NASA Technical Memorandum 79318

(NASA-TM-79318) A PHOTOVOLTAIC POWER SYSTEM IN THE REMOTE AFRICAN VILLAGE OF TANGAYE, UPPER VOLTA (NASA) 17 p HC A02/MF A01 CSCL 10B N80-12552 Unclas G3/44 46203

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ABSTRACT

As part of a project sponsored by the U.S. Agency for International Development (AID) and the Government of Upper Volta, a photovoltaic (PV) system powering a grain mill and a water pump has been installed in the remote West African village of Tangaye, Upper Volta. The technical aspects of the project are being managed by the National Aeronautics and Space Administration's Lewis Research Center (LeRC). The 1.8 kW_{peak} Tangaye PV system, which became operational March 1, 1979, was installed in part by the villagers of Tangaye and is being operated and maintained by village personnel. The system is well instrumented to enable NASA LeRC to monitor electrical operation. A baseline socio-economic study has been performed by AID and a follow-up study is planned to determine the impact of the system on the villagers. This paper describes village characteristics as well as system design, hardware, installation and operation to date. A brief discussion of PV system cost is included.

INTRODUCTION

The U.S. Agency for International Development (AID) is currently conducting a program entitled "Studies of Energy Needs in the Food System." The overall goal of this program is to improve the quality of life and productivity of small farmers in rural areas of developing countries.

As part of this activity, a project is being conducted in the remote village of Tangaye, Upper Volta, Africa to demonstrate the potential for use of solar cells as a power source for common village tasks, with special emphasis on women's tasks. The load devices selected for the project were a grain grinder and a water pump. A solar cell system was chosen as the power source because of its potential high reliability and low maintenance requirements. AID provided funding for hardware and software associated with the photovoltaic (solar cell) system, grain grinder and water pump, and a socio-economic (baseline and impact) study. The National Aeronautics and Space Administration (NASA) Lewis Research Center (LeRC) was assigned responsibility for system design, development, deployment and evaluation. The Government of Upper Volta (GOUV), Office of Rural Development, responsibility included organizing a village cooperative to manage the mill. The villagers of Tangaye contributed site preparation, a mill building, and labor to aid in the installation of the photovoltaic system, mill and water pump. Tangaye residents also operate the mill, maintain the system and keep daily records on system operation. This report describes the project background, village parameters including baseline conditions, the photovoltaic system, mill and water pump and system installation and operation. A brief discussion of PV system cost is included.

VILLAGE CHARACTERISTICS

The West African village of Tangaye (latitude 13° N, longitude 0°) is located about 190 kilometers east of Ouagadougou, Upper Volta, the capital city, on the main highway running between Ouagadougou and Niamey, Niger.

Tangaye's climate is typical of the Sahel region. The dry season, from December to May, is characterized by high temperatures (40° C), hot winds (at the beginning of the season), and low humidity. Water is scarce and is obtained from wells which often dry up as the dry season progresses. The rainy season generally begins in early May and extends through November. The average rainfall is about 100 centimeters annually. Mean daily (total horizontal) solar radiation varies from a low of 450 langleys in August to a high of 560 langleys in March.

A survey in 1978 indicated that Tangaye had a population of 2172 people comprising 290 families. A review of the age distribution indicates that about half the population is above the age of 14, and of that group, 585 are women. Most of the inhabitants of Tangaye belong to 1 of 10 families who have ancestral rights to the land.

Tangaye is divided into 8 quartiers and 20 sub-quartiers. The populated area of the village extends over approximately four square kilometers. Individual dwellings consist of circular, mud brick huts with thatched roofs. Most family compounds are surrounded by a fence made of millet stalks.

The number and type of water sites in the village varies depending on the time of year. Each sub-quartier, for example, has a number of shallow wells dug by the villagers. The village also has two large concrete wells built by the government as well as a cement-lined well built by an individual. The latter wells are normally 10 meters or so deep and contain water throughout the year while the hand-dug wells and ponds are about 2 to 6 meters deep and usually dry up within a month or so after the end of the rainy season.

