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SOLAR TOTAL ENERGY PROJECT AT SHENANDOAH, GEORGIA SYSTEM DESIGN

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A. J. Poche, General Electric Company, King of Prussia, Pa. 19406

ABSTRACT

The U.S. Department of Energy, with Sandia Laboratories providing technical support and management, is near completion of the Definitive Design Phase of the Solar Total Energy Project to be constructed at Shenandoah, Georgia. General Electric Company designed the Solar Total Energy System (STES) with the capacity to provide 50% of the total electrical and thermal energy requirements of the 25,000-square-foot Bleyle of America knitwear plant located at the Shenandoah Site. The system will provide 400 kilowatts electrical and 3 megawatts of thermal energy.

The STES has a classical, cascaded total energy system configuration. It utilizes one hundred twenty (120), parabolic dish collectors, high temperature (750°F) trickle oil thermal energy storage and a steam turbine-generator. The electrical load peak shaving system has been designed for interconnected operation with the Georgia Power system and for operation in a stand alone mode.

INTRODUCTION

The Solar Total Energy System at Shenandoah, Georgia, will be a large scale prototype of a classical cascaded system utilizing solar energy. Definitive performance and cost data for a solar system will be obtained during the operation of the system and an industrial solar total energy capability established.

Figure 1 is an illustration of the Project Site after installation of the STES. A high temperature silicone heat transfer fluid is used to transport solar energy from the parabolic dish collectors to thermal storage or a steam generator. Thermal energy storage is accomplished by use of a low cost, trickle oil system using an iron ore storage media. The power conversion system employs a steam Rankine cycle and high speed (42,500 rpm) turbine.

FIG. 1. SOLAR TOTAL ENERGY SYSTEM SHENANDOAH, GA

The STES has the flexibility to operate in either a stand alone or peak shaving mode while satisfying electrical power, process steam, heating and cooling requirements of the knitwear fabrication plant adjacent to the STES site.

Shenandoah is near Newman, Georgia and is an industrial-residential planned community. Sun right easements have been obtained on the land bounding the 5.74-acre STES site to prevent obstruction of the field insolation.

SYSTEM DESCRIPTION

Figure 2 depicts the three major loops of the STES: solar collection and storage, power conversion and thermal utilization.

A peak energy delivery rate of 10×10^6 Btu/hr is obtained from the solar collector field.

The solar collector field consists of twelve parallel branches with ten parabolic dish collectors in each branch. Energy is transported from the several collectors to thermal storage or the steam generator by a high temperature silicone (Syltherm™ 800) heat transfer fluid, which is stable over the operating temperature range of the solar collector field (500°F inlet, 750°F outlet). During periods of low insolation or inclement weather, the system can be operating with energy from the thermal energy storage system or a fossil-fired heater.

The power conversion loop which includes the steam generator, turbine-generator and condensor is located in the mechanical building shown in Figure 1. Process steam (1380 lbs/hr) for the knitwear facility is extracted at an intermediate turbine stage. Thermal energy from the turbine exhaust steam is extracted via condensor and transferred to the thermal utilization loop for heating and cooling (by chilled water from an absorption unit) of the Bleyle Plant and the STES Mechanical Building. The major components of the thermal utilization loop (Figure 2) are the low temperature storage tank, cooling towers and the absorption air conditioner.

In the peak shaving mode, the STES operates with a 50 to 75 kW_e baseload provided by the local utility. A summary of the system capabilities and load requirements is presented in Table 1. Fifty percent (50%) of the annual energy requirements of the Bleyle knitwear plant will be satisfied by solar energy conversion.

When operating in the automatic mode, start-up and operation of the STES will be based on a real time clock, as well as measurements of system status, demand and environmental conditions. A typical Operating Timeline for the system is shown in Figure 3.

