DEMONSTRATION PROJECT — A SOLAR-POWERED TRAFFIC COUNTER

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Solar electric systems have some applications in the maintenance and operation of highway facilities. This report describes a project, performed by the Council in cooperation with the Traffic and Safety Division, for the purpose of demonstrating the use of such a system in traffic counters and of developing practical experience in this new technology.

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INTRODUCTION

Recently, a program was initiated at the Council to seek ways to assist the Department in saving money through reductions in the use of conventional types of energy. One of the several approaches being considered in the program is the use of solar energy where possible.

Solar energy can be used in two general ways. One is to generate heat through the use of solar collectors; the second is to generate electricity through the use of solar, or photovoltaic, cells. A review of the literature pertinent to the latter use has indicated that, from the standpoint of economics, the use of electric power generated from solar radiation is advantageous only in situations involving relatively small power demands and locations so remote from electrical power sources that the cost for installing a power line is high in comparison to the cost of a photovoltaic system. Examples of such applications in the operation and maintenance of highway and transportation facilities are the operations of automatic traffic counters,(1) warning signs(1,2) and railroad crossing signals,(3) and cathodic protection of concrete bridge decks.(4)

To develop practical experience in the use of solar electricity, a project was undertaken by the Council, in cooperation with the Traffic & Safety Division of the Department, in which photovoltaic cells were used to power a traffic counter at one of the 16 permanent traffic counters maintained by the Division across the state. This report documents the project.

PHOTOVOLTAIC SYSTEM

The heart of a photovoltaic system is the solar cell, which often is made of semiconducting silicon, the most abundant element on the earth's surface after oxygen. Other solar cell materials are cadmium sulfide, gallium arsenide, and zinc phosphide.

The conversion of silicon into a light-sensitive device that will generate electricity when struck by sunlight is simple. When pure silicon is treated with a trace amount of boron, positive (p) charge carriers (or holes) appear in its crystal lattice, and it becomes a p-type silicon. The boron is introduced into molten silicon that is then carefully cooled in a special furnace to form a large, cylindrical crystal. The crystal is sawed into thin wafers that are then treated on the front surface to incorporate a second impurity such as phosphorus. When phosphorus is added, the silicon crystal lattice develops negative (n) charge carriers (or electrons) and becomes n-type silicon. The result is a "p-n junction" that allows the electrons and the holes where electrons previously were,generated when the wafer is illuminated by sunlight, to migrate in opposite directions, thus creating a voltage across the thickness of the wafer. If an external circuit is connected to the front and back surfaces of an illuminated wafer cell, an electric current flows.

All solar cells produce about the same voltage, 0.45 volt. However, the amount of current produced varies with the surface area of the solar cell in addition to the light intensity. Therefore, numerous solar cells are interconnected to achieve a particular operating voltage and peak watt output to satisfy particular requirements. For example, the charging of a 12-volt lead-acid battery requires at least 30 cells connected in series. (This allows for the low efficiency of today's solar cells, which ranges from 12.5 to 15 percent;[6] i.e., for every 100 watts of sunlight striking a cell, only 12.5 to 15.0 watts of useable electric power are produced.) A panel consisting of 36 cells is normally used in such an application, with the extra margin being provided to allow for system losses, high temperature operation, low light levels, etc.

Standard panels are constructed by wiring solar cells together in series, parallel, or both to provide standard voltage and current outputs. A photovoltaic system includes solar cell panels, a support structure, electrical storage, and associated power conditioning circuit, e.g., voltage regulators. Sufficient solar cell panels should be wired together in series to provide the required output voltage and enough in parallel to provide the required current. The electricity produced by the panels usually is stored in rechargeable batteries and supplied to a load on demand (Figure 1).