The people of Tangaye live in a subsistence level agricultural economy. The main occupation of its inhabitants are farming and cattle raising. The principal crops are sorghum, millet, rice, corn, beans, peanuts, sesame, soybeans and cotton. Little of the cereal grown is sold since the villagers generally do not produce enough to satisfy their own needs. Villagers also raise cattle, sheep, goats, donkeys, horses, pigs and poultry.

The men of the village spend much of their time farming while women are responsible for all aspects of family care. This includes a number of laborious and time-consuming daily tasks such as drawing water and pounding and stone-grinding grain, the primary source of food, into fine flour. These tasks generally occupy about two to three hours per day. During the growing season, women also assist the men in the fields.

Tangaye is considered typical of many of the rural villages of Upper Volta, a country with a per capita income (based on GNP) of about $90 per year.

Organization of the Village Mill Cooperative

With the assistance of the Government of Upper Volta, Office of Rural Development, a cooperative was formed to manage the Tangaye mill. About 60 village families each invested 500 Fr CFA (about $2.35) in the enterprise. Charges for milling were set by the cooperative and are competitive with mills in nearby villages. Milling is open to member and nonmember families alike. Proceeds from membership and milling are used to pay two full-time millers and to accumulate funds for spare parts and repairs after the first year of operation. Once adequate funds are accumulated, profits will be distributed to cooperative members.

SYSTEM DESCRIPTION

Design and Fabrication

The Tangaye photovoltaic (PV) system consists of a solar cell array, battery storage, controls and instrumentation as shown in Figure 1. The system supplies DC electrical power to the pump and mill subsystems. System size was established based on limitations of available funding and site specific details obtained during a visit in February 1978. The water pumping was set at 5000 liters/day based on the measured recovery rate of the well. A mill was selected to provide approximately 320 kg/day of finely ground grain, enough to meet the daily requirements of about 640 villagers.

The PV array, battery and loads operate at 120 volts DC. Controls and instrumentation operate at 12 V DC. Use of DC systems avoids the costs, complexities, and losses associated with DC-AC inverters while 120 volts minimizes line losses and permits the use of commercially available DC switches and motors. All electrical load devices were individually selected on the basis of energy efficiency and reliability. PV array and battery sizes were determined using a NASA LeRC-developed computerized PV system simulation program. The program combines PV cell characteristics, average monthly insolation and atmospheric data, and an hourly load profile to determine hourly battery depth-of-discharge (DOD) as a function of array size and tilt angle, and battery capacity. It also incorporates a factor for module output losses due to dirt and encapsulant darkening and a sub-routine to randomly vary insolation within selected limits to develop worst-case DOD conditions. According to the computations, the battery maximum depth-of-discharge is estimated to be 30%.

The system loads consisted initially of a positive displacement water pump with a 1/4 HP, 120 V DC motor and a commercial burr mill using a 1 HP, 120 V DC motor. Permanent magnet motors were chosen because of their high efficiency (about 85%). Because of excessive wear of the burr plates, experienced during the initial stage of the project, the burr mill was replaced by a commercial hammer mill driven by a 3 HP motor. Further, two 20-watt fluorescent lamps were added in the mill building at the request of the villagers. These units employ commercially available high efficiency 120 V DC, 23 kilohertz inverter ballasts which enable a standard 20 W lamp to produce about the same lumen output as a 100 W incandescent lamp.

The 1.8 kW_{peak}, 120 V DC PV array consists of 12 series strings of 8 modules each. (Peak power is the output of the solar array at noon on a clear sunny day. Modules are relatively small, low power, low voltage building blocks of the photovoltaic array containing a number of solar cells electrically connected and encapsulated in a supporting frame.) The modules were assembled into 12, 1.22m-by-2.44m panels (each containing 8 modules wired as 1 series string) by a small fabrication/assembly firm in the U.S. using semi-skilled labor. The panels are arranged in 3 rows of 4 panels each and are located within a fenced area of $256m^2$. Array tilt angle is 11^o from the horizontal. The panel frame and support structure are designed to withstand 161 km/hr wind loads and are fabricated from commercially available hardware. A separate 74 watt, 12 V DC panel and a 100-ampere-hour battery provides power for instrumentation and controls.

The battery for the 120 V DC system consists of 55, 540-ampere-hour cells designed specifically for PV systems operation. The battery cells are mounted on two single-tier racks located in a separate vented room of the milling building.