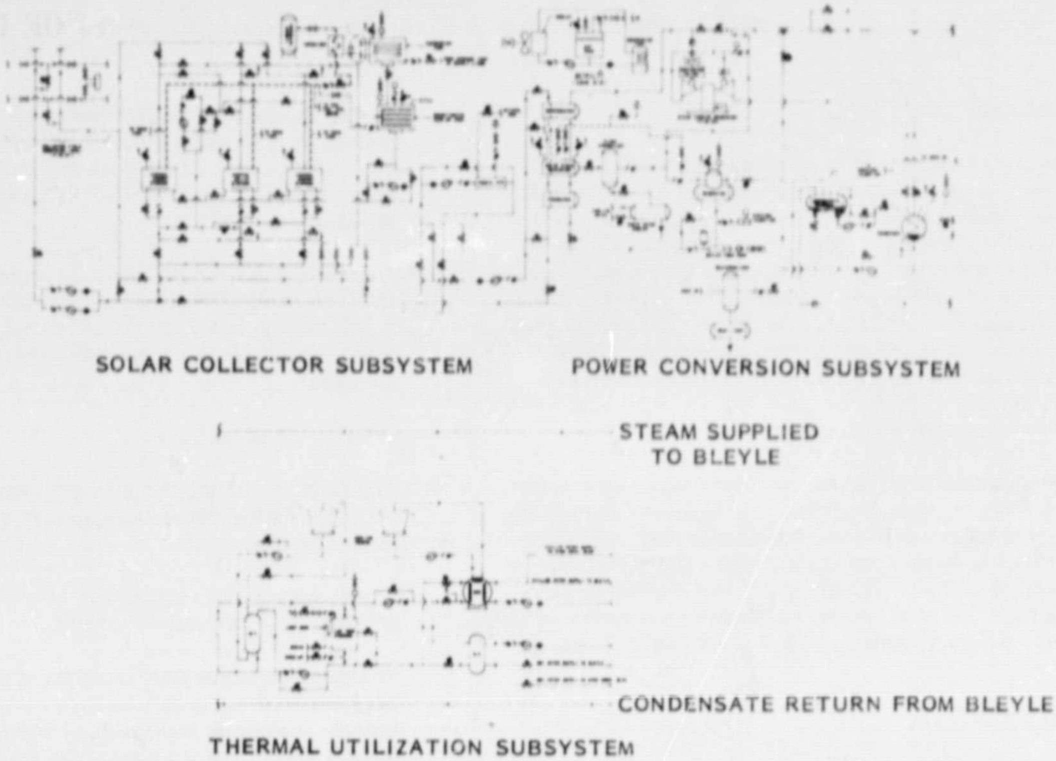

FIG. 2. STES - THREE MAJOR LOOPS

TABLE 1. PEAK DEMANDS AND ANNUAL STES ENERGY CONTRIBUTION

	LOAD REQUIREMENTS		STES CAPABILITY	ANNUAL STES CONTRIBUTION
	BLEYLE	STES		
ELECTRICAL	161 KW	137 KW	400 KW	34%
COOLING	113 TONS	20 TONS	133 TONS	78%
HEATING	324 KBTU/HR	32 KBTU/HR	356 KBTU/HR	98%
PROCESS STEAM	1.4×10^6 BTU/HR (1380 LBS/HR @ 114 PSIA, 337°F)	0	1386 LBS/HR	54%

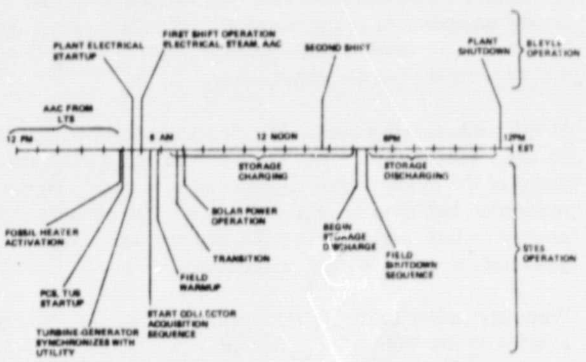

FIG. 3. WEEKDAY STES OPERATING TIMELINE
CASE: APRIL 13TH SSMY

The solar collector field operates independently of the electrical and thermal load supply equipment. Operation is initiated by solar clock (with a measured isolation permissive) for startup, and operation continues through the day as long as sufficient insulation is available. Based on solar availability, thermal storage status, and demands, a backup fossil heater is activated, so that the Bleyle plant loads are always supplied.

