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ABSTRACT

A cost comparison is made between a terrestrial solar cell array power system and a variety of other power sources for the ATS-6 Satellite Instructional Television Experiment (SITE) TV terminals in India. The solar array system was sized for a typical Indian location, Lahore. Based on present capital and fuel costs, the solar cell array power system is a close competitor to the least expensive alternate power system. A feasibility demonstration of a terrestrial solar cell array system powering an ATS-6 receiver terminal at Cleveland, Ohio is described.

INTRODUCTION

The ATS-6 satellite launched in May of 1974 is a link in an experiment to study the effectiveness of satellite relay of educational and instructional programs to schools, learning centers, and community antenna distribution systems. In the United States the experiment will operate until early 1975 as a Health Education Telecommunications (HET) program. Later the satellite will be moved to the opposite side of the world and operate as part of the Satellite Instructional Television Experiment (SITE) in India (ref. 1). Either the HET or SITE receiving equipment, with monochrome TV, will require a total of 200 watt-hours of electrical energy per day when operated 3 hours per day.

Many SITE terminals in India will be located in villages where skill levels are low, money is scarce, and electrical power in many instances is nonexistent. Areas without power will require dependable, locally generated electric power to operate the TV receiver terminal. The problem was examined by the Indian National Committee for Space Research (INCOSPAR) (ref. 2) in a study which considered a variety of power sources and estimated their costs for this application. The study concluded that a kerosene engine-generator-battery combination was the most economical method of producing electrical power in the quantity needed.

Although the study considered solar cells, they were rejected as a candidate because of the high cost. The costs that were available to the study group were those costs associated with space uses of solar cells. Since that time the number of terrestrial applications and the market for solar cells has increased. As a result, arrays designed specifically for terrestrial applications can now be obtained at a cost far lower than space solar cell array costs.

The objective of this report is to use current estimates of solar cell power system costs to assess the competitiveness of solar power for the SITE application. This involves a cost comparison of a solar cell power system with systems examined in the INCOSPAR study, after adjustment for general inflation and fuel cost increases since 1969.

ADJUSTMENT FOR INFLATION AND FUEL COST INCREASES

One of the tasks in the 1969 INCOSPAR study (ref. 2) was to determine the most economical means of supplying power to run the ATS-6 receiver terminal. This was accomplished by determining the cost in India for the various power systems and fuel. Capital costs were determined and an interest charge of 8% per annum on the capital cost charged over the lifetime of the original equipment. Operating costs of fuel were determined on a yearly basis. The total yearly operating cost was computed for each system by adding the annual fuel cost, annual interest, and the capital cost divided by the estimated useful life.

Using the data of reference 2, relative costs of the various systems are adjusted to reflect current capital and fuel costs and are presented in Table I. Capital cost inflation is assumed to be 34% (5% per year) and the cost of fuel is assumed to be double the 1969 costs. In each case the cost was determined for a system of 200 watt-hours per day capacity. Annual interest on the original investment is assumed to be 10%.

TABLE I. - ANNUAL COST FOR 200 WATT HOUR PER DAY REQUIREMENT

	1969	1974
Electrical Power from Distribution Lines		
1 mile	$155	$208
2 miles	240	321
3 miles	315	422
Gasoline Engine Generator Set with Battery	152	222
Diesel Engine Generator Set (1.5 kW generator) with Battery	135	200
Diesel Engine Generator Set (automobile generator) with Battery	150	285
Kerosene Engine Generator Set with Battery	110	190
Manual Power Bicycle Generator with Battery	366	500
Water Power (Too specialized an application)	---	---
Wind Power (Average wind speed too low)	---	---
Lead Acid Battery with Recharging Station up to 10 Miles Distant	200	268

SIZING OF THE SOLAR CELL ARRAY POWER SYSTEM

The solar cell array power system for SITE is a mechanically simple, low maintenance unit with no moving parts. The system consists of a solar cell array, storage batteries and a zener protective diode.

System design starts by first specifying the load requirements of the SITE TV terminals. In each case the basic premise is that the TV terminal will be operated for 3 hours each day. The TV terminals require a normal 65 watts of power, giving a basic daily requirement of 200 watt-hours. In order to determine the solar cell array and battery sizes to meet this requirement, the expected insolation of a selected location must be found. For the SITE terminals insolation conditions reported in reference 3 were used.

Locations in the northern areas of India were considered since direct broadcasts are scheduled for the region. The insolation readings for the city of Lahore were used in the design because they are representative of the average insolation of many reporting stations of northern India, such as Delhi, Allahabad, Jullundur, and New Delhi. Table II lists the average daily insolation of Lahore.

