PHOTOVOLTAIC POWER FOR REMOTE ARCHAEOLOGICAL RESEARCH:

A CASE STUDY

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ABSTRACT

A joint project between the Florida Solar Energy Center (FSEC) and the University of Central Florida (UCF) Division of Sponsored Research has demonstrated the practicality and benefits of a stand-alone photovoltaic (PV) power system for an archaeological research project in Caracol, Belize, located deep in the jungles of Central America. This paper describes the energy situation prior to installation of the PV system for the 40 to 100 project members investigating the ruins of the Classic Maya city, and gives details of the design and installation stages of the project. The benefits to the research project from the PV system are identified along with a discussion on the transferability and economic impact. With full-time electric power available from the PV system, the productivity and success of the archaeology project has been greatly enhanced.

1.0 INTRODUCTION

Caracol is located in the rain forests of the Vaca Plateau in Belize, Central America, near the Guatemalan border (1). Discovered in 1938, the full archaeological significance of the site is only now being unraveled through research conducted by the University of Central Florida. Originally thought to be a relatively small site, Caracol is now recognized as a significant center of Classic Maya civilization between A.D.300 and A.D.900, covering 250 square kilometers with over 1600 documented structures, including the tallest man-made structure in Belize at 42 meters.

The first full archaeological season for the Caracol Project took place in 1985 with the construction of the base camp and development of research plans for the following decade. The 1986 season saw continued excavation of the site, and the discovery of several monuments and extensive Maya causeways that linked the center of Caracol with surrounding areas. Figure 1 shows the extent of the archaeology site on a map prepared during the 1987 season (2). The base camp is located at the center of the map, and consists of two labs, two kitchens, two outhouses and a number of huts that serve as sleeping quarters for the project members and workmen.

During the first two years of the ten-year project, generators were used as the primary energy source and failed frequently from overuse and lack of maintenance. Fuel costs were approximately $ 2.00 (US) per gallon and the nearest fuel supply was three hours away via a crude lumber road carved through the jungle. Frequent rains render the road useless during most of the year. Due to the limited generator operation time, equipment vital to the success of the research project such as lighting, communications equipment, video cameras, transits and electronic distance meters could not be utilized to the full potential.

In November 1986, researchers at the Florida Solar Energy Center met with the directors of the Caracol Project at the University of Central Florida to discuss the energy needs of the remote project and potential solutions to some of the problems. Due to the difficulty and expense of operating and maintaining a generator as the primary energy source, it was concluded that photovoltaic (PV) power could help in reducing this dependence and provide a continuous source of energy for the researchers. Work then began planning and developing a stand-alone PV system design with regard to the needs of the researchers.

2.0 SYSTEM DEVELOPMENT

After a review of the energy needs of the project, a stand-alone PV system was designed to interface with existing equipment at the site. This analysis

