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Work performed for

U.S. DEPARTMENT OF ENERGY
Office of Energy Technology
Division of Distributed Solar Technology

Prepared for
Seminar on Solar Technology in
Rural Settings: Assessments of Field Experiences
sponsored by The United Nations University
Atlanta, Georgia, June 1-2, 1979

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by

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ABSTRACT

Schuchuli, a small remote village on the Papago Indian Reservation in southwest Arizona, is 27 kilometers (17 miles) from the nearest available utility power. In some respects, Schuchuli resembles many of the rural villages in other parts of the world. For example, it's relatively small in size (less than 100 residents), composed of a number of extended family groupings, and remotely situated relative to major population centers (190 km, or 120 miles, from Tucson). Its lack of conventional power is due to the prohibitive cost of supplying a small electrical load with a long-distance distribution line. Furthermore, alternate energy sources are expensive and place a burden on the resources of the villagers. On December 16, 1978, as part of a federally funded project, a solar cell power system was put into operation at Schuchuli. The system powers the village water pump, lighting for homes and other village buildings, family refrigerators and a communal washing machine and sewing machine. The project, managed for the U.S. Department of Energy by the NASA Lewis Research Center, provides for two years of technical monitoring as well as a one-year socio-economic study to assess the impact of a relatively small amount of electricity on the basic living environment of the villagers. The project background, implementation details and current status of the technical and socio-economic assessment are presented in this paper.

INTRODUCTION

Photovoltaics (PV), the direct conversion of solar energy to electricity by means of solar cells, represents one of the more promising renewable energy technologies for meeting small-scale energy needs in rural areas. Since 1970, the NASA Lewis Research Center (LeRC) has been actively engaged in developing and deploying "stand-alone"

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PV systems (i.e., no back-up power source) for a variety of terrestrial applications in rural or remote locations. Most of this work has been carried out as part of the U.S. Department of Energy (DOE) Photovoltaic Tests and Applications Project, managed by LeRC. One of the objectives of this DOE project is to acquaint potential users with the features of PV power systems to accelerate their entry into the commercial market. Applications offering a good potential for near-term cost-effectiveness, technical feasibility, and/or substantial use multiplication are considered for joint, cost-shared experiments.

In 1977, LeRC entered into discussions with the U.S. Public Health Service (PHS), Tucson, Arizona, regarding such an experiment involving water pumping in a remote village on the Papago Indian Reservation, located in the south-central portion of Arizona. Candidate villages were selected and screened using technical criteria established jointly by LeRC and PHS. Since groundrules established for the Tests and Applications Project limited the PV power system size, well depth and water requirements were important considerations in the selection of the village. Based on these and other criteria, representatives of the Papago Tribe and the PHS selected Schuchuli, a small settlement located on the western edge of the reservation, for the water pumping experiment. Subsequent analyses and discussions indicated that sufficient PV power was available to satisfy other basic electrical needs of the village; hence, the experiment was expanded to a village power project.

A meeting was held in the village to determi the devices that the residents wished to power with the PV system. The villagers responded with the following prioritized list:

1. Lights in each house (kitchen)
2. Lights in second room
3. Lights in feast house and church
4. Refrigerators
5. Washing machine
6. Food freezer
7. Irons
8. Sewing machine
9. Television

Lights were desired so that the school children would have the opportunity for extended study time in the evenings. Refrigeration was another popular choice since the only alternative was to purchase ice for home coolers, which was expensive and often difficult to obtain. A washing machine was needed because many villagers could not afford to make regular trips to the commercial laundromat located in Ajo, 16 miles away. The sewing machine was added as the final electrical load. Other loads such as electric irons and TV sets could not be accommodated within the total available PV power.

