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PHOTOVOLTAIC ENERGY

TECHNOLOGY REFERENCE NOTEBOOK

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RENEWABLE ENERGY RESOURCES FIELD TEST PROJECT

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1.0 INTRODUCTION

This document is one of a series of Technology Reference Notebooks developed for the Renewable Energy Field Test (REFT) Project sponsored by USAID and the Government of Egypt. The series includes individual notebooks on the following energy technologies:

- o Active and Passive Solar
- o Biomass
- o Geothermal
- o Photovoltaics
- o Solar Thermal
- o Wind

The objective of this series is to provide the most current information on renewable energy technologies in an easily updated and easily retrievable format.

This particular handbook is the Photovoltaic (PV) Energy Technology Reference Notebook. Operating principles, component descriptions, design considerations, implementation and continued operation, and applications of photovoltaic systems are addressed. Also included are special considerations of the Egyptian environment; extensive literature on state-of-the-art products from major manufacturers involved in PV; and a PV Projects Site Visit Book, providing information on specific projects that have been installed worldwide.

2.0 OPERATING PRINCIPLES AND DEFINITIONS

2.1 PHOTOVOLTAIC TECHNOLOGY DESCRIPTION

2.1.1 The Photoelectric Effect

The photoelectric effect is the basis for the direct conversion of light into electricity in photovoltaic (PV), or solar, cells. This phenomenon is made possible through the nature of the materials involved.

PV cells are solid-state devices made from semiconductor materials such as silicon (semiconductor materials are those that, due to their intrinsic electronic structure, exhibit significantly increased conductivity upon the application of heat, light or voltage). These semiconductors are diffused with specific impurities--a process referred to as doping. A basic PV cell (Exhibit 2-1) consists of two semiconductor layers: the top is doped such that there is an excess of negative charges (n-type material); the bottom is doped such that there is an excess of positive charges (p-type material). The layering of the materials in this way results in an electric potential across the cell. The region of material where these two layers intersect is referred to as the p-n junction.

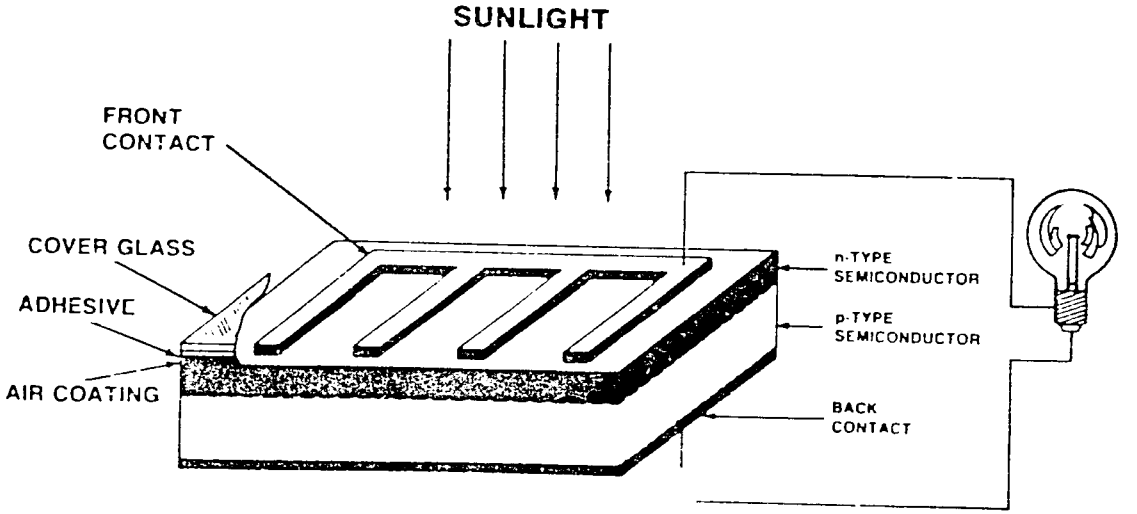
When light strikes such a cell, electrons are freed, and a unidirectional flow of electrons (i.e., a current) results. The current is collected and transported by metallic contacts placed on the surface of the cell. If the semiconductor material was not doped, the freed electrons would immediately recombine, producing heat.

