PHASE-ONE EXPERIMENT TEST PLAN
SOLAR PHOTOVOLTAIC/THERMAL RESIDENTIAL EXPERIMENT

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Abstract

Objectives, rationale, and method of a one-year experiment using a residential photovoltaic/thermal power system are presented. Data will be both archived and processed to investigate:

- (1) series heat pump system performance, and
- (2) electric utility impacts. A parallel heat pump system will be investigated in a subsequent experiment.

CONTENTS

1.0	Background and Objectives	1
2.0	System Description	4
3.0	System Operation	7
3.1	Winter Operation	7
3.2	Summer Operation	7
4.0	Reporting	9
4.1	Thermal-to-Thermal Transfers	9
4.2	Electric-to-Electric Transfers	9
4.3	Electric-to-Mechanical/Thermal Transfers	10
4.4	Weather Data	10
4.5	Quarterly Reports	10
	REFERENCES	11

1.0 Background and Objectives

This plan specifies the research activities to be undertaken at the University of Texas at Arlington, Solar Energy Research Facility (Fig. 1) for the Solar Hybrid Energy Project. This project is being conducted by Massachusetts Institute of Technology's Lincoln Laboratory with funding from the United States Department of Energy, Conservation and Solar Applications.

Fig. 1. (Below center) Solar Energy Research Facility at University of Texas at Arlington.

The overall goal of the Solar Hybrid Energy Project is to design, assemble and test promising hybrid (photovoltaic/thermal) solar energy systems for the heating and cooling of buildings. In particular, the Project focus is on systems utilizing hybrid collectors (Fig. 2) and water source heat pumps. The approach taken has been to conduct both analytical and experimental activities to assess the performance of various system concepts.

Fig. 2. Hybrid photovoltaic/thermal solar energy collector section.

The objectives of the Solar Hybrid Energy Project experiment at the University of Texas at Arlington are to acquire data on:

- Hybrid solar photovoltaic/thermal system operation
- Collector, heat pump, and inverter performance in a system environment.

These data will elucidate both system performance and utility impact issues. The Project will use the information to confirm analytic hybrid component and system performance predictions and to guide the design of improved components and systems. These data will also be used to identify the consequences of hybrid system operation perceived by the utility providing backup

power, and to forecast the suitability of numerous systems in a utility service area. The appropriateness of the hybrid system concept depends on favorable resolutions in both areas.

The Solar Energy Research Facility (SERF) at the University of Texas at Arlington (UTA) was selected in May 1978 as the site for on-site residential system experiments, proposed at the initiation of the Solar Hybrid Energy Project. The UTA facility was selected as best meeting the needs of the Project. In particular, it: (1) is located in a region where both heating and cooling tests can be conducted; (2) is thoroughly equipped to monitor both thermal and electric power usage; (3) is within the service area of a utility willing and eager to participate in experiments involving acceptance of electric power from an on-site generation capacity and (4) was available for the tests required. A substantial savings in both time and cost has been realized by utilizing the UTA/SERF and by the on-site direction of photovoltaic array assembly, array wiring and experiment operation by UTA faculty and staff.

Separate flat plate photovoltaic and flat plate thermal collectors are being used for the experiments at UTA. These collectors are located in two adjacent rows (Fig. 3) in the north yard of the SERF. Hybrid collectors are not used because they were not being manufactured at the time they were required, nor are they presently. According to theories presented in various photovoltaic system studies (1-6), the system performance with the separate collectors should not differ significantly from that with hybrids. The UTA experiment can therefore provide early experience with the utilization of solar thermal and solar photovoltaic energy used to power a residential heat pump heating and cooling system.

This document describes the solar photovoltaic/thermal system at UTA/SERF, the modes in which it will be operated and the data which will be reported. It covers the Phase One Experiment during the period from 1 November 1978 through 31 September 1979. A separate test plan will be written for the Phase Two Experiment. The second plan will be written following the conclusion of the current Conceptual Design task which will be completed in February 1979.

Fig. 3. Thermal and photovoltaic collectors at the Solar Energy Research Center, University of Texas at Arlington.