VILLAGE BASELINE CHARACTERISTICS

Geography and Climate

The village of Schuchuli (latitude 32.2°N, longitude 112.7°W) is located on a valley plain at an elevation of 1990 feet, approximately 190 kilometers (120 miles) west of Tucson, Arizona and about 27 kilometers (17 miles) from the nearest available utility power. Schuchuli's geographical position is distinctive because it is on a highway (State route 86) literally at the gateway between the Papago Reservation and a number of white farming and mining settlements. White settlements such as Why, about 8 km (5 miles) from the village, and Ajo, a mining town less than a half-hours drive and the Mexican border town of Sonoita, about 48 km (30 miles) south of Why, are places where villagers work and/or shop and sometimes live.

Schuchuli's climate is typical of the Sonoran Desert with an average mean temperature of 21° C (70° F) and an average rainfall of 15 centimeters (6 inches) annually. Humidity is generally low except during the summer rainy season of July and August when it rises quite sharply. Winds average about 13 km per hour (8 miles per hour) on a yearly basis with a maximum wind velocity of about 97 kph (60 mph). Mean daily (total horizontal) solar radiation varies from 300 langleys in winter to 700 langleys in summer.

History of Village

Schuchuli was founded around 1930 when the Papago Juan Luis took possession of a chicken ranch that the U.S. Government had repossessed from its white owner. It was among the last parcels of land added to the 2.7 million acre reservation. The name Schuchuli, pronounced SCHTEW-chewlik, means "many chickens."

For many years, Schuchuli was without many of the niceties of life. For example, until only recently, villagers had to haul water from an unprotected dug well. In 1960, the U.S. Public Health Service (PHS) provided protection for the well and installed a pump, a small water storage tank and a simple distribution system. In 1966, the PHS improved the well and pumping equipment, installed a 11,000 gallon storage tank and expanded the distribution system to provide water in each house. The PHS also installed a kitchen sink in each home, and sanitary pit privies. In 1975, PHS drilled a new well, renovated the water tank and expanded the distribution system further. In addition, three new homes were equipped with individual septic tank systems.

Initially, power to operate the water pump was supplied by a windmill and the supply of water varied with the wind. Later a gasoline and then a diesel engine were used. Consideration was given to bringing power lines to Schuchuli but the cost was considered excessive. The electric utility economics are such that the Papago Tribal Utility Authority requires one customer (user) per 300 meters (1000 feet) of power line extension. On this basis, Schuchuli does not meet the criterion for power line extension.

Village Population and Physical Characteristics

A survey conducted in August of 1978, revealed that Schuchuli had a total population of 64 people comprising 12 families. By comparison, the population in 1977 when the project was initiated was 95 with 16 families. The fact that 25% of the households were not in residence during the August '78 survey is considered about normal for a Papago village and is due in large part to the movement of young families, on a more-or-less long-term basis, to wage-paying jobs off the reservation. In fact, all the adults of the resident households have lived for periods of months or years off the reservation in conventionally electrified housing.

Based on the latest survey conducted in early March 1979, the village still consists of 12 resident households out of the total of 16. However, the population was 11 less than in August '78, i.e., 53. Of the 11, 8 were children attending boarding schools. There were 9 additional departures and 6 arrivals for other reasons. All told, this resulted in a 33% circulation of residents in the six-month interval. Such is the emerging picture of population mobility.

A review of the age distribution of the 64 residents from the 1978 survey indicates that the village has many children and elderly people, and significantly fewer men than women in the age group 20 to 49. Half of the households with children are three-generation households, illustrating the "extended family" nature of Papago society in general. Further, Schuchuli is a society of relatives. Only 3 of the 16 households do not have kinship bonds with at least 1 other household in the village.

In terms of physical characteristics, Schuchuli consists of 22 houses distributed among the 16 households. Five of the households consist of multiple house units. The village also has a church and a feast house.

The older houses are constructed from traditional hand-made adobe bricks or adobe mud packed between boards used as a form to hold the mud in place until dry. The adobe is covered with a layer of cement to prevent erosion. Four new homes, plus one under construction, are of modern construction built with masonary block. The typical older home has two rooms. Cooking is performed in one room or outside under the ramada. New homes have a bathroom. Older homes have an outside privy.

