ARIZONA SOLAR POWERED PUMPING PROJECT: OPERATING EXPERIENCES

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INTRODUCTION

In 1974, the magnitude of irrigation energy requirements, potential natural gas shortages and greatly increased energy costs motivated Arizona farmers to request an evaluation of the use of solar energy to drive irrigation pumps. A 1975-76 University of Arizona feasibility study listed development of efficient, economical equipment, full utilization of the produced energy and availability of capital at a modest price as primary conditions to be met for successful marketing and use of solar powered pumping plants (Larson et al., 1978). In 1977, three firms prepared conceptual designs of solar thermal-electric power plants to provide energy for deep well pumping. The Acurex concept was selected for construction on the Dalton Cole Jr. farm, located southwest of Coolidge in Central Arizona. Procurement began in 1978. The operational plant was dedicated in November, 1979. It is operated by the University of Arizona with Sandia Laboratories direction.

PLANT DESCRIPTION

The Coolidge power plant consists of solar collector, energy storage and energy conversion subsystems, Figure 1. The collector field, manufactured by Acurex, consists of 2140 m^2 (23,040 ft^2) of collectors arranged in 8 north-south oriented loops, each containing 48 line-focusing, parabolic trough collectors. Collector reflective surfaces are polished aluminum; the solar concentration ratio is about 36 to 1. Collector receiver tubes are coated with a selective black chrome surface and surrounded by a pyrex tube.

A heat transfer oil, Caloria HT-43, is pumped through the receiver tubes at a rate controlled to obtain the desired outlet temperature, usually 288C (550°F). Energy storage is a 114 cubic meter (30,000 gallon) tank of hot oil, sufficient for approximately six hours of turbine generator operation.

Hot Caloria is circulated through a vaporizer heat exchange unit to expand the organic fluid toluene. Energy conversion is accomplished by a Rankine cycle turbine engine made by Sundstrand. The toluene is recondensed in a cooling tower. Nominal gross generator output is 200 kW; net electrical power production is over 150 kW.

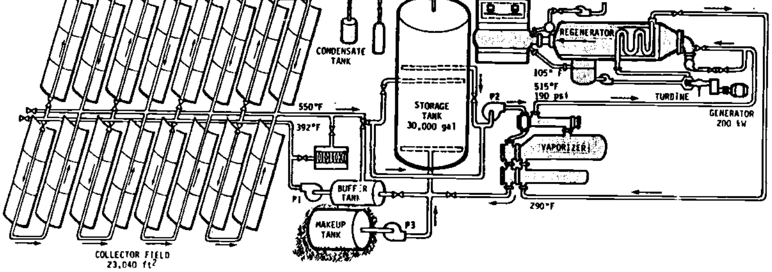

Figure 1. 150-kW Solar-Powered Irrigation Facility Flow Diagram (Duffy et al., 1980)

The plant is interconnected with the utility grid. Electric District Number Two, the local utility company, receives energy generated by the plant and supplies energy required to meet solar plant and irrigation pump needs. Energy above plant requirements is purchased by the utility.

SYSTEM PERFORMANCE

The solar power plant has been operated on a daily basis. Collector subsystem efficiency was determined quarterly. The performances of power conversion subsystem, thermal storage tank and other plant components also were evaluated during specific tests. When tests were not being conducted, the plant was operated as normally and fully as possible.

Since April 1980, the collector subsystem has operated 90-95 percent of times having sufficient insolation (Torkelson and Larson, 1981). Evaluation tests and maintenance efforts were responsible for inoperative periods. Subsystem modularity contributed to the high percentage. One or more of the eight collector loops or 48 tracking systems can be removed from service during subsystem operation.

Available solar energy, collected thermal energy, and generated electrical energy have been compiled for 1980. A relatively small amount of thermal energy was collected in January, February, March and December, Figure 2a. Fifteen days of cloudy weather limited January output. Collector system pump repair caused February energy collection to be very low and greatly reduced March operation. Thermal energy collection then increased, peaking in May and June. October had clearer weather but less energy was collected due to lower sun angle than in cloudier September. Downtime for piping modifications contributed to the low December value. The amount of collected thermal energy as a percentage of available direct radiation received during collector system operation was 7.5 in January, 20.6 in March and 32.5 in June.

Collector subsystem efficiency was determined on clear days near winter solstice, spring equinox, summer solstice and antumnal equinox. Collectors were washed prior to tests. During tests, the Caloria flow rate was controlled to maintain the desired, constant collector system outlet fluid temperature. Collector system efficiency was computed as the thermal energy gained by Caloria during passage from inlet to outlet manifold locations divided by the total direct normal solar radiation intercepted by the collector area.