TABLE II. - AVERAGE DAILY INSOLATION, IN LANGLEYS

($cal/cm^2/day$)

Month	J	F	M	A	M	J	J	A	S	O	N	D	Annual Ave.
Lahore	320	410	510	610	660	650	550	470	550	480	390	310	501

To determine the array size for this location computational methods described in reference 4 were used. Briefly, this consisted of using the insolation data to compute the average monthly energy available from a solar cell, taking into account factors such as temperature, sun angle, latitude of location, turbidity, cloud cover, and cell efficiency. From the average monthly energy input the array size and storage battery capacity is calculated based on battery depth of discharge, charge efficiency, temperatures and specific load profile. The solar cell array power system is designed, then, on the basis of an annual watt-hour budget whereby the array generates, over the course of a year, enough watt-hours to satisfy the annual load requirements and battery charging inefficiencies.

A typical set of array and battery specifications for a power supply sized for Lahore, India with a load profile of 200 watt-hours per day would be as follows:

ARRAY

5.6 centimeter round silicon cells (terrestrial quality)

10% cell efficiency

40 cells in series (four 10-cell modules 12-volts/section)

5 cells in parallel (five 12-volt sections)

1.08 square meters (0.0197 square meters/watt)

55 watts-peak array output

BATTERY

12 volts nominal

500 ampere-hour total capacity

SOLAR CELL ARRAY POWER SYSTEM COSTS

Annual costs of the solar array system are dependent upon the lifetime estimates of both the array and battery. The silicon cell array lifetime is estimated to be in excess of 10 years. Based on past experience, battery lifetimes of 5 years or more can be expected. The battery operating conditions are not strenous, entailing only shallow discharges with near full charge maintained most of the time. For this study a ten-year solar cell array life and five-year battery life is assumed.

System costs are based on present and projected commercial prices for solar cell arrays and present battery prices. Present prices for arrays are $17 per peak watt of output (ref. 5) for 12-volt lead acid batteries, 35 cents per ampere-hour. Future array cost estimates are based on the goals of the Photovoltaic Energy Conversion Program of the Energy Research and Development Administration: $5/watt by 1977, to $2/watt by 1979 and $.50/watt by 1984. These cost reductions are expected to result from the automation of present production techniques.

Table III shows the annual costs for a solar cell array power system computed using the same assumptions as for the systems in Table I.

TABLE III. - ANNUAL COST OF A SOLAR CELL ARRAY POWER SYSTEM FOR A LOAD OF 200 WATT HOURS PER DAY AT LAHORE INDIA

Array Cost	$17/W	$10/W	$5/W	$2/W
Array prorated/10 years	93	55	27	11
Battery prorated/5 years	35	35	35	35
Interest 10% of original cost	111	73	45	29
Total	$239	$163	$107	$75

Using Table III solar cell array power system annual costs may be compared to the least expensive system in Table I, the kerosene engine-generator at $190 per year operating cost. At today's prices the annual cost for a solar array system for Lahore India would be 26% more than for the kerosene-engine generator system. With an array price of $10/W the annual cost of the solar array system would be 14% less than for the kerosene-engine generator system. With array prices at $2/watt, the annual cost would be less than half that of the generator system. These results show that the solar cell array power system is presently competitive with the alternate power systems and can be expected to be substantially less expensive than the others in the near future.

Logistics considerations of refueling or skilled maintenance, as required for the generator type systems, are unnecessary for the solar cell array power system. Only periodic checks of the electrolyte level in the batteries and perhaps occasional cleaning of the array surface would be needed.

A SOLAR POWERED ATS-6 RECEIVER TERMINAL DEMONSTRATION

To illustrate the feasibility of a solar cell array power system for a SITE or a HET receiver terminal a demonstration system was put into operation at the Lewis Research Center, Cleveland, Ohio (figure 1). The system consists of the antenna, solar panel, and battery box located outside and the receiver and TV monochrome monitor located within the adjacent building. The solar array charges lead acid batteries that supply power to a D C. to 110 V. A.C. converter which operates the receiver and TV unit.

In figure 2 a close-up of the solar array shows the south oriented array, at a tilt angle of 64° for Cleveland latitude, mounted on the antenna mast. The array consists of four 12-volt (nominal) sections connected in parallel, providing 44 watts of peak power. Each section can be seen to consist of four 10-cell modules which are in connected series to provide a 40-cell string. Additional sections may be added in parallel to increase the charging capacity of the array to suit most design needs.

The solar array in figure 2 is slightly smaller (20%) than required for the Lahore, India location. This array was sized for local demonstrations which have a shorter operating period than prescribed for the SITE applications. The 55-peak-watt output for the Lahore design would be provided by five sections as previously described.