2.1.2 Conversion Efficiency

One of the most important characteristics of a photovoltaic cell is its conversion efficiency. The amount of incoming sunlight that is converted to electrical energy, directly affects the cost of electricity produced by photovoltaic systems. Cell efficiencies are limited by theoretical and practical

Exhibit 2.1

BASIC PHOTOVOLTAIC (SOLAR) CELL



considerations. The primary limitation on the theoretical maximum efficiency is that semiconductors, based on their intrinsic electronic structures, can absorb only energy from a certain range of the solar spectrum. This range varies according to material and results in approximately 56 percent of the conversion losses. The primary practical limitations result from material defects and the fact that cell operating temperatures are higher than ideal.

One way of achieving cell conversion efficiencies that are higher than the theoretical maximum for a single material is with multiple-junction cells. The most common type under development involves the layering of semiconductor materials such that each layer converts a different portion of the solar light spectrum. A table of current efficiencies for various materials is shown in Exhibit 2-2.

EXHIBIT 2-2: CURRENT LABORATORY CELL EFFICIENCIES
(Under No Concentration)

Single-Crystal Silicon Ingot	19%
Polycrystalline Silicon Ingot	17%
Silicon Ribbon/(Single-Crystal/Polycrystal)	17%/15%
Amorphous Silicon	11.5%
Other Thin Films	11%

For a more detailed discussion of the physics involved in photovoltaic energy conversion, the publication Solar Cells: Plugging into the Sun (John Fan, MIT, 1978) is recommended.

