided for installation, check-out, testing and maintenance. General functions are 1) automatic/manual control of all plant subsystems, 2) coordinated sequencing of plant subsystems for all operating modes, 3) failure protection and 4) status monitoring.

Operating Principle

The plant control system will operate the plant with high efficiency under continuously varying solar energy input. It is also simple in concept and provides totally stable operation in all possible modes. There are three elements of the concept: 1) concentrator control, 2) fluid control and 3) turbine speed control.

Concentrator control consists of 2-axis tracking and associated sequencing, e.g., start-up, shut-down, emergency de-track, etc. The essential feature of the LCC tracking concept is its dual operation, i.e., 1) coarse tracking via computer-stored ephemeris data and concentrator angular position sensors and 2) fine tracking via auto-nulling of optical (sun) sensor signals.

The fluid control loop operates the coupled receiver and ORC engine to make certain that 1) the net thermal energy absorbed by the receiver is transmitted to the engine in concert with the time-varying solar energy input, and 2) high part-load efficiency is achieved. These requirements are met by adjusting the working fluid (toluene) flow rate - via a flow control valve at receiver outlet - to maintain virtually constant turbine inlet temperature. The combination of constant turbine inlet temperature and optimum turbine speed (as discussed below) serves to maintain nearly constant PCS efficiency over a very wide range of solar input.

An additional control requirement is to maintain the turbine speed at near optimum so as to maximize turbine/alternator overall efficiency. This is done by providing a constant-voltage load for the individual alternators, (or, equivalently, a constant alternator output voltage is maintained), and the speed is then controlled by the balance of the power applied to the turbine and the power absorbed by the alternator. The constant-voltage load is produced by the inverter, which has an active circuit that senses its input voltage and varies the duty cycle of the SCRs so that the effective input impedance is varied so as to draw the current required to keep the alternator output (or inverter input) voltage constant. The resulting turbine speed is very close to optimum if the appropriate alternator impedance is selected. With multiple power conversion units connected to the inverter(s) in a parallel electric circuit, the voltage across each generator's terminals is the same and is determined by the equivalent impedance of the complete circuit, which includes the inverter. The inverter impedance can thus be varied to maintain constant voltage in the face of continuously varying solar input. Power output variations among 1 or more engines are thus represented by current variations in the electrical circuit. Individual alternator field control is thus avoided and all power units are controlled by the central inverter. Additionally, alternator and turbine torque/speed characteristics are matched by careful design of the equivalent alternator impedance so that the imposition of constant voltage assures operation at or near the speed which yields highest turbine efficiency.

Hardware Implementation

A central digital microprocessor or Master Power Controller (MPC) is provided for mode control, sequencing, protection and monitoring of all plant subsystems. The flow control loop and other PCS control functions are mechanized in the Remote Control Interface Assembly (RCIA) microprocessor which is located at each power module and slaved to the MPC. As currently envisioned, concentrator pointing control will be shared between the RCIA and the MPC, with the latter providing the sequencing and coarse tracking commands while the RCIA performs the fine suntracking control.

SYSTEM PERFORMANCE

Each module will produce approximately 18.3 kW_e of ac power at rated conditions (1000 W/m^2 and T(amb) = 28°C) at the output of the central inverter (19.6 KW_e dc output at the rectifier). At these conditions, a 56 module plant will produce about 1 MW_e when all plant losses (ETS, parasitics, etc.) are included. Table 1 summarizes performance by component and includes annualized figures for the Barstow, California site based on 15-minute environmental data tapes for 1976.

Peak output for a 56 module plant, corresponding to a solar insolation of 1100 W/m^2, is approximately 1113 kW_e.

FIGURE 1 EE-1 POWER MODULE

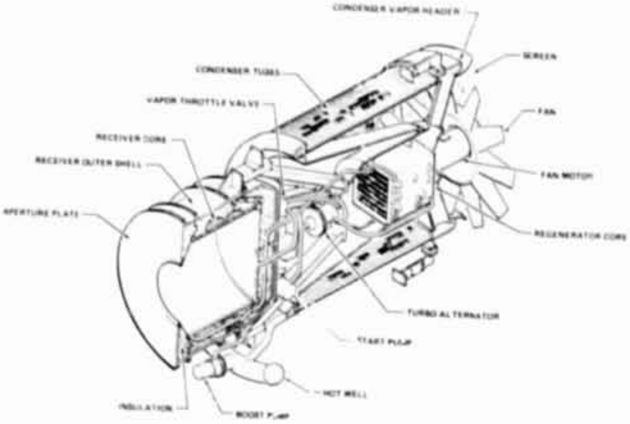

FIGURE 2 EE-1 POWER CONVERSION CONVERSION (PCA)

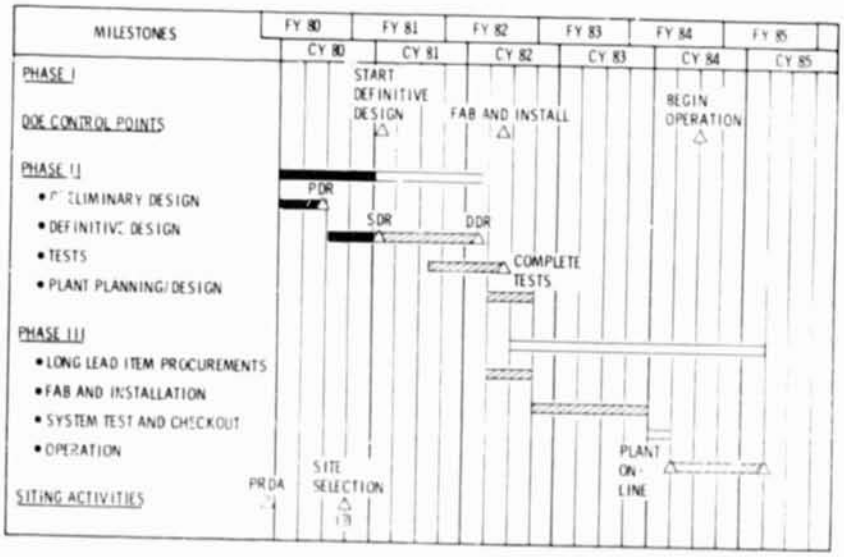

FIGURE 3 EE-1 MASTER SCHEDULE

TABLE 1 SCSE SYSTEM PERFORMANCE

Parameter	Value	Conditions/Comments
• Net power delivered to grid	1001 kW_e (56 modules)	At rated conditions: ● Insolation = 1000 W/m^2 ● T_∞ = 28°C
• Plant efficiency (end-to-end)	0.158 (plastic reflector) 0.200 (glass reflector)	At rated conditions and average LCC reflectivity
• Component/subsystem efficiencies	● Collection Eff.=0.669 (= 0.817 with glass reflector) -Concentrator (0.691) -Receiver (0.971) -Intercept (0.998	● Concentrator Eff. includes: Reflectivity = 0.78, Dust = 0.95, Blockage = 0.932 ● Concentration Ratio = 1000
	● PCS Eff. = 0.258	Barber-Nichols calculation
	● ETS Eff. = 0.935	System Analysis
	● Plant Parasitics = 0.978	8 kW_e + 250 W/module for A/C, stationkeeping, drives, etc.
• Annual performance (plastic reflector)	● Output = 2621 MWh/yr ● Annual Capacity Factor (ACF) = 0.298 ● Annualized Plant Efficiency = 0.147	1976 Barstow data