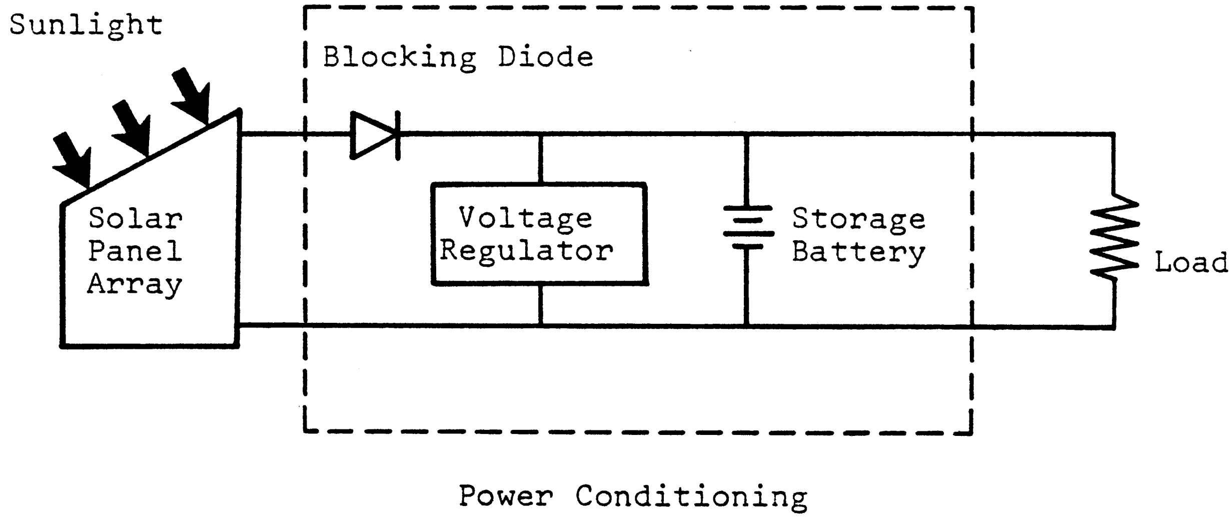

Figure 1. Typical solar battery charger.

Because solar cell panels are relatively expensive, they are economically practical only for applications with small power demands. However, energy experts have recently forecast that, through intensive ongoing research in industry and universities, there will be such improvements in the efficiency and cost of photovoltaic cells that by the middle 1980s photovoltaics will be supplying electricity to American residences at about six to seven cents per kilowatt-hour, or at a system price of $1.60-$2.20 per watt.[5] Although somewhat overly optimistic, the forecast does point out that it will not be long before there are wider uses of solar electricity.

SIZING OF SOLAR ELECTRIC SYSTEM

For each application, or load condition, the solar cell panel, or panel array for heavy load requirements, and storage battery must be sized to allow for seasonal variations in insolation and climate. The primary objective is to select that particular solar cell panel and battery combination which compensates for variances in local solar irradiation and gives the desired electrical power at the lowest cost.

To determine the approximate number of solar cell panels required, it has been suggested that the following formulas be used:

$$RSO = \frac{(1 + SM)\ AH}{SH}, \text{ and} \tag{1}$$

$$N = \frac{RSO}{OPS}, \tag{2}$$

where

AH is average daily load in ampere-hours per day at nominal operating voltage;

SM is safety margin, at least 20%;

SH is equivalent sun hours, approximately 3.0 hours per day for Virginia, allowing for worst-case winter operation;

RSO is required system output in amperes;

OPS is output in amperes at nominal operating voltage of the certain types of standard panel selected; and

N is number of standard panels required.[7]

However, this approximation gives no guidance as to the energy storage capacity required to assure a continuous power supply regardless of weather conditions.

For a complete analysis to determine the optimum combination of panel array size, array tilt, and battery storage capacity for meeting application requirements at the least cost, the following information is needed:

1. Application

2. Location (city, state, and/or latitude and longitude)

3. System voltage and/or battery voltage

4. Average current drain in ampere-hours for a 24-hour period

5. Ambient temperature, minimum and maximum, if known

6. Maximum number of consecutive no-sun (overcast) days to be expected, if known

7. Special or unusual operating conditions

Since this determination takes very tedious optimization calculations, manufacturers of solar cell panels (the major ones are listed in Appendix A) have computerized the analysis and provide it without obligation to prospective users.

SIZING OF SOLAR CELL PANEL FOR THE TRAFFIC COUNTER

Two pneumatic-type, automatic traffic counters are in constant operation at the selected traffic recorder station, which is located on Interstate Rte. 64, 1.2 miles (1.9 km) east of Route 15. These recorders, manufactured by Leupold & Stevens, Inc., of Beaverton, Oregon, provide a continuous series of traffic counts at 15-minute intervals and in coded entries punched on a paper tape.

Each counter is operated by current supplied from a 12-volt Ni-Cd rechargeable battery pack, rated at 5 ampere-hours. Although the battery pack lasts for at least two weeks, the recorders and road tubes are inspected every week for malfunctions or damage.

Since each fully charged battery pack lasts for two weeks, it was estimated that the average daily load of the counter is

$$\frac{\text{Battery capacity}}{\text{Days between charges}} = \frac{5 \text{ amp-hr.}}{14 \text{ day}} = \frac{0.36 \text{ amp-hr.}}{\text{day}} .$$

And using equation (1) the required system output is estimated to be

$$\frac{(1 + 0.2)\ 0.36 \text{ amp-hr./day}}{3 \text{ hr./day}} = 0.14 \text{ amp.},$$

allowing a 20 percent safety margin. This means that the solar cell panel needed to operate each of these counters would have to produce at least 0.14 ampere at 12 volts.