For the case shown in Figure 3, which was abstracted fro... annual system simulation using Shenandoah Solar Model Year climatology, the storage tanks were depleted in the early morning. The fossil heater was activated, the power conversion system and thermal utilization were started, and the turbine-generator synchronized with the utility. All this occurred prior to the Bleyle 1st shift startup. The collector field started up at approximately 6 o'clock and solar energy was provided to the system at 8 o'clock.

Solar Collector (SC)

The solar collector is a 7-meter diameter, paraboloidal dish with a cavity receiver. Reflected solar energy is focused onto a cylindrical coil of blackened stainless steel tubing (1/2-inch diameter) within the receiver. As the collectors are hydraulically connected in parallel, the total field temperature rise occurs in each receiver (250°F). The reflector assembly consists of 21 die-stamped aluminum petals with a highly reflective laminated surface (FEK 244).

Each collector tracks the sun through its daily and seasonal variations by use of a polar-declination gimbal arrangement. A hybrid sun tracking technique is employed: course tracking of the sun (($\pm$ 0.6°) is computer controlled; and fine tracking of the sum ($\pm$ 1/4°) is obtained by nulling the output of optical sensors. The optical tracker employs a pair of sensors on each axis. Sensors of each pair are located on opposite sides of the receiver aperture plate, and the collector is positioned by balancing the intensity of the "tails" on the reflected, focused image straddling the aperture. The use of a .6° computer limit prevents wandering of the collector because of extraneous reflections, i.e., cloud glint.

Four full size prototype solar collections (Figure 4) were built and tested in the Sandia Laboratories' Quadrant Facility to verify the performance and design adequacy of the Shenandoah Solar Collector. The test program established that excellent performance can be obtained from a high temperature (750°F fluid outlet temperature) parabolic dish collector fabricated with existing industrial processes. On a clear day, a collector thermal efficienty of 67% was realized, Figure 5.

FIG. 4. QUANDRANT TEST OF SHENANDOAH SOLAR COLLECTOR

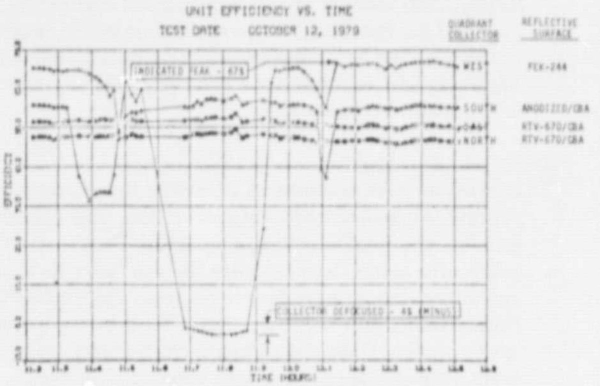

FIG. 5. QUADRANT TEST SOLAR COLLECTORS

Several required design modifications were identified and implemented during the test program. As a result of the high heating rate imposed on the receiver (concentration ratio of 234), it was necessary to add a quartz cloth covering to the receiver aperture plate. This layer reduced the stainless steel aperture plate temperature level sufficiently to eliminate plate warping. In addition, the epoxy used to stiffen the ends of the fiber optic sensor bundles degraded and distorted the sensor measurement. This was eliminated by replacing the optic bundle ends with a solid cane design that is compatible with the high temperatures occurring during acquisition and defocus of the collector. Subsequent tracking experimentation showed that the optical tracking system focused the receiver within the design tolerance ($\pm$ 1/4°).