2.0 System Description

The Solar Energy Research Facility at UTA comprises a lived-in 1550 square foot residence equipped with a series configuration solar-assisted heat-pump system. Roof mounted single axis tracking concentrators have been used with an absorption chiller during previous experiments, but are not part of the current configuration. During the Phase One Experiment, the heat pump will be powered by separate photovoltaic and thermal collectors located in the yard to the north of the residence (Fig. 1). Twenty-two single glazed Northrup, Inc. thermal collectors and two hundred and forty Solar Power Inc. photovoltaic modules are mounted on adjustable-tilt racks (Fig. 3).

The Phase-One Experiment heating and cooling configurations are shown in Figure 4. In Figure 4a, the heat pump evaporator is supplied with heat from a 1200 gallon thermal storage tank. Domestic hot water is also pre-heated using the thermal storage. When the temperature of the stored water

Fig. 4. Residential solar (a) heating (b) cooling system at the University of Texas' solar energy research facility.

exceeds 80°F, heating is accomplished directly by diverting the water to an air handling unit with a larger-than-normal heat transfer surface area. Should the temperature in storage fall below 45°F, resistance heating is utilized in the air handler. Two compressor speeds are used in the heat pump, 1750 or 3450 RPM depending on the compressor head pressure or the evaporator outlet temperature.

Figure 4b shows the cooling mode configuration. In addition to heating-mode components, a wet cooling tower and cold thermal energy storage are required. The cooling tower rejects heat from the heat pump condenser to ambient air as in any air conditioning system. The additional storage is used to store cold water for cooling purposes. It permits shifting the operation of the compressor (and large subsequent electric power demands) to periods when either (a) solar photovoltaic electric power is available or (b) inexpensive off-peak utility power can be purchased.

The electrical subsystem in both Figure 4a and 4b is the same. The photovoltaic modules supply DC electric power approximately in direct proportion to the insolation received. They are wired in twenty-four series strings of ten modules each to produce 7.5 kilowatts (DC) at 166 volts (DC) and 45.4 amps (DC) at the Standard Operating Condition of 100 mW/cm^2 at air mass one and 46.0°C cell temperature (7). The DC power from the array is converted to 120/240/1Ø AC power by a Windworks Gemini 8 kW power inverter which is mated to the Texas Electric Service Company residential service with a 10 kVA isolation transformer. This electrical configuration is known as a two-way utility interactive ("line-stuffing") mode, as the electric power flows either to or from the utility depending on the instantaneous residential generation and consumption. (The two meters in Figure 4a and 4b are used between the house main and the utility to monitor the power in each direction.)

A comprehensive description of the system installed at UTA is the subject of a separate Lincoln Laboratory report prepared by UTA (8). Additional preliminary information is included in a report prepared by UTA for the Electric Power Research Institute (9).

3.0 System Operation

This section describes the algorithms which will be used to control the UTA/SERF system during the Phase One Experiment.

3.1 Winter Operation: 1 November 1978 - 31 March 1979

During this period the heating system will be controlled by a conventional room temperature thermostat and a temperature probe in the 1200 gallon thermal storage tank. Hot water or electric power will be provided to the air handler at the demand of the room temperature thermostat. When the tank temperature is less than or equal to 45°F, electric resistance heating will be used to meet the demand. Between 45°F and 80°F tank temperature the heat pump will operate between the tank and the air handler. Above 80°F tank temperature the air handler will use hot water directly from the tank.

Electric power produced by the photovoltaic array is inverted instantaneously to AC and fed into the array-house-utility junction at the house electric main (Fig. 4). During the Phase One Tests various electric load management concepts will be considered, but will not be implemented until the Phase Two Experiments begin (e.g., using the 1800 gallon tank for thermal storage on the condenser side of the heat pump, "load side storage", opens a variety of powering options for the heat pump compressor).

3.2 Summer Operation: 1 April 1979 - 31 October 1979

During this period the cooling system will be controlled by a conventional indoor thermostat and a temperature probe in the 1800 gallon chilled water tank (Fig. 4b). Water circulation from the chilled water tank temperature will be held in the range 40°F to 60°F. Whenever enough photovoltaic power is available to run the compressor and the tank temperature is above 40°F, the compressor will be operated to remove heat from the tank. When the tank temperature is 60°F or higher, the compressor is operated independently of the availability of photovoltaic power. When the tank temperature is below 40°F, any photovoltaic power available is fed to the utility. Each of the above control points will be modified to prevent on-off cycling instability problems.