CONCLUSIONS

The solar array power system proposed for the ATS-6 TV terminal load is a viable power supply that should be considered in competition with other systems specified in reference 2. The much lower production costs of present terrestrial solar cell arrays, as compared to costs of space cell arrays used in previous power system cost estimates makes solar powered systems a close competitor to the cheapest of the alternate power systems. And, in the near future, it is expected that solar array power systems will drop in cost significantly below the least expensive alternate system.

The simplicity, clean and quiet operation, minimal maintenance, and low yearly operating cost make the solar cell power system an excellent system for operating the ATS-6 Educational TV receiver terminal.

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Figure 1. - Demonstration System of HET Receiver Terminal

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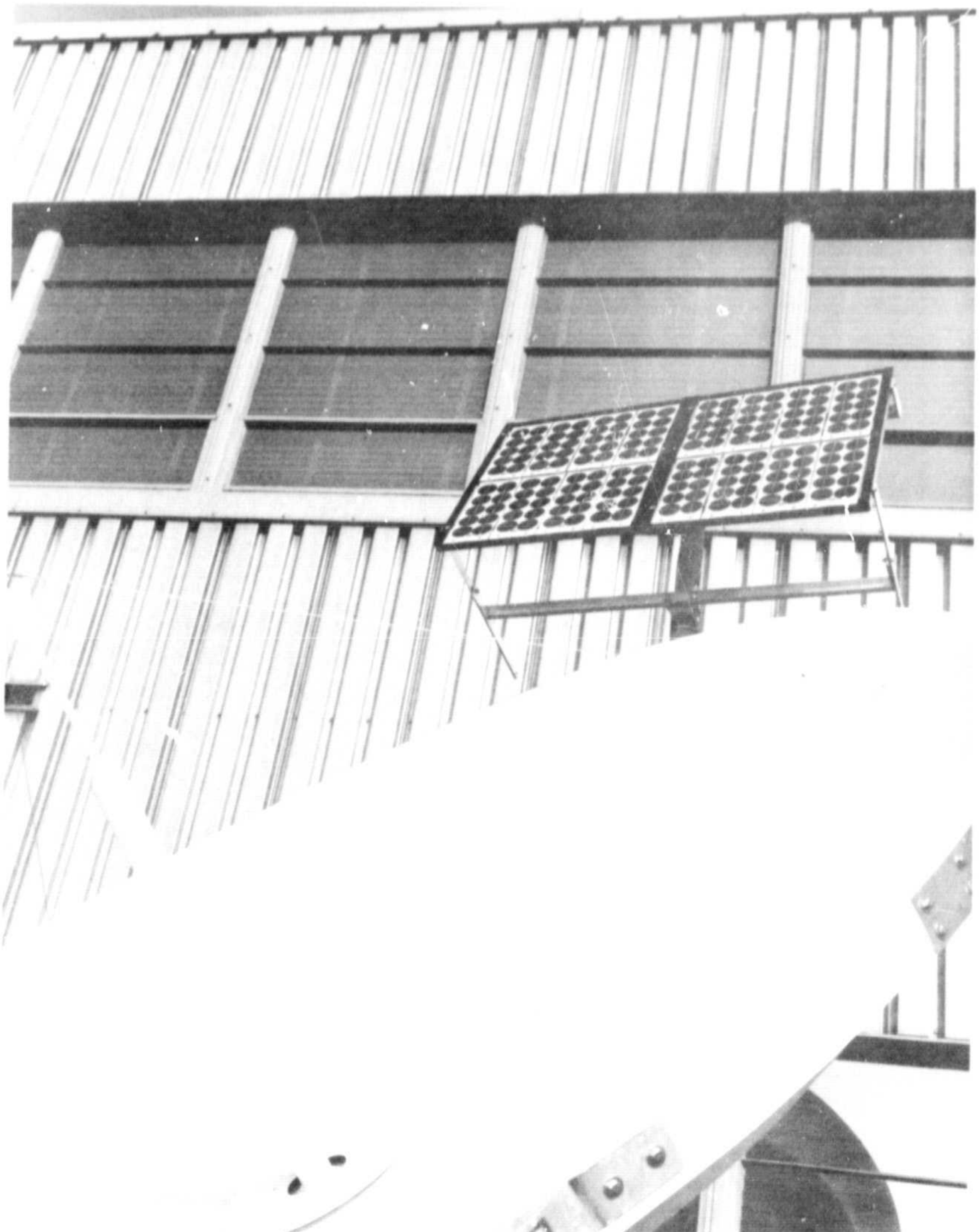

Figure 2. - Close-up of Solar Array on HET Receiver Terminal

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