The mid-day collector system efficiency was 30-37 percent on April 3 and September 24, 40-42 percent on June 25 and 5-14 percent on December 24. Thermal energy collection rates were about 650, 750, 500 and 150 kW for spring, summer, fall and winter test days, respectively. Collector fluid outlet temperature was maintained at about 284C (545°F) during the first three tests. Too little energy was collected to conduct a stable, comparable evaluation at the higher temperature during the winter solstice period. That test was conducted with an outlet temperature of 232C (450°F). Average collector system efficiencies were 36.9 percent on the summer test day, 30.1 and 31.4 percent during the spring and fall tests and 7.2 percent on the winter test day.

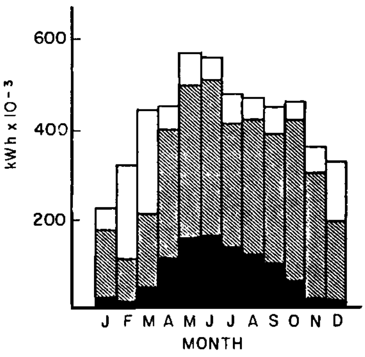

Figure 2a. Solar energy collected in 1980. Clear, crosshatched and shaded areas represent solar energy availability, solar energy available during collector operation and collected thermal energy, respectively.

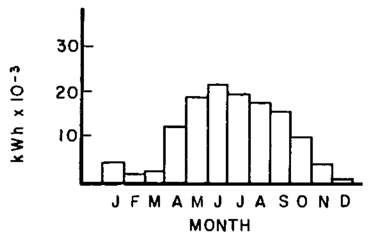

Figure 2b. Electrical energy generated by the plant in 1980.

The efficiency was lower than predicted, largely because collector reflectivity did not meet expectations. Reflectivity of polished aluminum collector surfaces was only about 60 percent at year's end, at least 10 percent below expectations. In August 1980, aluminized mylar (FEK-244) film was applied to the surface of 8 of the 384 collector modules for environmental testing. Reflectivity of this surface is 80-85 percent as anticipated. Film is being applied to the other reflector surfaces in 1981. Dust intrusion into glass receiver covers, deterioration of black chrome receiver surfaces at high, perhaps 260C, temperatures and deterioration of flexible hose insulation covers in sunlight also may have reduced collector subsystem performance. Dust seal and insulation cover modifications have been developed and new component installation is being contemplated.

The power conversion subsystem was operated whenever sufficient thermal energy was available. To provide additional thermal energy for operational testing, a natural gas boiler was operated at times. Natural gas provided much of the thermal energy for generator operation in January and December, Figure 2b. February and March operation was reduced due to the pump outage. Electrical energy production rose from 12,480 kWh in April to 22,000 kWh in June before declining again. August production was 18,530 kWh; October output was 10,540 kWh. Peak daily production was about 1200 kWh on June 21.

Performance of the power conversion system was measured in January 1980 tests. Gross efficiency at the 200 kW output design point was 19.7 percent, close to the manufacturer's projected value of 20.2 percent. Gross cycle efficiency is the electrical energy output from the generator divided by the thermal energy input to the vaporizer. The average power requirement for the power conversion system equipment was 24 kW. Subtracting this usage from 200 kW yields a net cycle efficiency of 17.3 percent at the design point. A key operational finding was the nearly constant gross cycle efficiency over a wide power range, a desirable attribute in power conversion system operation.

Power conversion subsystem operation varied from about one hour on a sunny January day to six hours on a June day. Operation was limited by collector field size. Operator assistance was required during startup and periodically during operation. Replacement of the vaporizer level sensor reduced operator requirements. Modifications planned for 1981 are expected to make completely automatic turbine-generator operation possible.

When tests were not being conducted, the solar plant was operated to maximize utilization. Performance of systems and components was observed, problems noted and changes made as deemed appropriate to improve plant performance and operating reliability. The Arizona environment contributed to some troubles.

Collector tracking sensors have been adversely affected by moisture condensation and thermal stresses. Erratic tracking resulted and a number of sensors were replaced. Modified sensor units were developed; two units have been operated successfully at the plant since September. Several electric tracking motors failed during the year; failures attributed to manufacturing problems. Flow meters and other electronic equipment also have required periodic repair. Moisture condensation has caused a number of the problems.

