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DESIGN AND FABRICATION OF A PHOTOVOLTAIC POWER SYSTEM FOR THE PAPAGO INDIAN VILLAGE OF SCHUCHULI (GUNSIGHT), ARIZONA

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ABSTRACT

In its role of supporting the DOE National Photovoltaic Program, the NASA-LeRC is designing and fabricating a stand-alone photovoltaic power system for installation in the Papago Indian village of Schuchuli, located approximately 120 miles west of Tucson, AZ. This village presently has no electrical power. The photovoltaic system is being designed to provide electricity for village water pumping and basic domestic needs as part of a cost-shared experiment involving LeRC, the U.S. Public Health Service and the Papago Tribe of Arizona. The system will consist of a 3.5 kW (peak) photovoltaic array; controls, instrumentation, and storage batteries located in an electrical equipment building; and a 120 volt DC village distribution network. The photovoltaic system will power a 2 HP DC electric motor (replacing an existing diesel engine) for water pumping; 15 refrigeration units, a washing machine and a sewing machine in a domestic services building; and fluorescent lights in the feast house, church and each of the 15 homes in the village.

INTRODUCTION

The NASA Lewis Research Center (LeRC), acting on behalf of the Department of Energy (DOE), is planning a photovoltaic village power experiment in Schuchuli (Gunsight), Arizona, located about 120 miles west of Tucson on the Papago Indian Reservation. Other participants in this cost-shared experiment include the Public Health Service (PHS) and the Papago Tribe of Arizona (PTA). Some of the funds for the PTA portion of the project are being provided by the Four Corners Regional Commission.

This paper discusses the design and fabrication of the photovoltaic system to be installed including a brief description of the selection process employed in choosing the village of Schuchuli and the specific load devices to be powered. Supporting activities are also discussed briefly.

BACKGROUND

The DOE is pursuing a National Photovoltaic Conversion Program aimed at developing cost-effective photovoltaic power systems capable of providing a significant amount of the nation's energy requirements by the year 2000. This program has been divided into several projects, one of which is the Tests and Applications Project which is being managed for the DOE by the LeRC.

One of the objectives of this Project is to acquaint potential users with the features of photovoltaic power systems to accelerate their entry into the commercial market. Applications which indicate near-term cost-effectiveness, technical feasibility, and/or substantial use multiplication are considered for joint, cost-shared experiments.

Through discussions with the Public Health Service (PHS), Tucson, one such application was identified: village power for remote Indian villages. Technical criteria were established jointly by the LeRC and PHS to enable selection of a specific village for a photovoltaic experiment. Representatives of the Papago Tribe of Arizona, using the LeRC/PHS technical criteria as a guide, selected Schuchuli for the experiment. This village, shown in Figure 1, is located on the western edge of the Papago Reservation and consists of 15 families (95 people). No electric power service is available to the village. Petroleum fuelled equipment is used for pumping water. The diet of the villagers includes items such as chili, beans, tortillas and commercially available nonperishable vegetables and canned foods. Food is generally purchased at Ajo, about 20 miles from Schuchuli, with only ice chest storage available. Cattle raising and wild game hunting provide an occasional supplemental source of food. Most dwellings in the village are of traditional adobe construction with a few of masonry block construction. Lighting is provided by kerosene lamps.

Representatives of the Papago Tribe and the village approved the installation of the photovoltaic system for the village of Schuchuli. The selection of the loads to be powered was based on a prioritized list developed by the villagers. An electric motor to operate the existing water pump was an obvious choice to replace the 7 HP diesel engine currently used. This will eliminate the cost burdens associated with diesel fuel and maintenance which place a strain on the financial resources of the village. In addition, the villagers agreed to use other load devices

(appliances) in a communal fashion and approved the construction of a domestic services building to house the appliances. The other load devices chosen by the villagers based on power availability and need are listed below in order of priority:

1) A light in the kitchen of each house
2) A light in another room of each house
3) Lights in a community building and feast house
4) Refrigerators in a community building
5) Washing machine
6) Sewing machine

Following the site selection and the preliminary definition of the photovoltaic power system and loads, a Memorandum of Understanding and an Implementation Plan were prepared defining roles and responsibilities as follows: The DOE/NASA-LeRC is responsible for the design, fabrication and installation of the photovoltaic power system, the electrical equipment building, and load devices. The Papago Tribe has overall responsibility for the electric distribution network and the domestic services building. The PHS is responsible for the well and pump, and water drainage as well as on-site project coordination. The duration of the experiment is two years with installation scheduled for the Fall of 1978.

