A 150 kW Solar Power Plant to Drive Irrigation Pumps

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Summary

An experimental 200 kW solar power plant was operated for the past three years to determine its applicability to on-farm powering of deep well irrigation pumps. A number of equipment improvements resulted which improved equipment reliability, increased plant energy production and reduced operational requirements. Plant cost and operating requirements presently limit its application.

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Introduction

In 1974, motivated by rising energy costs and threatened energy shortages, Arizona farmers requested an evaluation of solar energy to drive irrigation pumps. A University of Arizona feasibility study concluded development of reliable, economical equipment was the key to harnessing solar energy for irrigation pumping.

In 1977, conceptual designs were prepared for solar thermal electric power plants sized to meet deep well irrigation pumping requirements (150 kW for 80 ha of irrigated cropland). Plant component procurement began in 1978; construction was completed in October 1979. The plant is located six miles southwest of Coolidge on the Dalton Cole farm.

The solar power plant was operated by the University of Arizona with Sandia Laboratories direction until experiment termination in November 1982. Operational objectives were to quantify energy collection and conversion, quantify operating and maintenance requirements, determine equipment reliability and identify desired improvements, and evaluate the suitability of locating this type of solar plant on-farm to drive irrigation pumps.

Solar Plant Description

The solar plant consists of solar collector, energy storage and power conversion subsystems, Figure 1. The collector field contains 2140 m^2 of line-focusing parabolic trough collectors. The collectors, oriented north-south to maximize summertime energy production, were arranged in eight flow loops. The flow loops contain six collector groups, each having its own tracking system which causes it to follow the sun.

The collector troughs are about 1.8 m across by 3 m long and originally had aluminum reflective surfaces. These surfaces were laminated with aluminized acrylic film (FEK-244) in Spring 1981 to improve reflectivity. A heat transfer oil, Caloria, is pumped through the receiver tube, located at the solar collector focus, at a rate controlled to obtain the desired collector loop outlet temperature. The receiver tubes are coated with a selective black chrome surface and surrounded by a glass tube to enhance energy collection. The sun's energy, concentrated about 36 times by the reflectors, is absorbed by the oil, heating it to an operating temperature of about 288°C (550°F).

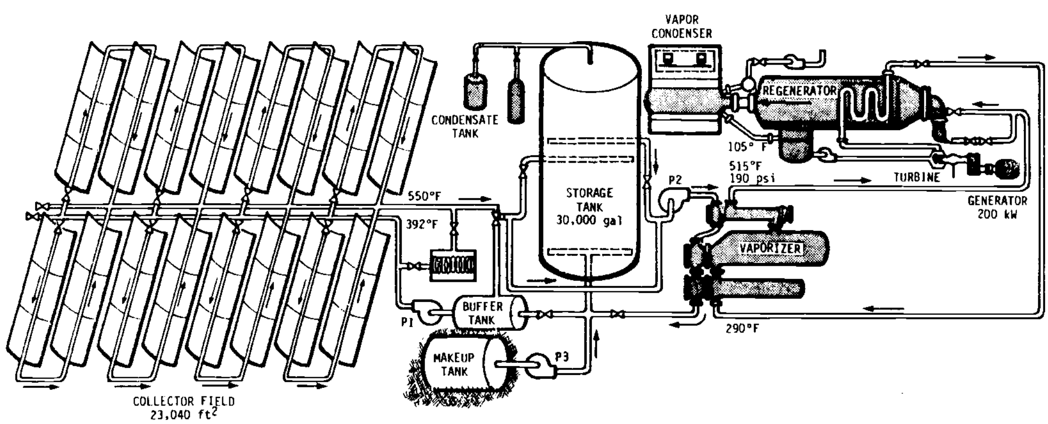

Figure 1. Schematic diagram of the solar thermoelectric power plant at Coolidge, Arizona

Heated Caloria is stored temporarily or sent directly to a vaporizer heat exchanger. A 114 m^3 insulated tank of Caloria provides energy storage capacity sufficient for over 5 hours of power conversion subsystem operation.

Thermal energy is converted to electrical energy by means of an organic Rankine cycle engine and generator. The power conversion subsystem (PCS) includes a heat exchanger to vaporize the working fluid toluene, single stage impulse turbine, gear reduction unit, synchronous generator and evaporative cooling tower to recondense the toluene. A regenerator stage is included to improve energy conversion efficiency.

The electrical generator is interconnected with the Electric District Number Two utility company grid. The utility 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.

Operation and Maintenance

The Coolidge Solar Irrigation Facility operated every day during the hours of solar availability. Initially, an operator was in attendance during all plant operation. The operators performed operational, repair, and maintenance tasks, recorded data and incidents of interest, explained plant operation to visitors, and made plant equipment improvements. Because of these improvements, the plant operated automatically on routine, incident-free days in 1981-82. However, operator attendance was mandated during turbine startup for safety reasons. An estimated one hour per day of operator time was required to inspect the plant, replenish operating supplies, and monitor turbine startup in 1982. These tasks were not complex and were performed routinely by student employees after a short period of on-the-job training.