Summer peaking utilities have a major problem meeting peak loads caused by air conditioner operation during mid-afternoon hours. Consequently, many have proposed high time-of-use rates for this time period (Fig. 5). Additional electric power be required for cooling should not be consumed during these peak hours. To supplement the solar system, the compressor can be run during early morning off-peak hours to chill the cold thermal energy storage temperature sufficiently to preclude the use of peak utility power during the following afternoon. A means of estimating off-peak cooling requirements will be adopted prior to the beginning of summer operation.

Fig. 5. Time-of-use electric utility residential rate structures.

4.0 Reporting

The UTA/SERF is highly instrumented to monitor and record both electrical and thermal energy transfers. Because the back-up power to the house is provided by an electric utility, both the quantity and time-of-use of energy transfers are important. Accordingly, each transfer process listed below will be integrated in three separate time categories: off-peak, shoulder and peak. These integrations will accumulate one month's data, be recorded and then reset. The data will then be presented on a per day basis (e.g., kilowatt-hours supplied in July to the heat pump compressor motor from the house electrical main [Fig. 4a] during; (a) off-peak hours, (b) shoulder hours, and (c) peak hours).

4.1 Thermal-to-Thermal transfers

- 4.1.1 Flat plate collectors to thermal energy storage (1200 gallons).
- 4.1.2 Thermal energy storage (1200 gallon) to domestic hot water heater.
- 4.1.3 Thermal energy storage (1200 gallon) to heat pump evaporator.
- 4.1.4 Thermal energy storage (1200 gallon) to air handler.
- 4.1.5 Heat pump condensor to air handler.
- 4.1.6 Heat pump condensor to wet cooling tower.
- 4.1.7 Cold thermal energy storage (1800 gallon) to heat pump evaporator.
- 4.1.8 Air handler to heat pump evaporator.
- 4.1.9 Air handler to cold thermal energy storage (1800 gallon).

4.2 Electric-to-Electric transfers.

- 4.2.1 Photovoltaic array to inverter.
- 4.2.2 Inverter to isolation transformer.
- 4.2.3 Isolation transformer to house electrical main.
- 4.2.4 Utility service to house electric main.
- 4.2.5 House electric main to utility.

4.3 Electric-to-mechanical/thermal transfers.

- 4.3.1 House electric main to washer and dryer.
- 4.3.2 House electric main to stove and oven.
- 4.3.3 House electric main to flat plate collector pumps.
- 4.3.4 House electric main to hot water tank resistance heating element.
- 4.3.5 House electric main to hot water tank circulation pump.
- 4.3.6 House electric main to wet cooling tower fan.
- 4.3.7 House electric main to wet cooling tower pump.
- 4.3.8 House electric main to heat pump evaporator/thermal energy storage pump.
- 4.3.9 House electric main to heat pump compressor.
- 4.3.10 House electric main to heat pump evaporator/cold thermal energy storage pump.
- 4.3.11 House electric main to air handler/cold thermal energy storage pump.
- 4.3.12 House electric main to air handler electric resistance heaters.
- 4.3.13 House electric main to air handler fan.
- 4.3.14 House electric main to indoor lighting and miscellaneous.
- 4.3.15 House electric main to outdoor lighting and instrumentation.

4.4 Weather data.

- 4.4.1 Insolation: total insolation on the plane of the array and collectors during off-peak, shoulder and peak hours.
- 4.4.2 Degree-hours (21°C basis): heating or cooling, during off-peak shoulder and peak hours.

4.5 Quarterly Reports

Quarterly reports will be issued giving the above energy transfer information in SI units for each of the three months during the quarter and for the consolidated three month period. To a first approximation

the above transfers should provide a set of energy exchanges consistent with the conservation of energy. Both un-accounted thermal losses and changes in the quantity of stored energy will complicate the exact conservation balance. Where possible, such effects will be identified, quantified and reported.

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