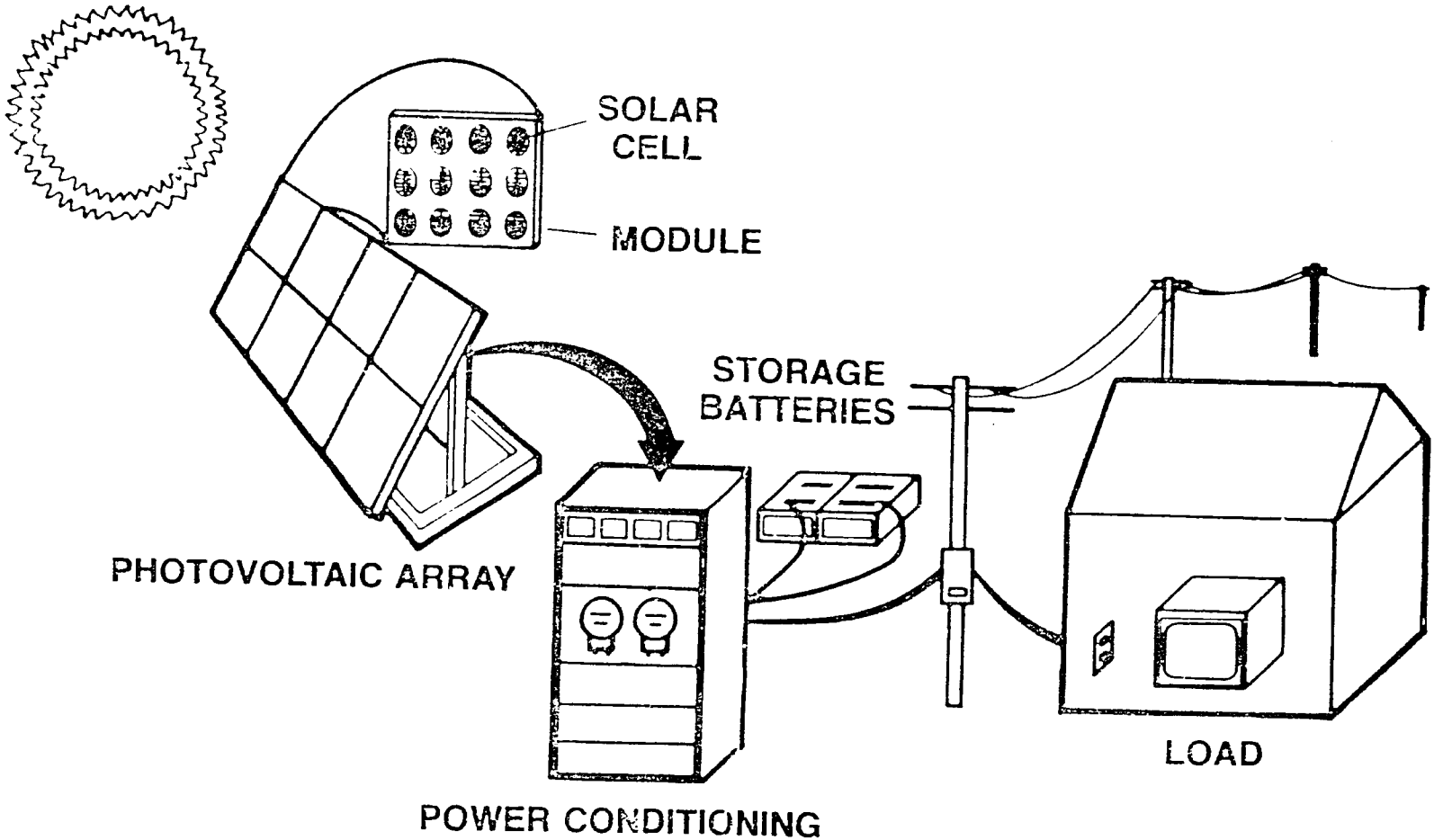
2.2 PHOTOVOLTAIC SYSTEM

2.2.1 Cells, Modules, Arrays

[illegible] system (Exhibit [illegible]-3), groups of cells are mounted, interconnected, and sealed to form modules (or collectors) which are in turn connected into arrays. The way cells and modules are connected, in terms of their series and parallel config-

Exhibit 2.3

PHOTOVOLTAIC SYSTEM



uration, determines the nominal voltage and current: the voltages of each component in series are additive, while the current is the same; in parallel, the voltages across each are equal, while the currents are additive.

2.2.2 Types of Systems

2.2.2.1 Stand-Alone

A stand-alone system is an independent power generating system that is the sole source of power for local electrical loads. These systems may or may not include storage systems. The majority of current PV applications are of this type. They can be remote applications where power is otherwise unavailable or unreliable, or they can be applications where owners prefer to exist autonomous of the utility. Typical stand-alone applications include communications, cathodic protection, navigation aids, water pumping and rural electrification. More detailed descriptions of these applications can be found in Chapter 8 and in Appendix D.

2.2.2.2 Grid-Interactive

This type of system consists of one or more power generating systems that feed into an electrical transmission and distribution network that provides power to a large number of widely dispersed loads. Grid-interactive systems have been applied most commonly in the U.S. Applications range from small residential systems to multi-megawatt central station plants for utilities. These applications are also discussed in more detail in Chapter 8. Examples of currently operating systems are given in Appendix D.

2.2.3 Power Conditioning System

Power generated by the arrays is usually fed into a power conditioning system. Those situations where power conditioning is not necessary will be discussed in section 3.3.1. This subsystem "conditions" power such that it is compatible with the loads or the utility grid, as applicable. Compatibility

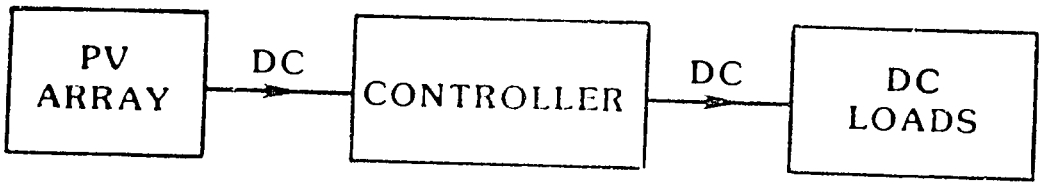
is based both on the magnitude of the voltage and the type of current (direct versus alternating). The actual components that make up a power conditioning system (the combination of inverters, converters, controls and regulators) vary according to application. Examples of possible power conditioning systems are given in Exhibit 2-4. The reasons for selecting given components are detailed in section 3.3.

2.2.4 Storage System

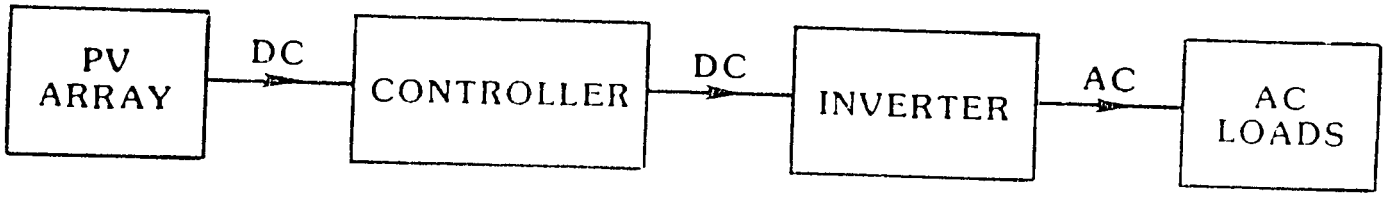
PV systems generate power only when the sun is shining. Often, this daytime supply of power does not coincide with the time of energy demand. Thus, to provide power during periods of little or no sun (i.e. at night and during cloudy days), a storage system can be employed. Of the many possible energy storage systems available, most are not practical due to their high initial costs and energy storage capability mismatch (many can store much more energy than is required). Pumped hydroelectric, compressed air, thermal or hydrogen storage, super conducting magnets, and flywheel storage fall into this category. Chemical storage of electrical energy via batteries is the most practical and cost-effective method of storing energy in conjunction with a PV system. In this sense, batteries act as a load to the PV system and as a source to the other loads.