Village Economy

The village, in some respects, is self-sufficient. The villagers bury their dead in their own cemetery, and maintain their own church. People generally repair their own houses, which in most instances were designed and built by local labor. Sharing with all families is a strong tradition in the community. On feast days, a steer is slaughtered and the villagers serve a multi-course free dinner to hundreds of guests. For the most part, however, the material means for the village's activities are purchased from the outside.

Sources of money income for the villagers include pensions, full-time jobs, tribal public works programs, social security, welfare/food stamps, short-term government jobs and home industry.

Based on the August '78 survey, the resident population of 26 adults derived income from a total of 47 sources, 13 of which fall under the broad heading of hourly jobs. The remaining sources are home industry or some category of financial assistance, including pensions or social security. All but 7 of the income sources stem from the Tribal or Federal government. The annual household income was found to average about $7000.

Cattle raising provides a small supplemental income for some families (five households own cattle). Cattle and wild game also represent an occasional supplemental source of food.

Energy Use

The primary sources of energy in the village prior to the introduction of the solar electric system were wood, propane, kerosene and gasoline. Wood and propane are used extensively for space heating; 8 resident households use propane exclusively. For cooking, only 4 resident households use propane exclusively and in the summer, wood is more commonly used since cooking is often done in stoves or fireplaces located outside the house. In general, however, the majority of households spend at least $240 annually for propane ($1.20 per gallon, or 32¢ per liter). Wood is either gathered locally or purchased at about $10 per cord. Those who use wood primarily report annual expenditures of about $360.

As of the latest survey, 9 operable cars or trucks were owned by residents. Estimated gas expenditures ranged from a high of $6 per day to a low of $10 per week. The average cost was about $20 per week ($1000 annually). The use of vehicles for trips to the local laundromats accounted for 30 to 90 miles per week. The current local price of gasoline is about 85¢ per gallon (22¢ per liter).

Kerosene is used in the village for starting fires and house lighting. The current local price of kerosene fuel is about $1.80 per gallon (48¢ per liter).

Prior to the introduction of the solar electric system, diesel fuel was used to run the pump motor. Each household was assessed $3.50 per month for the fuel. The current local price of diesel fuel is about 60¢ per gallon (16¢ per liter).

Based on this preliminary information, it appears that Schuchuli has a relatively high energy budget.

SYSTEM DESCRIPTION

Design, Fabrication and Installation

The Schuchuli village PV power system (Fig. 1) became operational on December 16, 1978. It provides the residents of Schuchuli with electric power for potable water pumping, lights in the homes and community buildings, family refrigerators, and a communal washing machine and sewing machine.

The power system consists of a 3.5 kW, 120 volt, DC PV array, 2380 ampere-hours of battery storage, controls, voltage regulation and instrumentation, and an overhead electrical distribution network. The battery and controls are located in an electrical equipment building (EEB), shown on the right in Figure 1.

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

System design, exclusive of the overhead distribution network, was performed by LeRC. The overhead distribution network was designed by the Papago Tribal Utility Authority. A brief description of the major system components and features depicted in Figure 2 follows.

The PV array consists of 24, 1.22m-by-2.44m (4-ft-by-8-ft) panels. Each panel contains 8 modules connected in series to make up a 120 VDC series string. The panels are arranged in 3 rows of 8 and are located in a 21.3m-by-30.5m (70-ft-by-100-ft) fenced area. Panel frame and support structure are designed to withstand 161 km/hr (100 mph) wind loads and are fabricated from commercially available hardware.

The battery consists of 53, 2380-ampere-hour capacity cells (at a 500-hour, 25° C (77° F) discharge rate) connected in series. The cells were designed for operation with PV systems and have lead-calcium plates capable of deep discharge cycle operation. The batteries are housed in a separate, vented room in the EEB.

A 2 HP permanent magnet, 120 VDC motor powers a positive displacement water pump which delivers approximately 4165 liter/hour (1100 gal/hr) into the village water distribution system which includes a 41,635 liter (11,000 gallon) storage tank located approximately 365m (1200 feet) from the well. During normal operation, a control system limits pumping to daylight hours, roughly centered about mid-day.