SYSTEM DESCRIPTION

The Schuchuli Photovoltaic (P/V) Village Power System consists of a 3.5 kW, 120 volt DC P/V array field, 2380 ampere-hours of battery storage, controls and instrumentation, and a pole line electrical distribution network. The batteries and controls are located in an electrical equipment building (EEB) as indicated in the block diagram of Figure 2. The P/V array field and EEB are located in the vicinity of the existing well, as shown in Figure 3, to minimize power losses to the largest electrical load.

An all DC system was selected to avoid the losses associated with commercially available DC/AC inverters and hence maximize system efficiency. The system voltage was set at 120 volts to meet electrical code requirements for distribution line losses and to enable use of commercially available switches and appliance motors. The load devices were individually selected on the basis of energy efficiency.

System design, exclusive of the pole line distribution network was performed by LeRC personnel. The pole line distribution network was designed by the Papago Tribal Utility Authority. Modules for the P/V array field were supplied from the DOE/JPL Block II procurement. A brief description of the major system components and features follows.

Loads and Load Profiles

The P/V power system provides power for a village water pump, village lighting, 15 refrigeration units, a clothes washer and a sewing machine as described below:

Water Pump. - A 2 HP permanent magnet 120 volt DC motor will be used to power an existing jack pump on the main well. The pump delivers approximately 1100 gal/hour into the village water distribution system which includes an 11,000 gallon storage tank located approximately 1200 feet from the well. LeRC and PHS personnel jointly estimated water consumption for villagers and livestock to range from 2500 gal/day in the winter to 5000 gal/day in the summer. An additional 960 gal/day was estimated by LeRC to be required for the clothes washer. Total pumping time therefore ranges from 3.1 hours/day in the winter to 5.4 hours/day in the summer. A control system limits pumping to daylight hours roughly centered about mid-day, except for emergency situations. Another well, powered by a gasoline engine, can provide water if problems occur with the main well or P/V system.

Lights. - A total of 44 20 watt/12C VDC fluorescent lights will be installed in the village. The lights will employ a special design 120 VDC/23 kHz inverter ballast which enables the lamp to produce the same number of lumens as a 120 VAC/60 Hz ballast. The lights will be distributed as follows: 2 in each of the 15 houses, 6 in the feast house, 2 in the domestic services building, 2 in the church and 4 in the electrical equipment building. A lighting load profile was generated by LeRC after consultation with the Schuchuli Village Chairman. The total load profile varies with time of year as does the morning and evening distribution of the profile.

Refrigeration Units. - A total of fifteen (15) 4 cubic foot refrigerators (with a small freezing compartment) will be provided in the domestic services building. These refrigerators are a custom design developed by a manufacturer of marine refrigerators and will be completely installed with a minimum of 3 inches of polyurethane foam. Each will have an automatic door closer and a key lock. Three refrigerators will be assembled as a unit and powered from a single compressor with a 1/8 HP 120 VDC permanent magnet motor. The manufacturer reports that the duty cycle should be about 25% "on" in a 110° F ambient environment based on test results from a similar unit. The refrigerator evaporator cold wall contains a refrigerant gel which is frozen by the refrigerant circulating in the system. The refrigeration units will be located against the north wall of the domestic services building in a locker-type arrangement with the compressors located on the outside of this wall for improved heat rejection.

Clothes Washer. - A standard wringer-type washer has been procured and fitted with a 1/4 HP permanent magnet 120 VDC motor. A wringer-type washer was selected for overall simplicity and to reduce water consumption. The washer, operated from a clock timer, can be run for 12 hours/day, seven days a week. At 1/2 hour/load, this provides for washing approximately 1.75 loads/person/week. Water consumption was estimated at 40 gal/load.

Sewing Machine. - A commercially available sewing machine with a variety of stitches, a light and a 1/8 HP, 120 V universal motor will be installed in the domestic services building. For system sizing purposes, the unit was assumed to operate in the late afternoon for 3 hours/day.

P/V Array and Battery Sizing

The design of a P/V system depends almost entirely on two factors: an accurate definition of load power requirements and duty cycles, and the determination of the proper size P/V array and energy storage capacity. In addition, loads should be designed or modified to operate only when required and should be selected based on their energy efficiency characteristics.

The basic approach to determining P/V array size and battery capacity is to match the combination of P/V array output and energy storage capacity to the load requirements. For stand-alone systems, this means that the P/V array must generate enough power to meet the total annual load requirements including battery charging inefficiencies, and that the batteries must be large enough to sustain system operation during periods of below average seasonal and diurnal insolation.