A major design concern was the slope error of the dish and its ability to concentrate the solar energy to satisfy the design intercept factor requirement (96%). A micro-densitometer evaluation was made of the reflected illumination from the dishes while tracking the moon and while focused on a boresight light. These measurements confirmed that the design intercept factor was satisfied.

<u>High-Temperature Thermal Energy Storage Subsystem</u> (HTS)

Excess collected energy will be stored for use during periods when the collector field cannot provide sufficient energy to operate the system. To minimize the capital investment in heat transfer fluid, the STES utilizes a trickle oil storage system, Figure 6.

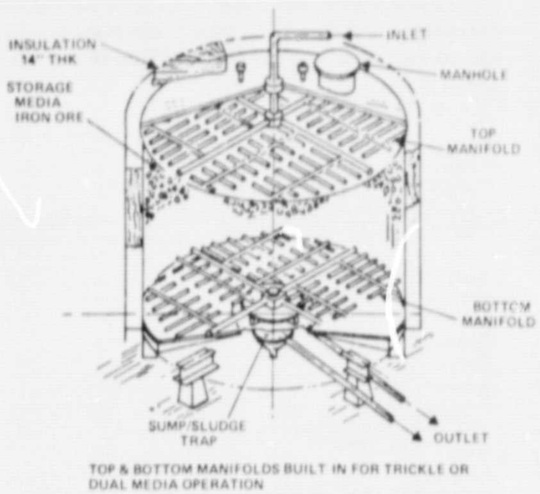

FIG. 6. TRICKLE OIL THERMAL ENERGY STORAGE

The heat transfer fluid is introduced at the top of the tank by a distribution manifold and allowed to trickle through a low cost, iron ore storage media. In both the charging mode and discharging mode, energy is transferred between the storage media and a thin film of the heat transfer fluid. For the STES, three storage tanks will be employed with a combined capacity of 60 million Btu. Maximum charge and discharge requirements for the thermal storage subsystems are 10 million Btu/hr.

To validate the trickle oil concept, a column test representative of the STES operational conditions was performed. It was shown that uniform heating and cooling of the bed, during charging and discharging, occurred if the fluid was distributed uniformly at the top of the tank, Figure 7, and that sharp thermoclines resulted.

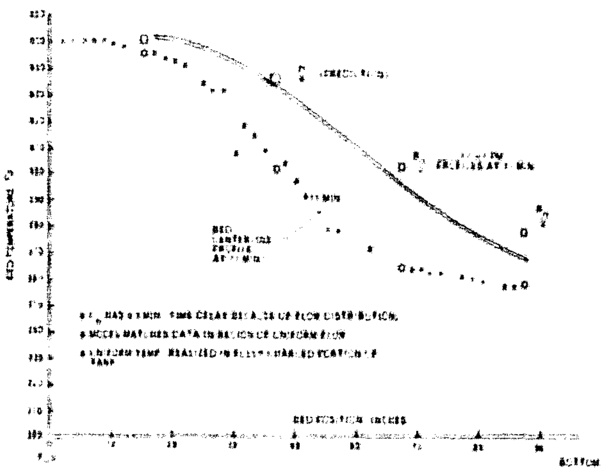

FIG. 7. TRICKLE OIL COLUMN TEST, CHARGING MODE

In addition, the test showed that the temperature gradient in a partially charged or discharged tank would not experience significant axial heat flow during normal operation, which would degrade the temperature of the stored energy in the charged portion of the tank, Figure 8.