A total of 47, 20 watt/120 VDC fluorescent lights are installed in the village. The lights employ a high-efficiency 120 VDC/23 kHz inverter-ballast which enables the lamp to produce the same number of lumens as a 120 VAC/60 Hz ballast.

A total of 15, $0.13m^3$ (4.7-cubic-foot) refrigerators (with small freezing compartments) are installed in the domestic services building (DSB). These refrigerators are of a custom design developed by a manufacturer of marine refrigerators and are completely insulated with a minimum of 7.5cm (3 inches) of polyurethane foam. Each has an automatic door closer and a key lock. Three refrigerators are 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 43° C (110° F) ambient environment based on test results from a similar unit.

A standard wringer-type washer was refitted with a 1/4 HP, 120 VDC permanent magnet motor. A wringer-type washer was selected for overall simplicity and to reduce water consumption. The washer is connected to a cumulative timer which allows up to 12 hours per day of washer operating time. At 1/2-hour/load, this provides for washing approximately 1.75 loads/person/week based on a village population of 96.

A commercially available sewing machine with a 1/8 HP, 120 V universal motor was also installed in the DSB. Additional details on system design are given in reference 1.

Cost Considerations

The installed PV system cost for the 3.5 kW peak system at Schuchuli was $108,483 (1978 $), excluding experiment-related costs. Assuming a 20-year life (10 years for batteries), an 8% discount factor, the levelized annual capital cost of the system is $11,000. For the predicted value of annual energy consumption, i.e., 6255 kWh/yr, the resultant energy price of the solar electricity is $1.76 per kWh. By comparison, the corresponding price for diesel-generated electricity is $.82 and $1.27 for $.64/gal and $1.59/gal fuel, respectively; for utility line extension, energy price ranges from $1.55 to $1.91/kWh; assuming a 20-year life, 8% discount factor and 5% escalation per year in fuel and electricity costs (over normal inflation).

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 both diesel generators and power line extensions where annual energy consumption is under 15,000 kilowatt-hours (reference 2).

Education/Orientation

An orientation and education program was provided as part of this project to acquaint the residents of Schuchuli and other Tribal personnel with the use and operation of the PV system and associated electrical devices. User Manuals were provided for the villagers as well as Operation and Maintenance and Troubleshooting and Repair Manuals for the Village Power System Manager and the Papago Tribal Utility Authority (PTUA).

INITIAL IMPACT OF SOLAR ELECTRICITY

Water Consumption

Patterns and rates of water use have not changed markedly since the PV system became operational in December 1978. Domestic activities such as drinking, cooking, cleaning, clothes washing and bathing use the most water. Houses with indoor plumbing have an additional requirement for use in waste disposal. The second largest demand is for watering livestock - primarily cattle which are occasionally held in the village's corral and, secondarily, horses kept in the village by their resident owners. The last noteworthy use of water is for the irrigation of a few trees and small family gardens. There are no indications at this point to suggest that the change in power source or the lower costs paid by the residents to run the pump will significantly alter water consumption in the domestic, stock and agricultural contexts.

Dietary Patterns

Installation of 15, 0.13m^3 refrigerator units has greatly expanded the refrigerated food storage capacity in the village. Each family has access to one of these refrigerators in addition to the use of ice chests. All refrigerators are located in the DSB; ice chests are kept in the respective homes and can now be supplied with ice from the refrigerators. As of March 1979, actual usage was concentrated in the refrigerators - all but one resident household were using their refrigerators; only two families were also using ice chests. It is quite likely that during the hot summer months ice chests will come into greater use for short-term storage and holding of foods with a relatively high temperature tolerance.

During February, items stored in the refrigerator, in order of frequency, were: meat, milk, juice, cheese, soda pop, jello, vegetables, eggs and fruit. These were essentially either ingredients for dishes which will require processing before consumption, or they were ready-to-use items that merely require serving. The chief exception to this generalization is the jello which is not only a prepared dish but one that was not common before the introduction of the refrigerators.