LeRC has developed a computer program which determines average hourly P/V cell output by month for a particular location and also calculates P/V array size, tilt angle and battery storage capacity. Inputs to the P/V cell output calculation are average monthly values of insolation, skycover from the Climatic Atlas, precipitable water and atmospheric turbidity; and solar cell area, efficiency and maximum power voltage. The P/V system simulation uses the output from the P/V cell calculation and matches it to an hourly load profile. The simulation program provides monthly system outputs for a 16 month period for specified numbers of series strings, battery capacities and tilt angles. The simulation includes provisions for P/V module degradation and random variation in insolation. The P/V array and battery are generally sized to limit battery maximum depth-of-discharge to about 50%. Tilt angle is selected to optimize the array size and battery capacity. Selection of the optimum array size and battery capacity combination can be modified by system considerations (e.g., physical limitations for P/V array or batteries) or economic considerations.

Using this sizing program, LeRC has determined that the P/V array for Schuchuli should be 3.5 kW and that the battery capacity should be 2380 ampere-hours. The sizing indicates that, with 20% degradation of cell output due to potential encapsulant darkening and dirt accumulation, and a ±20% variation from average values of insolation, the battery maximum depth-of-discharge should be about 60%.

P/V Array

The 120 VDC 3.5 kW (peak) P/V array will consist of 24, 4' x 8' panels. Each panel contains 8 modules connected in series to make up a 120 VDC series string. The panels will be arranged in 3 rows of 8 and will be located in a 70' x 100' fenced area. The second and third rows will be stepped 6" and 12" higher than the first row to minimize shadowing and row spacing. The panel frame and support structure has been designed to withstand 100 mph wind loads and will be fabricated from commercially available hardware. Tilt angle will be adjusted 4 times a year to 3.5° (summer), 26° (spring and fall), and 48° (winter).

Batteries

The battery storage will consist of 51 each 2380 ampere-hour capacity cells connected in series with a parallel arrangement of 4 pilot cells for load management. One pilot cell has a 1055 ampere-hour capacity and the other 3 have 310 ampere-hour capacities. All capacities are at a 500 hour 77° F discharge rate. The cells were designed for operation with P/V systems and have lead-calcium plates capable of deep discharge cycle operation. The batteries will be housed in a separate, vented room in the electrical equipment building.

Load Management

Because of unknowns in the use of the loads and variations in insolation, a load management subsystem was incorporated into the design to (1) protect the batteries from excessive discharge and potential damage, and (2) to maintain operation of the more critical loads at the expense of less critical loads. The load management subsystem sequentially disconnects loads as the battery capacity decreases to preset levels.

At 50% depth-of-discharge, the washing and sewing machines are disconnected, at 60% the lights, at 70% the water pump motor, and finally at 80% depth-of-discharge the refrigerators are disconnected. As the batteries are recharged, loads are sequentially reconnected into the system in reverse order. The four pilot cells provide sensing of the depth-of-discharge.

System Voltage Regulation

System voltage is regulated by array string switching. There are relays (one per string) which connect the 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. This same drum relay is also used for the load management subsystem.

In addition to system voltage regulation, under and over voltage protection is provided. If system voltage exceeds the maximum allowable value, the P/V array is disconnected. If system voltage drops below the minimum allowable, the loads are disconnected. Alarm lights are provided for these conditions.

Instrumentation

The Schuchuli village P/V power system is an experimental system and is completely instrumented. There are two independent instrumentation subsystems; a panel meter subsystem and an automatic cassette data recorder. The panel meters will be read daily by a village resident who will be trained to take readings and to recognize anomalous operation. Measurements will also be recorded every fifteen minutes by the automatic data system. The cassettes will be mailed to LeRC for analysis as will the panel meter data.

Parameters to be measured include currents, voltages and ampere-hours for the P/V array, batteries and all loads. Run-time meters will be provided for each load and water consumption will also be recorded. This instrumentation will enable direct determination of electrical performance and will provide local weather data and selected temperature data for comparison with basic design criteria.

Site Plan and Distribution System

A site plan and layout of the power distribution system is shown in Figure 3. The pole line distribution network has recently been installed by the Papago Tribal Utility Authority and generally follows the water distribution line, thus establishing a utility corridor around the village. The 120 VDC pole line distribution network consists of two circuits each with two No. 1 ACSR bare aluminum conductors. One of the two distribution circuits provides power for all appliances in the domestic services building. The other circuit provides power for lights in all the other buildings.