DISCUSSION

A Type 220 HP standard photovoltaic panel (Figure 2) produced by the Solarex Corporation was used to provide the required electricity for the traffic counter monitoring the eastbound traffic at the station. The panel is rated to produce 0.18 ampere at a nominal voltage of 12 volts, which provides

$$0.18 \text{ amp.} \times \frac{3 \text{ hr.}}{\text{day}} = 0.54 \frac{\text{amp-hr.}}{\text{day}}$$

during winter. The resulting safety factor would be

$$\frac{0.54 - 0.36}{0.36} \times 100 = 50\%,$$

conservatively. For the rest of the year, the safety factor will be higher due to longer days. The panel, which cost $160, came equipped with a blocking diode, which ensures that the current flows only toward the battery and the load, and a zener, which regulates the voltage. It was mounted on a pole at a tilt of approximately 45° and facing south (Figure 3). The current output from the panel was connected to the Ni-Cd rechargeable battery already in use with the counter.

During the past 16 months, since its installation in January 1981, the panel has been supplying solar electricity to the traffic counter, with only an occasional need to change the battery during the last winter — changes that likely were attributable to a worn out battery, as some of these batteries were already at least a few years old at the start of the project. However, the need for changes may also be an indication that the theoretical safety factor of 50 percent allowed by the panel may not be sufficient for a relatively harsh winter. In addition, the Ni-Cd rechargeable batteries are not the most suitable for use in photovoltaic systems.

It must be pointed out that the solar electricity eliminated the need to replace the battery pack every two weeks. However, for this case, and for all tube-activated counters, there is still a need for a technician to travel from his home base in Richmond every week to inspect the tubes, which are prone to damage by traffic, snow removal, or vandalism. Therefore, the use of solar electricity with these traffic counters would provide only minimal benefit.

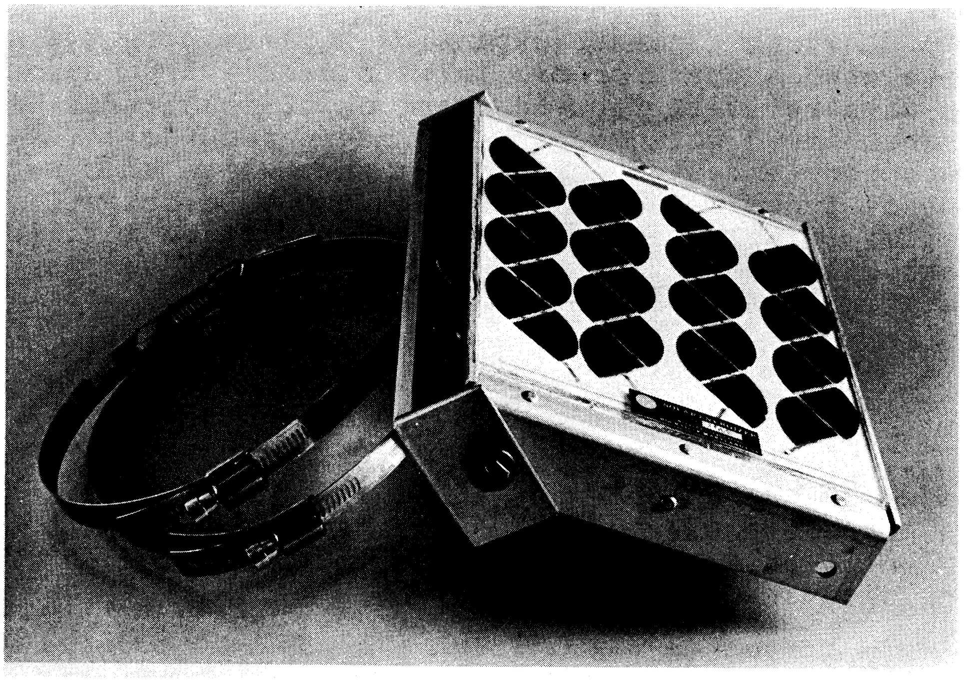

Figure 2. Solarex 220 HP panel, with tilt-adjustable frame measuring 7 in. x 8½ in. (18 cm x 22 cm). The stainless steel straps are for use in mounting.