It is notable that leftovers have not yet been stored in the refrigerators. As a matter of economy, excess food is generally prepared only during the cool months when spoilage is not a problem if the surplus is consumed the next day. It is for this reason that beans have been more commonly prepared during the winter than in the summer. Utilization of the refrigerators for storage of cooked food during the summer would therefore represent a significant change in dietary patterns. Increased consumption of meat, milk, and fresh vegetables may also be realized because of the refrigerators.

Concomitant with the impact of the refrigerators on dietary patterns is an effect on ice use and medicine storage. Ice has been conventionally used as a cooling medium in ice chests and in drinks. Previously, ice had to be purchased outside the village and brought in.

The installation of the refrigerators provides an alternative source within the village and has been so used by every household. One family has also started to keep an insulin supply in its refrigerator. This is considered to be a much safer way to store that medicine than in an ice chest.

Lighting Usages

Lighting in Schuchuli is currently being met with a combination of electric lights - powered by the PV system - kerosene lamps, candles and flashlights. Candles, which are burned at family altars, and flashlights, which are used to locate things at night, actually provide very little of the illumination used in the house. Electric lights and kerosene lamps are the primary lighting sources.

During February, domestic use of the electric lights followed a fairly common pattern: in the mornings they are turned on before sunrise and in the evenings they are used from sunset to about 9:00 pm. On the average, families reported using the lights a total of 3-1/2 hours a day. By contrast, kerosene lamps were used 5-1/4 hours a day. This difference in use can be attributed to the employment of lights for tasks requiring high visual discrimination such as [illegible]king, dressing, and school work but not during periods of social [illegible] and recreation. Lamps, or just candles, are utilized with these latter activities. Location of the fluorescent lights in kitchens and primary living/sleeping spaces encourages this practice. For those activities requiring electric lights, the brightness of the 20-watt fluorescents is considered adequate by the villagers.

Washing and Sewing Machine Use

For the village in general, the introduction of a washing machine may be the most valued feature of the electrification project to date. Nine of the eleven households resident in February 1979, reported that they had used the new machine at least once; five households were doing the majority of their laundry in the community building; and three families were doing all their laundry there. Even greater use can be anticipated once clotheslines are installed and the women become accustomed to the machine. Full utilization of the washing machine also depends upon the villagers developing a mutually agreeable machine-use schedule.

The sewing machine occupies the opposite pole along the continuum of public appreciation. Only two women reported using the machine since its introduction - both times for mending men's pants. These two women and three others stated that they intended to use the machine at some future date. Three women indicated that they might try it, another three said that they did not expect to. Those who do not plan to use the machine offered a variety of personal explanations for their attitudes: (1) preference for a treadle machine; (2) dislike for the low ambient temperatures (during the winter) and the relative isolation of the DSB; and (3) a general disinclination to sew. Those who do plan to use the machine, but have not yet done so, noted that a necessary condition for use of the sewing machine was additional training (an initial training session was held) and acquisition of accessory equipment such as bobbins for each user. These conditions may prevail but they are probably less of a deterent to use of the machine than the common view of sewing as a optional household activity.

Changes in Life Style

For the most part, no major changes in Schuchuli's life style are yet apparent as a result of the electrification project. However, a comparison between the summer baseline established in August 1978, and the situation as it was recorded in February 1979, indicated several noteworthy differences. With respect to daily schedules, village residents are tending to rise and go to bed later than they had stated previously. The morning differential is only about 30 minutes but the additional time at night is as much as an hour. Delayed bed times may be effected by later suppers since the preparation, service, and cleanup for that meal are no longer limited to daylight hours. A change in shopping patterns is also discernable: several families reported a decline in purchases from the crossroads store at Why, 5 miles distant. This trend toward shopping in larger, more economical stores may have been effected by the availability of the refrigerator units but it could equally well be explained by rapid increases in food prices during the period. Finally, as was mentioned earlier, more households are washing clothes in the village than did last summer. This is partially attributable to the availability of the washing machine in the community; however, the decision to use the machine has also been influenced by the higher cost of travel to laundromats in Ajo (16 miles distant).