General Safety Precautions

The photovoltaic system has been designed to withstand 100 mph wind conditions. In addition, the photovoltaic system design and installation will conform to National Electrical Codes and OSHA Safety Regulations and specifications. Additional safety features provided are listed below:

1) The array field will be surrounded by a 6-foot high chain-link fence and locked (access by authorized personnel only).
2) Warning signs (HIGH VOLTAGE) will be mounted on the fence.
3) System operation will be monitored and controlled automatically.
4) A sign will be mounted on the pump indicating automatic operation of the motor.
5) A shield will be provided for the pump motor pulley and belt.
6) The electrical equipment building will be secured by a suitable lock with authorized access only.
7) Turbine ventilators and an eyewash station will be provided in the battery room of the electrical equipment building.
8) Village personnel involved in monitoring and maintenance will be thoroughly trained to follow safe operating procedures.

SUPPORTING ACTIVITIES

Environmental Impact Assessment

The Environmental Impact Assessment prepared for this project concluded that the installation and operation of a photovoltaic power system in the village of Schuchuli will have no adverse environmental impact. As such, no Environmental Impact Statement is required for this project.

Socio-Economic Study

A concurrent study of the socio-economic effects of introducing the photovoltaic system into the village of Schuchuli is being conducted by Arizona State University. The study is divided into two parts: a 4-month "baseline study" to characterize the village prior to initial operation; and a 12-month follow-up study to document the impact of the solar cell system on the domestic and communal activities within the village.

User Education Program

An orientation and education program will be included as part of this project to acquaint the residents of Schuchuli and other Tribal personnel with the use and operation of the photovoltaic system including loads. This education program will be developed by representatives of the Papago Tribe, LeRC and the PHS. The Papago Tribal Utility Authority and Papago Construction Company will also participate in the orientation activity and will be responsible for maintenance and repair following conclusion of the 2-year experiment.

CONCLUDING REMARKS

The Schuchuli P/V village power system is now in the fabrication and construction phase. The experience gained during the design phase indicates that an all-DC photovoltaic power system is practical for remote sites. There are available appliances which operate from DC and which are more efficient than their commercial AC counterparts. System operation is scheduled for the Fall of 1978. This project has gained widespread interest and will be important to the future use of photovoltaics.