Various leakage problems required attention. Hot Caloria leakage developed from pump seals, flanged joints and valve stems. The potential hazard, of fire or burns, focused attention on eliminating this leakage. New seals are being evaluated and information for future designs has been developed. Power conversion system vacuum leakage and excessive pneumatic control system air usage have required maintenance attention as well as increased pump operation.

Thus far, plant operation has permitted evalution of components in a new operating system and unique environment. Information obtained and modifications and improvements made as a result of these experiences have made large contributions toward commercialization.

ON-FARM SITING

The desirability of on-farm siting of a solar power plant is dependent on a number of factors. Among these are the availability of sufficient land, the amount of personnel time required for operation and maintenance, load management and cost.

LAND REQUIREMENTS

The land area required for a solar plant is primarily due to the required collector area. The Coolidge plant has 2140 m^2 of collectors which occupy a ground area about three times as large to minimize collector shading and permit entrance by maintenance vehicles. These collectors collected sufficient energy for only 6 hours per day of turbine-generator operation in summer. With more efficient collectors spaced more closely, including land for the power plant, about 20,000 m^2 (5 acres) of land would be required for a 200 kW plant capable of 24 hour summertime operation.

OPERATIONAL REQUIREMENTS

University personnel have been in attendance during all plant operation to date. In part, attendance was deemed necessary because of the need to observe and record operational events of an experimental facility. However, daily plant start-up, shut-down and power conversion subsystem operational activities required about 2-3 hours of effort in winter, 5-6 hours during the summer. Tasks included inspecting components and replenishing supplies, such as cooling tower water treatment chemicals, as well as monitoring and controlling equipment during operation. A 1981 goal is elimination of the latter tasks through automation. Some daily attention still will be needed, though perhaps just inspection.

Recurring maintenance tasks required approximately 1-2 additional hours per day on the average. Activities included collector cleaning and periodic alignment inspection, equipment lubrication and filter replacement and site maintenance. A number of electronic components need periodic testing and recalibration. Recurring maintenance need not be performed daily, but may be concentrated and scheduled to accomodate other commitments.

Repair or replacement of malfunctioning devices or equipment is another operating responsibility. The requirement is not yet quantifiable. However, equipment reliability has been quite good and first year improvements should result in decreased repair requirements.

The solar plant provides a new and perhaps unique work environment. Plant operation requires a range of skills. These include electrical, plumbing, report writing and electronic maintenance abilities. However, personnel with the necessary basic skills can become proficient in solar plant operation through a relatively short period of on-the-job training.

LOAD MANAGEMENT

The solar power plant near Coolidge generates electricity. Electrical energy production is a less efficient method than is direct connection of power plant and pump. However, electricity can be readily transported to and used by other pumps, at the farmstead or by other users.

Isolation of solar plant and pumps makes pumping weather dependent and requires special scheduling to maximize utilization of produced power. A reservoir could buffer power production and use scheduling mismatches, but requires land and additional management and reduces water use efficiency.

The Coolidge solar plant is interconnected with the utility company grid system. This interconnection assures pumping power availability independent of solar power plant operation and provides a use for power generated when unneeded on the farm. Generated power excess to farm needs is purchased by the utility. A system composed of independent power plants interconnected by a grid appears well suited to solar application.

COST

The Coolidge solar power plant cost 5.3 million dollars to design and construct. Construction of a similar plant now would cost an estimated 2.5 million dollars. About half the cost would be for the collector subsystem, another quarter for the power conversion subsystem. Total cost is approximately $12 per gross watt capacity.

Mass production should reduce collector costs substantially. The energy storage and power conversion subsystem could be used with a larger collector field to increase annual electrical output. Changes in plant configuration and increases in collector production could reduce solar plant costs to under $5 per gross watt in the future.

SITING CONCLUSIONS

The land requirement is substantial, but probably not a barrier to on-farm siting of solar power plants in Arizona. The plant may require too much time and special skills to be appropriately operated on most Arizona farm enterprises. Interconnection with the electrical utility company grid offers the most efficient option for load management. Solar power plant costs will be higher than coal fired plants for a number of years.

SUMMARY

A 150 kW solar thermal electric power plant has been operated in Central Arizona since October 1979. Collector, energy storage, and power conversion subsystem performances have been determined, equipment operation evaluated and operational requirements determined during this period. The plant largely performed up to expectations, but some equipment modifications were found to be desirable. The changes are being made and will be evaluated in 1981-82.

ACKNOWLEDGEMENTS

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