The system utilizes three control subsystems: system voltage and battery charge regulation, pump controls and mill timer control. System voltage and battery charge regulation are accomplished by array string switching. There are relays (one per string) which connect the array strings to the main bus or open circuit the strings through a field-programmable drum relay. The drum relay is commanded to increase or decrease the number of connected strings by a controller which senses system voltage. The pump controls consist of a water level sensor in the water storage tank to stop and start the pump and a water level sensor in the well to stop the pump when the well water level drops below the pump intake. The mill control consists of a timer which will allow the mill to be operated for an accumulated time of 5 hours/day, 4 days per week.

Under- and over-voltage protection is provided in addition to system voltage regulation. If system voltage exceeds the maximum allowable value, the PV array is disconnected. If system voltage drops below the minimum allowable, the loads are disconnected. Alarm lights are provided for these conditions.

Instrumentation

The system contains two types of instrumentation: panel meters and an automatic data logger which records data on magnetic tape cassettes. Data from panel meters are recorded daily by the mill operator. The data tapes are forwarded to LeRC for data reduction and analysis.

Safety Features

The photovoltaic system design and installation conforms to National Electrical Codes and OSHA Safety Regulations and specifications. Additional safety features are: a 1.5m-high chain-link fence with a locked gate surrounding the array field; warning signs; and enclosed pump.

INSTALLATION AND OPERATION

The villagers of Tangaye, under the technical supervision of two NASA LeRC personnel, installed the solar cell power system and loads. Total on-site installation time was six weeks, exclusive of the time required for the villagers to build the mud brick mill/battery building. The system is depicted in Figure 2.

The PV array, located in a fenced-in area, provides power via underground cable to a control cabinet located in the nearby mill/battery building. Storage batteries are located in one room of the building; the mill and control cabinet are in the other. An underground cable carries power from the control cabinet to the water pump. A water storage tank and dispensing facility are located near the well. The tank was designed by LeRC and procured and installed by Upper Volta AID Mission personnel.

The system officially became operational on March 1, 1979. A formal dedication of the system was held on March 29, 1979, and attended by many local officials including the Prime Minister of Upper Volta and the U.S. Ambassador. During his address at the dedication, the Prime Minister indicated that Upper Volta's major need was adequate food and water and expressed his desire for an extension of the Tangaye project to other villagers when costs become economical.

During the initial period of operation, which coincided with the end of the dry season, water consumption from the tank reached as high as $15m^3$/day, nearly three times the normal yield of 10-12m deep wells in the Tangaye area. The mill was equally well patronized. However, problems with the burr mill (i.e., excessive wear of plates) limited output somewhat. Following replacement of the burr mill with a hammer mill in August, output increased substantially. In fact, millers reported that some women had walked as far as 10 km to avail themselves of the extremely fine flour produced by the hammer mill. A detailed examination of the impact of the solar cell system, mill and water pump is to be made by an anthropologist under contract to AID during 1980.

As of mid-September 1979, one electrical outage has been experienced at Tangaye. The outage was due to the failure of a timing device which governs operation of the battery charge regulator. Local personnel were able to bypass the failure using the manual mode of operation provided for such eventualities. This event, in a sense, demonstrates the potential "appropriateness" of PV technology in that the outage was rectified without the need for highly trained technicians.

In addition to replacing the original burr mill with a hammer mill during the six-month inspection in August 1979, the battery charge control method was altered to use solid state duty cycle regulators in place of an electro-mechanical device. A second visit to inspect the system is scheduled for March of 1980.

Training and Orientation

A training and orientation program was provided as part of this project to acquaint the mill personnel and other residents of Tangaye with the use and operation of the PV system and associated loads. Pictorial orientation handbooks concerning the system were provided to the villagers while Operation and Maintenance Manuals were provided to local mill and AID Mission personnel. Troubleshooting and Repair Manuals are in preparation.

NASA personnel provided training in system and mill operation to the local mill personnel prior to system start-up. Instruction was also given on the routine maintenance tasks. These consist of periodic cleaning of the array with a damp cloth, adding water to the battery cells (once or twice a year), and periodic inspection and lubrication of the pump and mill.