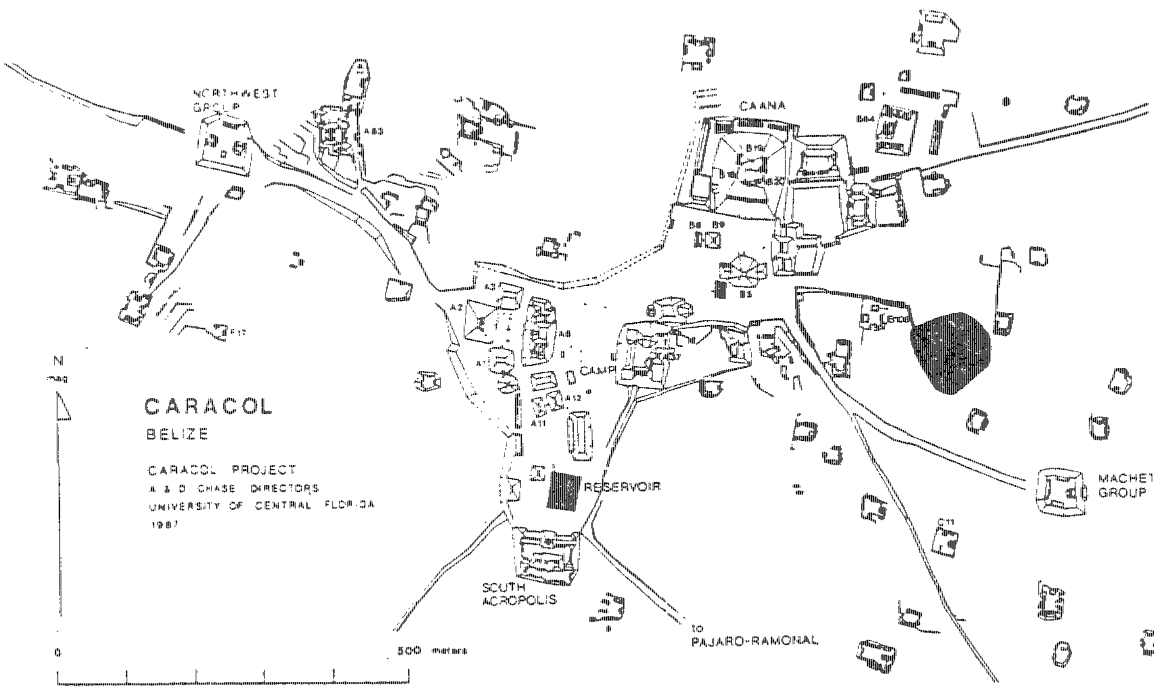

Figure 1. Caracol Project - Site Map.

involved estimates of the power consumption and time of use for the electrical equipment at the site. To improve the efficiency of existing practices, fluorescent lighting was selected to replace inefficient incandescent lighting.

To facilitate installation of the system in the field, a modular approach was used that allowed for partial system assembly and checkout in the States before shipment. This advance preparation was critical in ensuring proper operation of the individual components and the system as a whole. An inventory was developed listing all equipment, materials, hardware, tools and spare parts needed for the system installation, operation and maintenance. Twelve crates with a combined weight of over 1500 kilograms were packed with PV modules, batteries, controllers, an inverter, light fixtures and other balance-of-system (BOS) components for shipment to Belize.

3.0 SYSTEM INSTALLATION

Once the PV equipment arrived in Belize, the Royal Air Force graciously transported the equipment to Caracol via helicopter as part of a training exercise. Ground transport of the equipment would have been painstaking, surely taking several trips in and out of the site over the poor road.

After the equipment was unpacked and inspected for any damage, assembly of the PV arrays began and was completed within a few days. Six inch diameter hardwood posts were cut for the PV array support members and coated with diesel fuel to make them resistant to termite infestation. The preassembled system control panel was installed above the three battery boxes and inverter in an accessible location in the main lab building.

Electrical connections were coated with anti-oxidation compound and potted with silicone to reduce the potential for future corrosion problems with the wiring. Sunlight resistant cable was also used to minimize the degradation problems associated with long-term exposure in the hot, humid environment. Direct burial cable was used for the ac and dc load distribution circuits from the main lab to the rest of the camp. All wiring, source circuits and system components are clearly labeled and color coded for proper identification and correspondence with the system schematics and the operation and maintenance manual. Grounding is provided for the PV array structures and the ac output of the inverter with ten foot copper ground rods.

Figure 2 shows the completed PV array installation and Figure 3 shows the system control panel. The installation of the PV system at Caracol was completed over a two week period in March 1987.

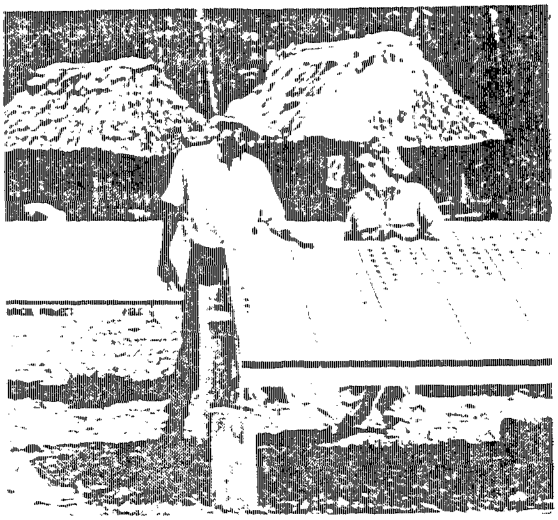

Figure 2. Caracol Project - Photovoltaic Array.