Communal Management/Maintenance

To date, the community has viewed the project primarily as something brought to it. The residents, as a whole, did not actively seek the project, nor have they had to exercise much control over it through overt collective action. Most, if not all, of the action which has taken place has been in the context of village-wide meetings. These meetings were called by a man of the village who is also chairman of the governmental district to which Schuchuli belongs. They were open meetings in which everyone who wanted to speak had an opportunity to do so. It was in the course of such meetings that the project was introduced prior to its installation, approval was granted for the installation, load devices were selected, and keys were issued for the refrigerators after the project dedication. Future decisions of a group nature will probably include maintenance of the DSB and scheduling for use of the washing machine.

General Reaction of Villagers

For the most part the residents of Schuchuli have been favorably disposed toward the electrification project. When asked in February 1979, how they felt about the project, the most common answer was, "All right." Lights, the washing machine, and the refrigerators were singled out by some as particularly appreciated. On the other hand, there were also problematic aspects to the project. For the most part they were either relatively minor technical difficulties - which were resolved shortly thereafter - or normal intra-village adjustments to the new equipment - such as the need for schedules and clotheslines to maximize use of the washing machine. The installation of domestic lighting in phases was the single-most frequently mentioned criticism of the project. This situation occurred because of a delay in shipment of some of the DC electrical switchgear from the vendor in Tucson. People, at the time, simply did not know why "...they have lights and we don't."

Regarding the system as a whole, several respondents indicated dissatisfaction with its limited capacity. They wanted to be able to use a larger number of electrical appliances without the attendant cost of running generators or buying batteries. There is also an emerging awareness and concern for the maintenance and protection of the system. These issues do not appear to be viewed either positively or negatively, but as an unavoidable part of the situation. This, perhaps, is close to the underlying attitude toward the project; unjudgmental and unemotional, with a hope that it will work out and with acceptance that it will unfold in its own time. As one woman put it, "I'm waiting to see how it is in the summer."

CONCLUDING REMARKS

The Schuchuli system has been operating satisfactorily since December 16, 1978. Water pumping has been about one-half that planned for this time of year because of the unusually cold and wet weather and because the women in the village are only gradually beginning to use the washing machine. The people enjoy the convenience of electric lights in their homes and are gradually changing their food-buying habits to use more refrigerated foodstuffs.

Experience to date indicates that stand-alone PV systems providing DC power are practical for remote sites. The appliances and load devices installed in Schuchuli are operating satisfactorily. The 6255 kilowatt-hours of electricity provided annually by a 3.5 kW peak PV array appears adequate to meet the basic electrical needs of the village.