COST CONSIDERATIONS

The installed PV system cost for the 1.8 kW_{peak} system at Tangaye was $50,400 (1978 $), excluding experiment-related costs. Assuming a 20-year life (10 years for batteries), and a 10% discount factor, the levelized annual capital cost of the system is $5922. Levelized annual replacement and maintenance costs are estimated to total $792. For the predicted value of the annual energy consumption, i.e., 2867 kWh/yr, the resultant energy price of the solar electricity is $2.34 per kWh. By comparison, the corresponding price for the same quantity of diesel-generated electricity is over $2.50 per kWh for $2 per gallon fuel (delivered). Cost estimates for diesel electricity are based on the use of a 3 kVA diesel generator and a back-up unit, and also include operation and maintenance as recommended by diesel manufacturers and suppliers.

Through continued cost reduction brought about by increased volume production and improved technology, PV-generated electricity is expected to decrease in price to less than $1 per kilowatt-hour by 1981. At this price, PV would be competitive with diesel generators where annual energy consumption is 15,000 kilowatt-hours or less (Rosenblum, L., et al, 1979).

CONCLUDING REMARKS

The Tangaye solar project represents the first major demonstration of photovoltaic technology in an AID program. The experience gained to date at Tangaye indicates the PV systems are practical for use in remote areas of developing countries. Installation of much of the system can be accomplished by local labor and operation and maintenance of the system as well is readily managed by local people.

The Tangaye system has been operating since March 1, 1979. Except for the one temporary outage, performance has been satisfactory. Of note is the fact that village personnel were able to bypass the failed component which caused the outage and continue operation of the system in a manual mode until the problem was corrected by an outside technician.

Cost estimates for the system indicate that photovoltaic energy cost is competitive with that of diesel generators for the amount of electricity required at Tangaye.

REFERENCE

1. Photovoltaic Power Systems for Rural Areas of Developing Countries, L. Rosenblum, et. al., NASA TM 79097. Presented at the Interregional Symposium on Solar Energy for Development, Tokyo, Japan, February 5-10, 1979.

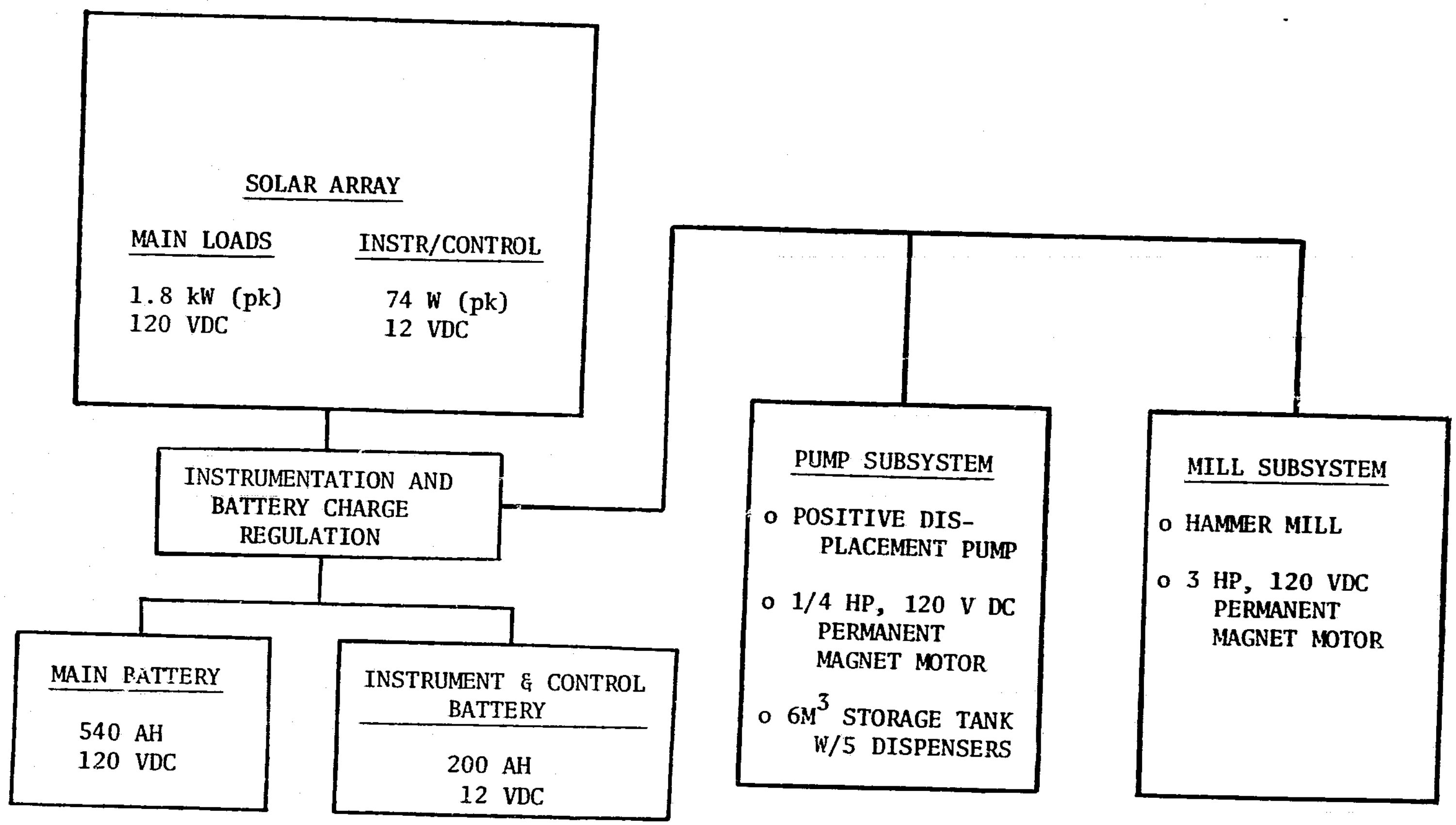
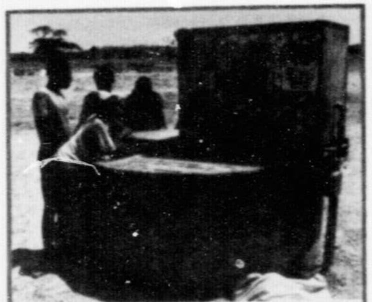