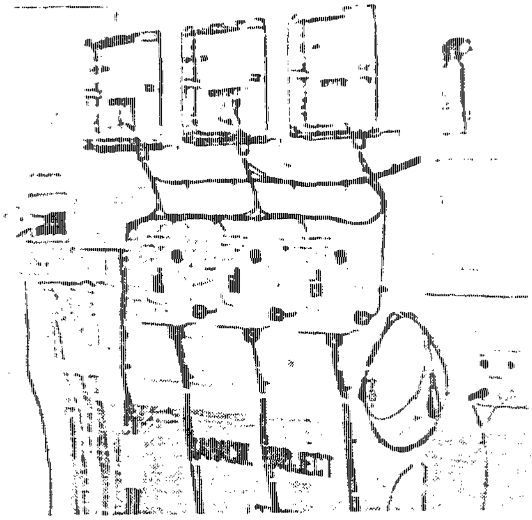

Figure 3. Caracol Project - PV System Control Panel.

4.0 SYSTEM DESCRIPTION

The stand-alone PV system installed at Caracol consists of a nominal 675 Wp photovoltaic array, divided into three array source circuits. Three voltage regulator circuits are used to connect the PV array source circuits to a nominal 12-volt, 1200-amp-hour battery bank. The three source circuits are used for redundancy in the event of a regulator failure and to reduce the high currents and voltage drop concerns with having the entire array in one circuit.

From the battery bank, a load distribution center serves the camp with 12-volt dc loads. In addition, a 1500-watt dc/ac inverter operates from the battery bank to serve 120-volt ac loads. A variety of ac and dc loads are operated from the PV system. Table 1 lists the ac and dc load distribution circuits for the Caracol PV system.

If the battery storage capacity is depleted after several overcast days, a hybrid system configuration may be used which exercises the generator as a backup energy source by replenishing the batteries through the battery-charging circuit of the inverter. Figure 4 shows the system block diagram and Table 2 list the specifications for the Caracol Project PV system.

5.0 SYSTEM OPERATION AND MAINTENANCE

Several important steps were taken after the installation to ensure the long-term reliability and performance of the PV system. These steps included developing a system operation and maintenance manual, a system log book, electrical schematics and mechanical drawings, and providing user training.

For user training, the individual designated as the site caretaker assisted with all phases of the installation, learning the basics of system operation and maintenance. A training seminar was also conducted to explain the system operation to all of the project participants. The users were trained to assess the performance of the system so that they could manage the use of non-essential loads. Although the system users had no prior knowledge of PV systems, analogies made to conventional energy systems were useful in presenting a clear understanding of the system operation.

A log book was developed to record daily events associated with the system operation and performance. Typical items entered in the log book are steady-state battery voltage, weather conditions, load usage, generator operation time and maintenance activities or other events. The intent of the log book was to encourage an active effort to maintain and monitor the system performance over the long term.

To summarize the operation of the system, an operation and maintenance (O&M) manual was developed to include specifications on individual components, electrical schematics, and mechanical drawings (3). The O&M manual gives a thorough explanation of the individual subsystems and the system as a whole. Periodic and routine maintenance operations are outlined along with troubleshooting procedures. Several copies of the O&M manual were left at the site for reference and user training.

TABLE 1. CARACOL PROJECT PHOTOVOLTAIC SYSTEM - LOAD DISTRIBUTION

12 VOLT DC DISTRIBUTION

Circuit	Location	#	Description
1	Lab #1	1	Fl flood, PL13
		1	Fl lamp, 15 watt
		1	Fl lamp, 34 watt
2	Lab #1	1	Communications
3	Main Kitchen	1	Fl flood, PL13
		1	Junction box
4	Lab #2	1	Fl flood, PL13
		2	Fl lamp, 15 watt
5	Lab #1	2	Battery outlets
6	Spare		

120 VOLT AC DISTRIBUTION

Circuit	Location	#	Description
1	Club	1	Duplex outlet
2	Men's Kitchen	1	Duplex outlet
		1	Fl lamp, 34 watt
3	Main Kitchen	1	Duplex outlet
		1	Fl lamp, 34 watt
4	Lab #1	4	Duplex outlets
		1	Quad outlet
		1	Fl lamp, 15 watt
5	Lab #2	3	Duplex outlets
		1	Fl flood, 2-PL13
6	Spare		