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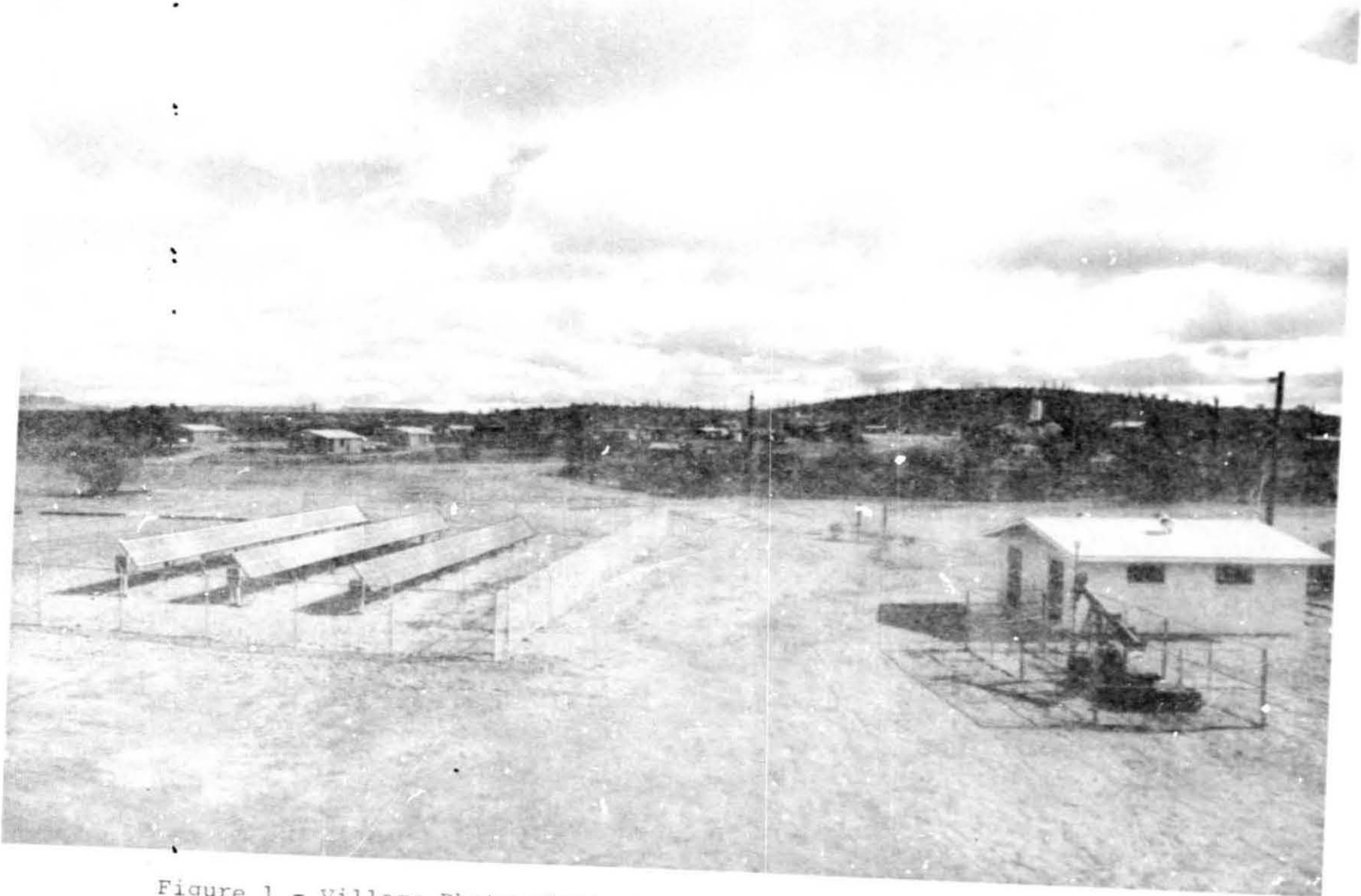