FIGURE 1 - SYSTEM DIAGRAM: PHOTOVOLTAIC-POWERED PUMPING/MILLING SYSTEM, TANGAYE, UPPER VOLTA

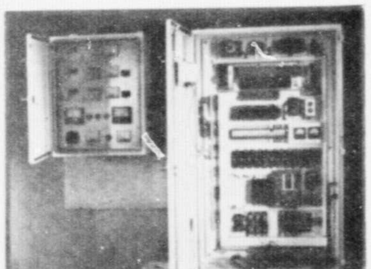

WELL & PUMP
1/4 hp 120 VOLT DC MOTOR 13.5m³/DAY


MILL & MILLERS
1hp 120 VOLT DC MOTOR & FLOUR MILL


6m³ WATER TANK


TANGAYE SOLAR ELECTRIC (PHOTOVOLTAIC) SYSTEM
MILL BUILDING, WATER TANK, WELL AND PUMP AND SOLAR CELL ARRAY


WEIGHING GRAIN


INSTRUMENTATION AND CONTROLS


1.8 kW 120 VOLT DC PHOTOVOLTAIC ARRAY


540 AMP-HR 120 VOLT DC BATTERY

FIGURE 2 - TANGAYE VILLAGE SOLAR ELECTRIC SYSTEM

1. Report No. NASA TM-79318	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A PHOTOVOLTAIC POWER SYSTEM IN THE REMOTE AFRICAN VILLAGE OF TANGAYE, UPPER VOLTA		5. Report Date
		6. Performing Organization Code
7. Author(s) William J. Bifano, Anthony F. Ratajczak, and James E. Martz		8. Performing Organization Report No. E-274
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address U.S. Agency for International Bureau for Development Support Development Washington, D.C.		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared under Interagency Agreement NASA/DSBO234-2-78

16. Abstract

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17. Key Words (Suggested by Author(s)) Photovoltaic power systems Rural photovoltaic applications	18. Distribution Statement Unclassified - unlimited STAR Category 44

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price*

* For sale by the National Technical Information Service, Springfield, Virginia 22161