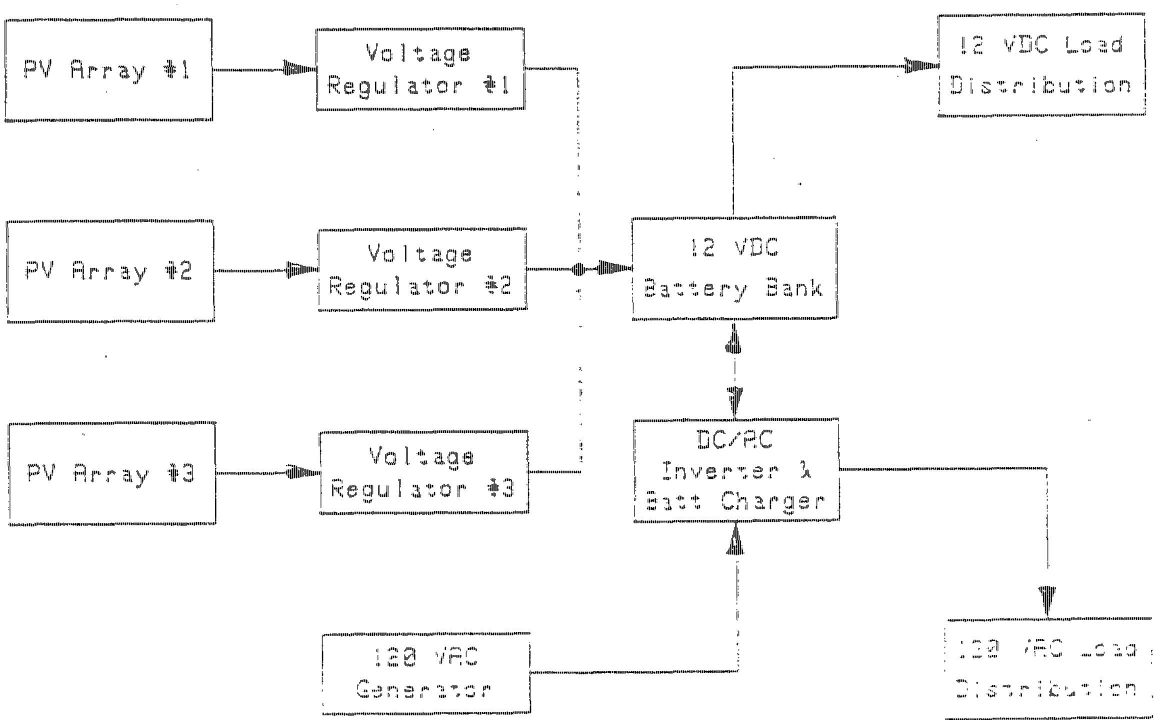

Figure 4. Caracol Project - PV System Block Diagram.

TABLE 2. CARACOL PROJECT

PHOTOVOLTAIC SYSTEM SPECIFICATIONS

Location:

- Caracol, Belize Central America
- Latitude 18° N

Photovoltaic Array:

- 48 Solec International S-3136 modules
- Three 16 module source circuits
- Array rating at STC 675 Wp

Battery Bank:

- Sonnenschein Dryfit Prevailer DF180
- Configuration 1 series x 12 parallel
- Nominal voltage 12 volts
- Nominal capacity 1171 Ah at 20 hr. rate

Inverter:

- Trace Engineering model 1512
- Input 12 vdc
- Output 120 vac, 1200 watt
- 80 amp battery charger

Voltage Regulator:

- Specialty Concepts PPC-12-F3M
- 30 amp PV and load current
- Low voltage disconnect
- Battery voltage and array current meters

6.0 PHOTOVOLTAIC SYSTEM BENEFITS

6.1 Benefits to the Project

The productivity of individuals and success of the archaeology project has been greatly enhanced since the installation of the PV system. Researchers now have full-time electric power to operate computers, communications equipment, radios, and battery chargers. Highly efficient quality lighting allows them to read, catalog, prepare maps, and label artifacts well into the night. Previously, kerosene lamps were used for these tasks when the generator could not be operated, which resulted in eye strain and fatigue.