Operational supplies cost about $240 per month. Cooling tower water, purchased from the municipality, and water treatment chemicals each cost about $60 per month, together totaling half the operational supply cost. Carbon dioxide and nitrogen gas cost about $60 per month, largely for carbon dioxide. Replacement toluene cost $50 per month. Reduced water expense, elimination of Caloria pump seal cooling requirements and decreased toluene loss could reduce operational supply costs substantially, perhaps to less than $100 per month.

Maintenance activities included cleaning, lubrication, and adjustment efforts required to keep equipment in good operational condition, maximize plant energy producion, and maintain good site appearance. These tasks do not require skilled technicians and can be learned on-the-job. Maintenance activities required an average of about 2 hours per day or 10 hours per week. Collector washing and maintenance of site appearance accounted for about half of the time.

Repairs performed by plant personnel required an additional hour per day. Repair efforts involved determination of the source or cause of a problem and repair or replacement of the identified component. Fluid leakage was a significant problem, usually requiring seal or gasket replacement. Electrical controls and activators were another source of repair requirements. A skilled technician was required to isolate and identify problem causes and perform the needed repairs which required electronic, electrical, plumbing and mechanical skills.

Maintenance supplies included lubricants and filters, fuses and lamps, cleansing products, pesticides, and office supplies. Repair parts included gaskets and electrical relays. Repair and maintenance supplies cost an estimated $160 per month.

Energy Production

Thermal energy collection and electrical energy production were recorded daily to obtain an energy budget for the plant. Electrical energy production for October 1981 through September 1982 was about 180,000 kWh. Plant equipment used about 40,000 kWh, so the annual net plant output was 140,000 kWh.

The energy production schedule was, as intended, the same general shape as the pumping energy demand schedule. On a sunny June day, the plant produced about 1080 kWh of electrical energy, but utilized 220 kWh to power plant equipment and cool the control building. Solar energy collection and thermal energy conversion efficiencies were found to be 35 and 19 percent, respectively. About 4.3 percent of the received solar energy was made available as electrical energy for pumping. Total June electrical energy production was 27,400 kWh.

At the times of vernal and autumnal equinoxes, all day solar energy collection efficiency was reduced to 29 percent, but plant energy requirements also were less. Gross electrical energy production on a hypothetical sunny March day was about 810 kWh with about 180 kWh of that amount being used by plant equipment. Thus, about 3.5 percent of the received solar energy was made available as electrical energy. Electrical energy production totaled about 14,000 kWh in March.

Economics

Design and construction of the Coolidge solar power plant cost about 5.5 million dollars in 1978-79. In 1983, a similar plant would cost an estimated 1.5 million dollars due to design simplification and improved production methods. The present collector field is so small that energy storage and power conversion subsystems are underutilized at Coolidge. Increasing the size of the collector field and energy storage capability to permit all day operation of the PCM in June would increase the estimated solar plant cost to three million dollars. The larger power plant would produce an estimated 550,000 kWh of electricity per year, as compared with the actual 1981-82 generation of about 180,000 kWh. Solar power plant design lifetime is 20 years.

Operating and maintenance tasks required about 20 hours per week of operator/technician effort at the Coolidge plant. Supplies cost about $400 per month. Future plants should require less maintenance; the magnitude of some operational and maintenance tasks will increase only marginally with plant size. Thus, an estimated 20 hours per week of operating and maintenance effort will be required at a 550 MWh/yr size plant. Supplies would cost an estimated $10,000 per year.

Collector density is limited by mutual shadowing and the need for access by maintenance equipment. Physical isolation of the turbine may increase operating safety. The larger solar plant referred to above could be sited on 2 ha (5 ac) of land.

In addition to capital, land and operational costs, solar energy production costs depend on interest rates and investment incentives. Comparison with competitive energy costs depends on relative rates of price increases for energy and other goods. The cost of electricity produced by the 550 MWh solar plant has been estimated to be 13 to 38¢/kWh depending on the estimates for interest and inflation rates, capital and operating costs and investment incentives.

Conclusions

The schedules for energy production by solar power plants generally match irrigation pumping demand schedules. Crop water demand is greatest when more solar energy is received. Arid areas receive greater amounts of solar energy than do areas receiving more rainfall.

Solar power plants can be used independently to drive irrigation pumps, either directly or through production of electricity. However, energy or water storage likely would be required for efficient, timely irrigation. Interconnection of the solar plant with the electrical utility grid might yield a more cost effective, readily managed system where electrical utility service is available.

Only enterprises capable of assigning sufficient, trained personnel to the operation should consider on-farm siting of a solar power plant.

Acquisition of solar power plants will require a substantial investment. A 200 kW capacity solar thermal-electric power plant will cost an estimated 2 to 3 million dollars.

The highest known retail rate for electricity sold in Arizona in 1982 was less than 8¢ per kWh. Many irrigators have access to much less expensive energy. Energy from solar power plants will not be cost competitive in Arizona unless solar equipment cost decreases, investment credits are substantial, interest rates are low, and/or alternative energy source prices increase substantially.

References

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