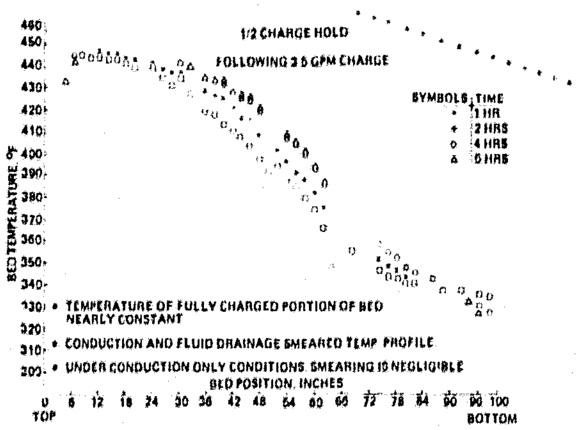

FIG. 8. TRICKLE OIL COLUMN TEST, HOLDING MODE

Power Conversion Subsystem (PCS)

Major elements of the power conversion subsystem are a drum-type steam generator with preheat and superhear sections, a high-speed steam turbine-generator set rated at 400 kW_e, a condenser, a condensate storage tank, a make-up demineralizer, a deaerator, required pumps and local controls.

The recirculating heat transfer fluid from the solar collector field can deliver 10 million Btu/hr to the steam generator and provide up to 10,500 lb/hr superheated steam at 700 psig/720°F to the steam turbine. Alternately, in the event of turbine outage or no electric power demand, the steam turbine can provide saturated steam at 110 psig for process and other thermal uses. To avoid particulate erosion of the high-speed turbine blading (42,500 rpm), the steam flow is filtered to reduce the contaminate level to 0.1 ppm, with 95% of the particles less than 4 microns.

The steam turbine generator produces electric power in the range of 100-400 kW_e at 480 volts, 3 phase, 60 Hz. The steam turbine is a high specific speed/high efficiency design: high pressure stage efficiency is 66% and low pressure stage efficiency is 76%. Controlled extraction of superheated steam (110 psig) from the turbine provides process steam for the Bleyle plant and deaerator.

The turbine exhaust is condensed at 6 psig and the condenser cooling water (210°F) is used as the energy transport to the Thermal Utilization Subsystem.

Thermal Utilization Subsystem (TUS)

The thermal utilization subsystem consists of a 10 million Btu low temperature water (210°F) storage system, a 250-ton absorption air conditioner de-rated to 133 tons with inlet water at 210°F, and two cooling towers for heat rejection from the absorption air conditioner and excess energy from the PCS.

On an annual basis, the thermal utilization subsystem will provide 78% and 98% of the combined STES Mechanical Building and Bleyle Plant cooling and heating loads, respectively.

Controls and Instrumentation Subsystem (CAIS)

The control and instrumentation subsystem initiates, regulates and terminates collector tracking, energy storage, power generation and thermal utilization for heating and cooling of the Bleyle plant and the STES Mechanical Building. When operating in the peak shaving mode, the control and instrumentation subsystem monitors and regulates the generation of power to satisfy system requirements.

The control and instrumentation subsystem includes a central control console, a central minicomputer and remote microprocessor control units. The control system has the flexibility to be operated in a manual or automatic mode, and permits the operator to monitor or control the system functions from the control panel. Both mimics and color graphic CRT's are employed for data display. Data archiving is performed with magnetic storage tapes, and real time data in hard copy form is available via the computer line printer.

SUMMARY

A solar total energy system utilizing parabolic dish collectors has been designed that has the capability to provide greater than 50% of the energy requirements of a knitwear fabrication plant with 25,000 square feet of floor space.

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The solar collector test program performed at the Sandia Laboratories test facility in Albuquerque has demonstrated that high thermal efficiencies (67% measured) can be obtained from a parabolic dish built with existing fabrication technology. Thermal efficiency and optical measurements have verified that the Shenandoah solar collector design will satisfy design criteria and performance requirements.

Column tests have demonstrated that the trickle oil thermal energy storage system will provide an efficient and cost-effective means of storing thermal energy.

ACKNOWLEDGEMENT

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