Much of the equipment at the site uses rechargeble batteries, requiring recharge times up to 14 hours per use. This equipment includes video cameras, walkie-talkies, a plane table transit and an electronic distance meter (EDM). Due to the limited generator operation time prior to the PV installation, this equipment could not be utilized to the full extent. With the continuous source of power from the PV system, the equipment may now be fully utilized. Most significantly, the full use of the EDM has resulted in an increase in the mapped structures at Caracol from 450 to over 1600 since the PV system was installed. This survey work is a key to making interpretations about the history of the site, thus indirectly enhancing the ability to attract external project funding (4).

Auxiliary batteries that can be connected to the PV system for recharging provide essential power for portable lighting and pumping equipment used in the field. The portable lighting equipment is used for excavations deep inside tombs where no daylighting is available. The low-flow, high-head pumping system is used to lift water from the reservoirs up to the tops of the tall structures for mixing of the mortar for consolidation and re-construction purposes.

Perhaps the most critical benefit to the project has been the ability to reliably operate communications equipment. VHF radios are used extensively to communicate around the vast site and to contact the forestry station some 25 miles away in emergency situations. During the 1988 season, one of the project members operated HAM radio equipment from the PV system, facilitating the project organization and communications with the States.

While the PV system has greatly improved the productivity of the Caracol Project, there have been other equally important benefits. The PV system has provided power for recreational activities, such as reading, games and twice weekly video shows that help keep up project morale through the long months at the isolated Caracol site.

6.2 Economic Impact

The primary economic impact can be attributed to the replacement of the gasoline generator with the stand-alone photovoltaic system as the primary energy source. In estimating these savings, generator maintenance, fuel costs and availability play an important role. Direct fuel savings were estimated to be approximately $30 (US) per week. However, the majority of savings are implicit in generator maintenance and fuel acquisition costs, and are extremely difficult to quantify. Any parts required for generator maintenance would have to be obtained from the States and would result in several weeks of generator downtime and a significant loss of productivity for the researchers. The nearest fuel supplies are located three hours from the camp over a poor dirt road through the jungle. The transportation costs incurred are a significant part of the PV system economics.

6.3 Transferability

Considerable follow-up interest has been generated as a result of the PV system installed at Caracol. Several project directors at other remote research projects around the world have contacted FSEC about the Caracol Project, including the Smithsonian Institute and other universities. At FSEC's Photovoltaic System Design workshops, the project is used as a case study to demonstrate system design and installation techniques, energy conservation and load management, and system operation and maintenance procedures.

The successful completion of this project provides an example of the diversified benefits of PV power, hopefully promoting the implementation of photovoltaic applications in the Central American and Caribbean regions, and other developing areas.

7.0 CONCLUSIONS

The PV system installed at Caracol has become a critical aspect of the archaeological research, significantly enhancing the effectiveness of the project. Already, plans are being made to use photovoltaics to facilitate the touristic development of the site. The successful completion of this PV project establishes effective use of university resources through a joint effort between the Florida Solar Energy Center and the University of Central Florida. This demonstration of the benefits of PV power suggests unlimited possibilities for implementation of the technology worldwide.

8.0 ACKNOWLEDGMENTS

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9.0 REFERENCES

(1) "Belize: Country Environmental Profile - A Field Study." Robert Nicolait & Associates, Ltd., Belize City. USAID Contract No. 505-0000-C-00-3001-00, April 1984.

(2) Chase, Arlen F. and Diane Z. "Glimmers of a Forgotten Realm: Maya Archaeology at Caracol, Belize," Prepared in conjunction with an exhibit at the Orlando Museum of Art at Loch Haven, Orlando, FL., January 25 to December 21, 1987. University of Central Florida, 1987.

(3) Dunlop, J. "Caracol Project: Photovoltaic System Design and Operational Manual," Florida Solar Energy Center, FSEC-RR-12-88, April 1987.

(4) Chase, Arlen F. "Jungle Surveying: Mapping the Archaeological Site of Caracol, Belize," Point of Beginning, Vol.13 No.3, February-March 1988, pp.10-24.

(5) Sheinkopf, K. "Archaeologists Dig PV Power," Solar Today, Vol.1 No.5, September-October 1987, pp.12-13.

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