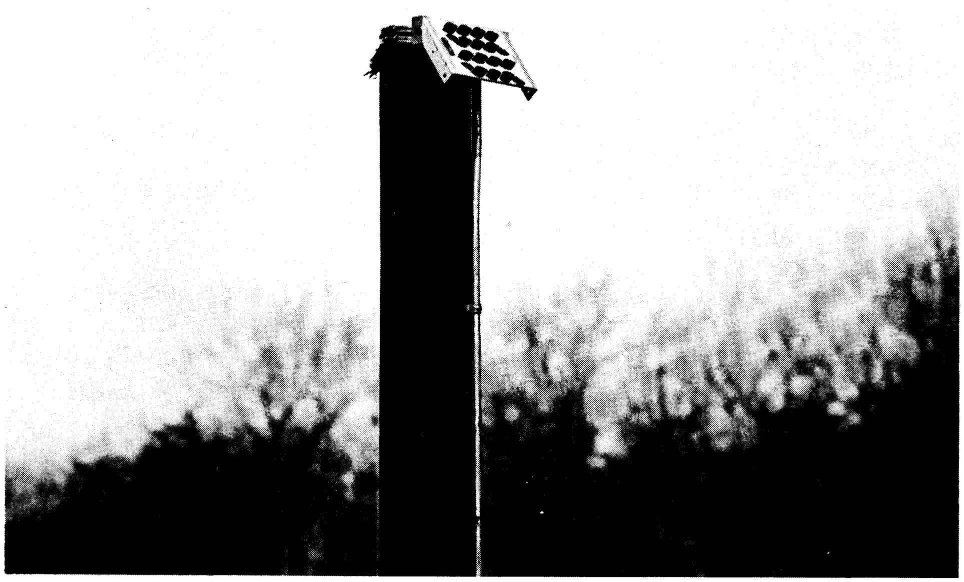

Figure 3. The Solarex 220HP panel mounted on a utility pole.

The Department is expanding its network of permanent traffic recorder stations from the present 16 to a total of 59. It is estimated that this needed expansion will require two additional people to handle the increase in maintenance from approximately two man-days per week for the existing 16 stations. This expansion is being achieved with the use of modern recorders that incorporate loop detectors embedded in the pavement, which eliminates the maintenance problems associated with the tube detectors. Now, the application of solar electricity in conjunction with these loop detectors will definitely reduce the number of service trips to those stations and hold down maintenance costs.

CONCLUSIONS

Based on the experience gained in this project, the following conclusions are presented. It is noted that a portion of the last conclusion is based on observations that, for the sake of brevity, were not discussed in this report.

1. There are uses for solar electricity in highway operations and maintenance.

2. In designing a solar electric system, the photovoltaic panel must be carefully sized. It appeared that a safety factor greater than 50 percent should be considered; however, the high cost of panels precludes the use of arbitrarily large safety factors. An optimum balance of the safety factor and panel cost may be arrived at by consideration of the relationship between size of the panel (or array) and cost.

3. For the small system considered in this project, the existing Ni-Cd rechargeable batteries may give marginal service. For larger systems, calcium-lead alloy batteries (see Appendix B) should be used.

4. Equations 1 and 2 are adequate for sizing small systems such as the installation examined in this project. For larger systems, computer modelling provided without obligation by solar system manufacturers (Appendix A) to achieve an optimum balance between the size of the solar array, the tilt angle, and battery storage capacity should be utilized. In such cases, the user should be aware that some manufacturers may tend to oversize the system and that choosing an optimum size (or safety factor) is a relatively difficult task, since there is no clear-cut guideline available.

RECOMMENDATION

In view of the saving in maintenance cost that would accrue from the use of solar electric systems in the many new permanent traffic counters that will be using embedded loop detectors, and possibly also sophisticated data devices, it is recommended that a thorough study be conducted on one of the new stations. The study should evaluate the design of a complete solar electric system that can be adapted for the new stations and include a cost/benefit analysis projected for the entire network of stations.

It is also recommended that the use of solar electricity should be considered in such other applications as remote warning signs and cathodic protection systems where the cost of installing a conventional utility line is more than a few thousand dollars and risk of the panels being vandalized or stolen is acceptable.

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7. "Building Blocks for Solar Electricity," Solarex Corporation, Maryland, 1979.

APPENDIX A

SOME MANUFACTURERS OF SOLAR ELECTRIC SYSTEMS

Solarex Corporation
1335 Piccard Drive
Rockville, Maryland 20850
(301) 948-0202

Motorola, Inc.
Semiconductor Group
P. O. Box 2953
Phoenix, Arizona 85062
(602) 244-6511

Photowatt International Inc.
2414 W. 14th Street
Tempe, Arizona 85281
(602) 894-9564

Arco Solar, Inc.
20554 Plummer Street
Chatsworth, California 91311
(213) 998-0667

Silicon Sensor, Inc.
Highway Street, East
Dodgeville, Wisconsin 53533
(608) 935-2707

Applied Solar Energy Corporation
15251 E. Don Julian Road
City of Industry, California 91749
(213) 968-6581

APPENDIX B

SOME MANUFACTURERS OF BATTERIES FOR USE IN PHOTOVOLTAIC SYSTEMS

Elpower Corporation
Santa Ana, California
(714) 540-6155

Gates Energy Products
Denver, Colorado
(303) 744-4806

Gould, Inc.
Langhorne, Pennsylvania
(215) 752-0555

Wisco Division, ESB
(919) 834-8465