PAPAGO INDIAN VILLAGE - SCHUCHULI ARIZONA

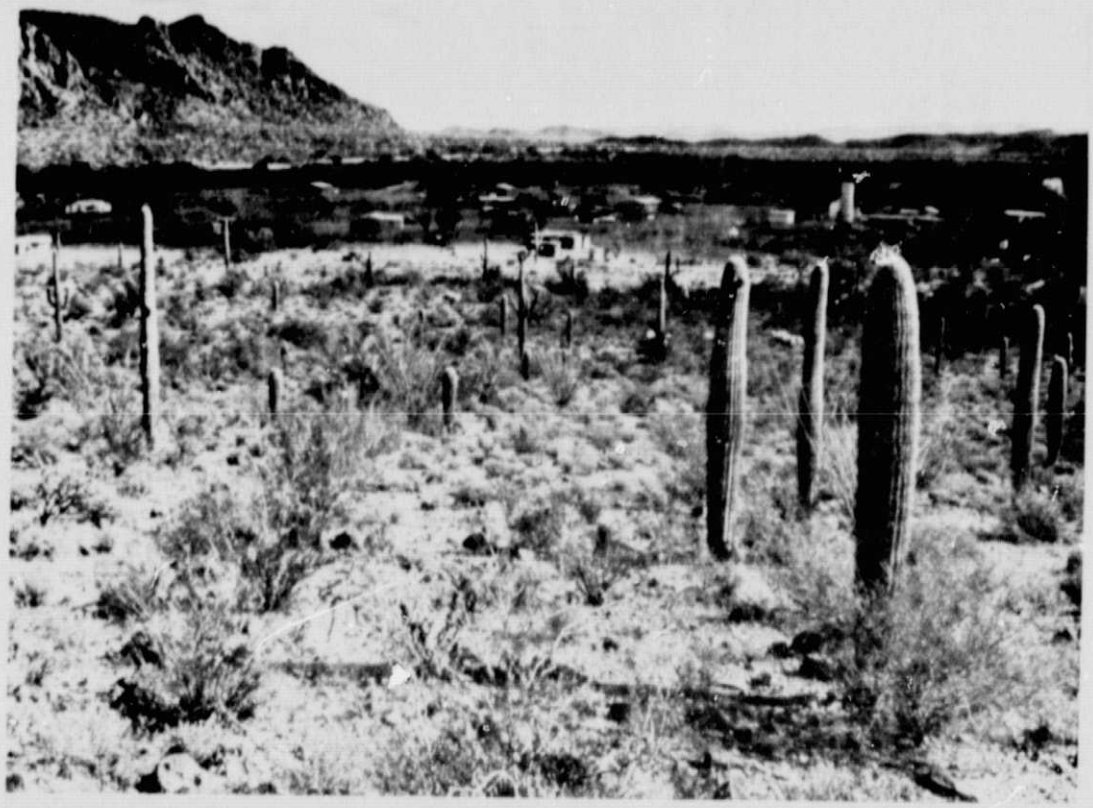

Figure 1.

BLOCK DIAGRAM OF SCHUCHULI VILLAGE POWER SYSTEM

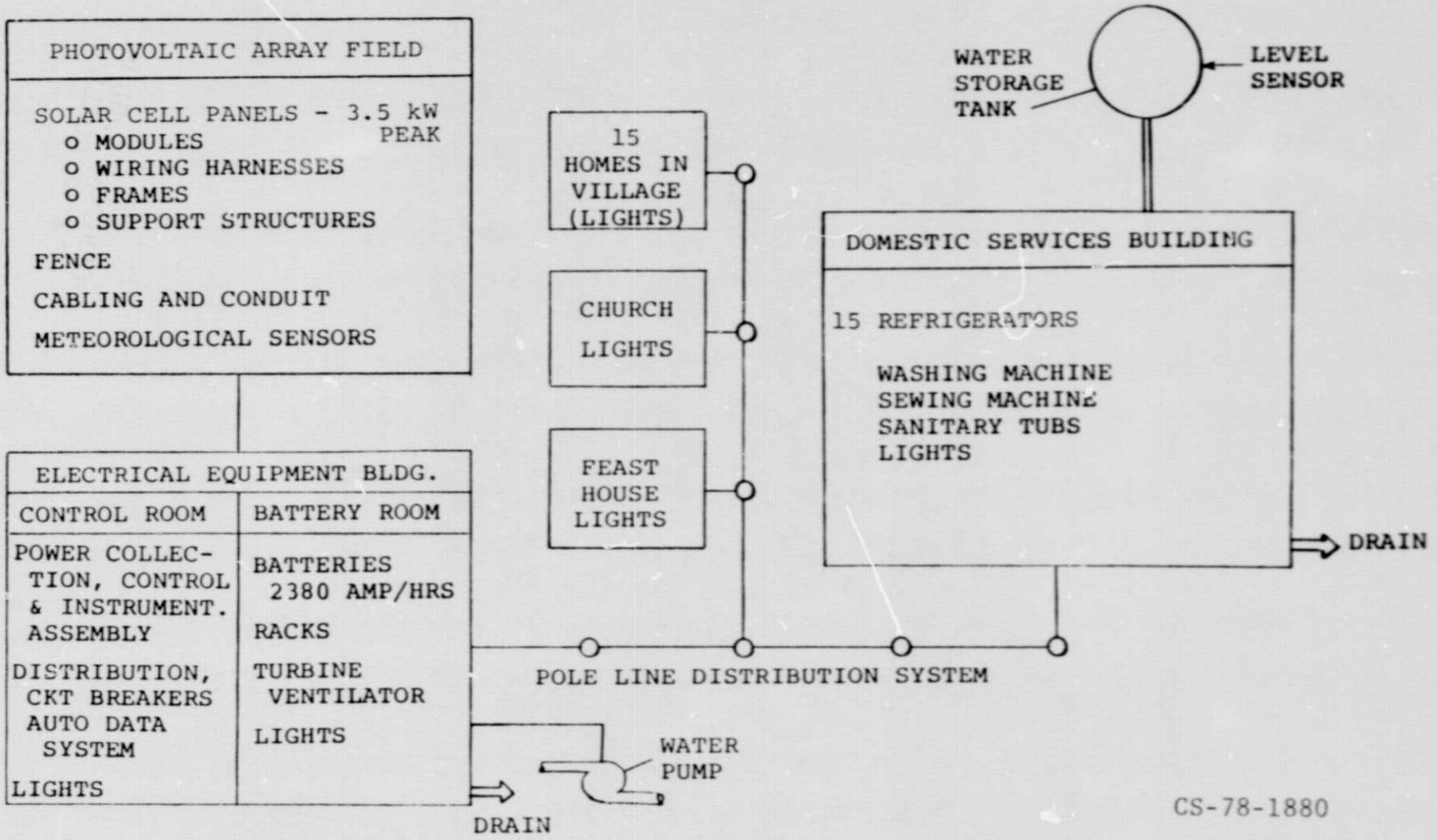

Figure 2.