Figure 1 - Village Photovoltaic Power System, Schuchuli, Arizona

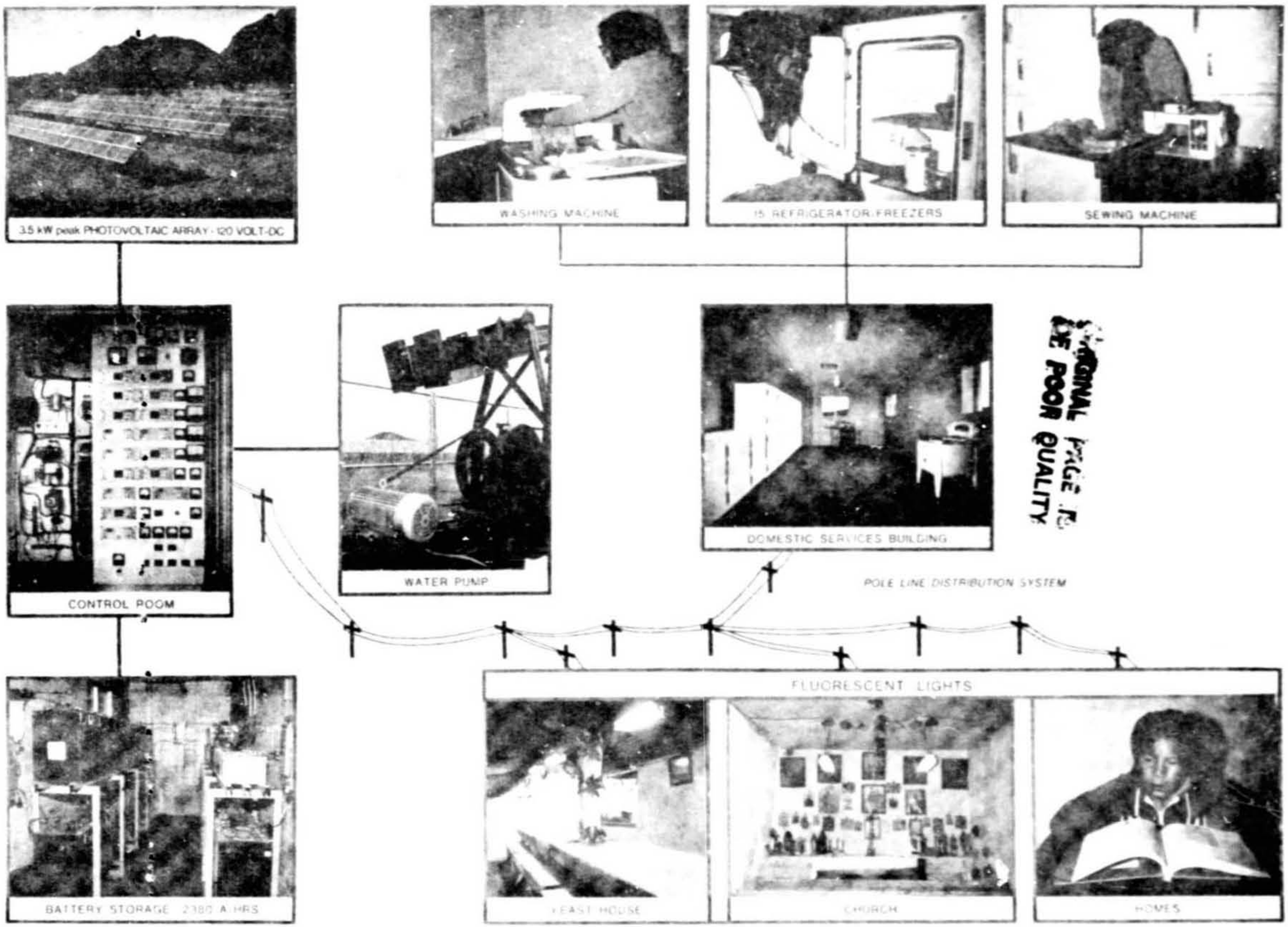

Figure 2. - Block diagram of Schuchuli villiage photovoltaic power system.

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16. Abstract

Schuchuli, a small remote village on the Papago Indian Reservation in southwest Arizona, is 27 kilometers (17 miles) from the nearest available utility power. In some respects, Schuchuli resembles many of the rural villages in other parts of the world. For example, it's relatively small in size (less than 100 residents), composed of a number of extended family groupings, and remotely situated relative to major population centers (190 km, or 120 miles, from Tucson). Its lack of conventional power is due to the prohibitive cost of supplying a small electrical load with a long-distance distribution line. Furthermore, alternate energy sources are expensive and place a burden on the resources of the villagers. On December 16, 1978, as part of a federally funded project, a solar cell power system was put into operation at Schuchuli. The system powers the village water pump, lighting for homes and other village buildings, family refrigerators and a communal washing machine and sewing machine. The project, managed for the U.S. Department of Energy by the NASA Lewis Research Center, provides for two years of technical monitoring as well as a one-year socio-economic study to assess the impact of a relatively small amount of electricity on the basic living environment of the villagers. The project background, implementation details and current status of the technical and socio-economic assessment are presented in this paper.

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