NASA/LeRC/02/01/78

VILLAGE OF SCHUCHULI, ARIZONA SITE AND LOCATION PLAN

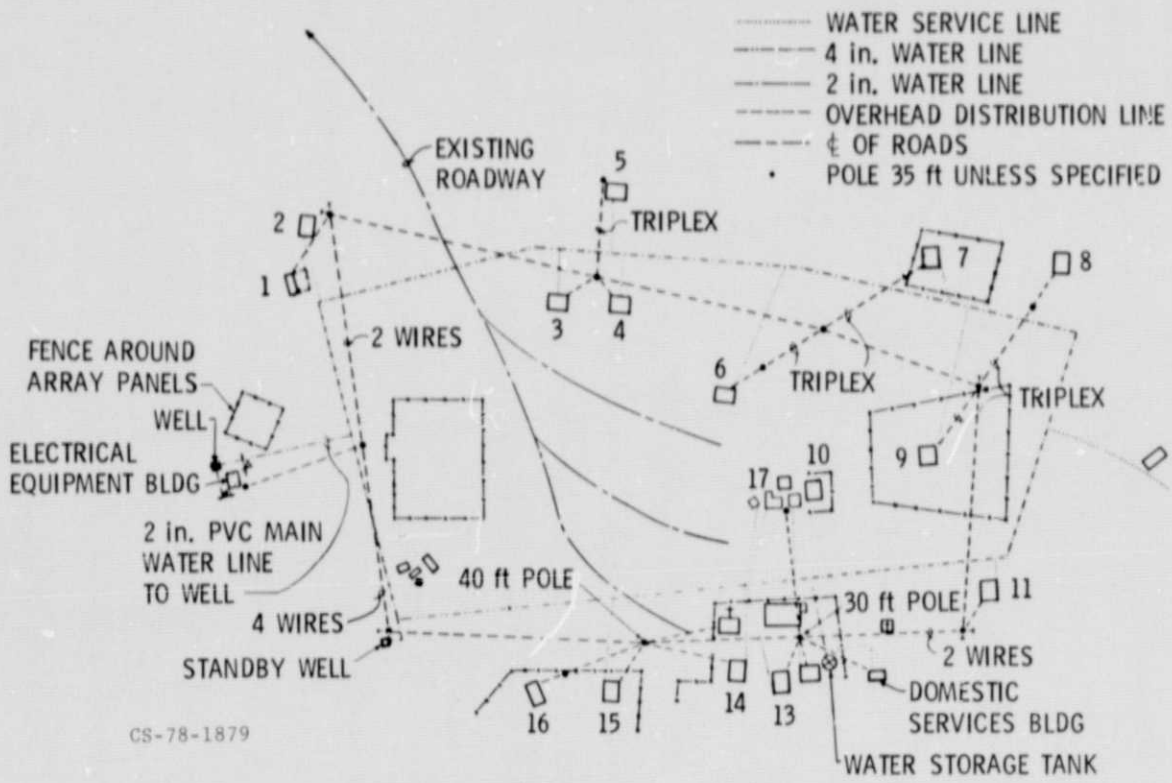

Figure 3.

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16. Abstract

In its role of supporting the DOE National Photovoltaic Program, the NASA-LeRC is designing and fabricating a stand-alone photovoltaic power system for installation in the Papago Indian village of Schuchuli, located approximately 120 miles west of Tucson, AZ. This village presently has no electrical power. The photovoltaic system is being designed to provide electricity for village water pumping and basic domestic needs as part of a cost-shared experiment involving LeRC, the U.S. Public Health Service and the Papago Tribe of Arizona. The system will consist of a 3.5 kW (peak) photovoltaic array; controls, instrumentation, and storage batteries located in an electrical equipment building; and a 120 volt DC village distribution network. The photovoltaic system will power a 2 HP DC electric motor (replacing an existing diesel engine) for water pumping; 15 refrigeration units, a washing machine and a sewing machine in a domestic services building; and fluorescent lights in the feast house, church and each of the 15 homes in the village.

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