Exhibit 2.4
POWER CONDITIONING SYSTEMS

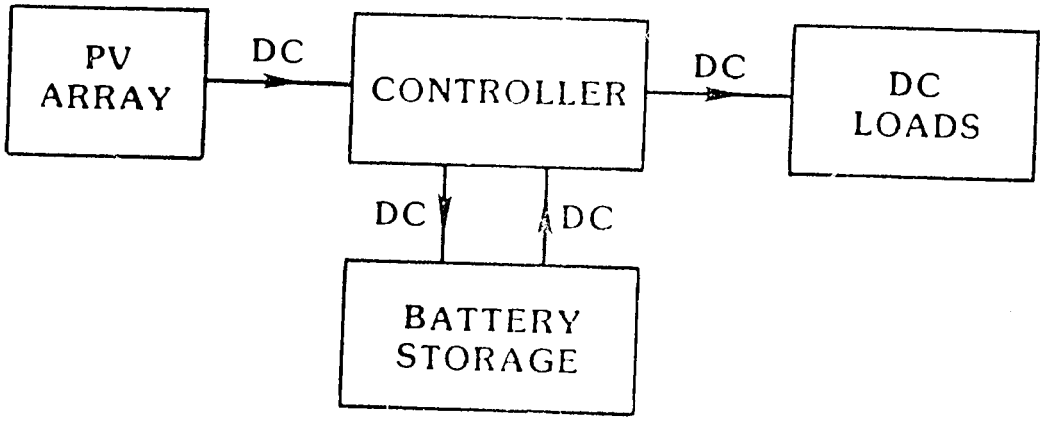
1. DC Loads, No Storage



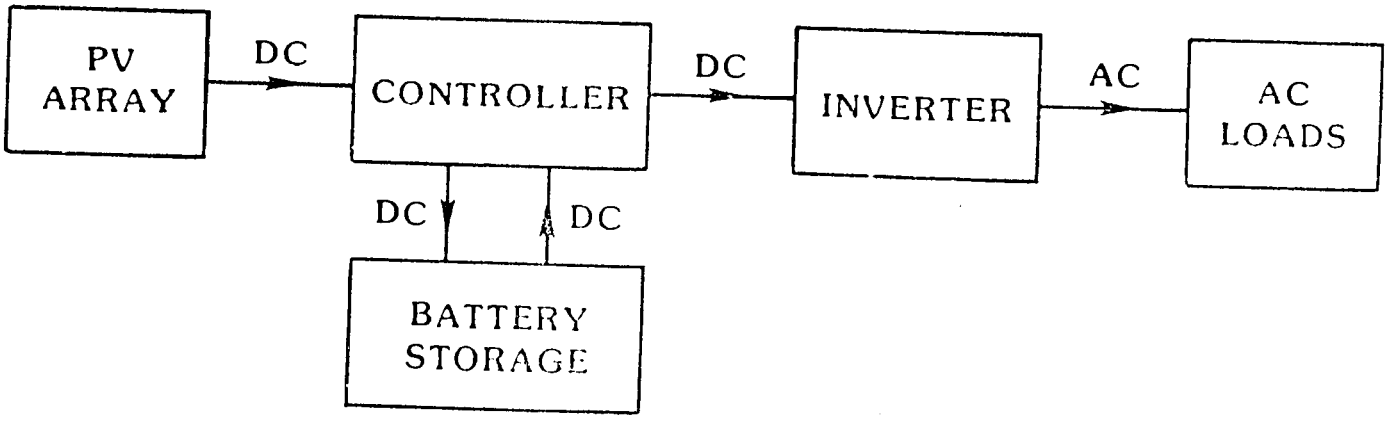
2. AC Loads, No Storage



3. DC Loads, Storage



AC Loads, Storage



3.0 DESCRIPTION OF COMPONENTS

3.1 PV ARRAYS

3.1.1 Cell Types

There are basically three generations of PV cell technology: ingot, ribbon and thin films. The current PV market is dominated by first generation technology--ingot cells. Second generation technology entered the market within the last few years. The first, third-generation product for the power market was introduced in November 1984.

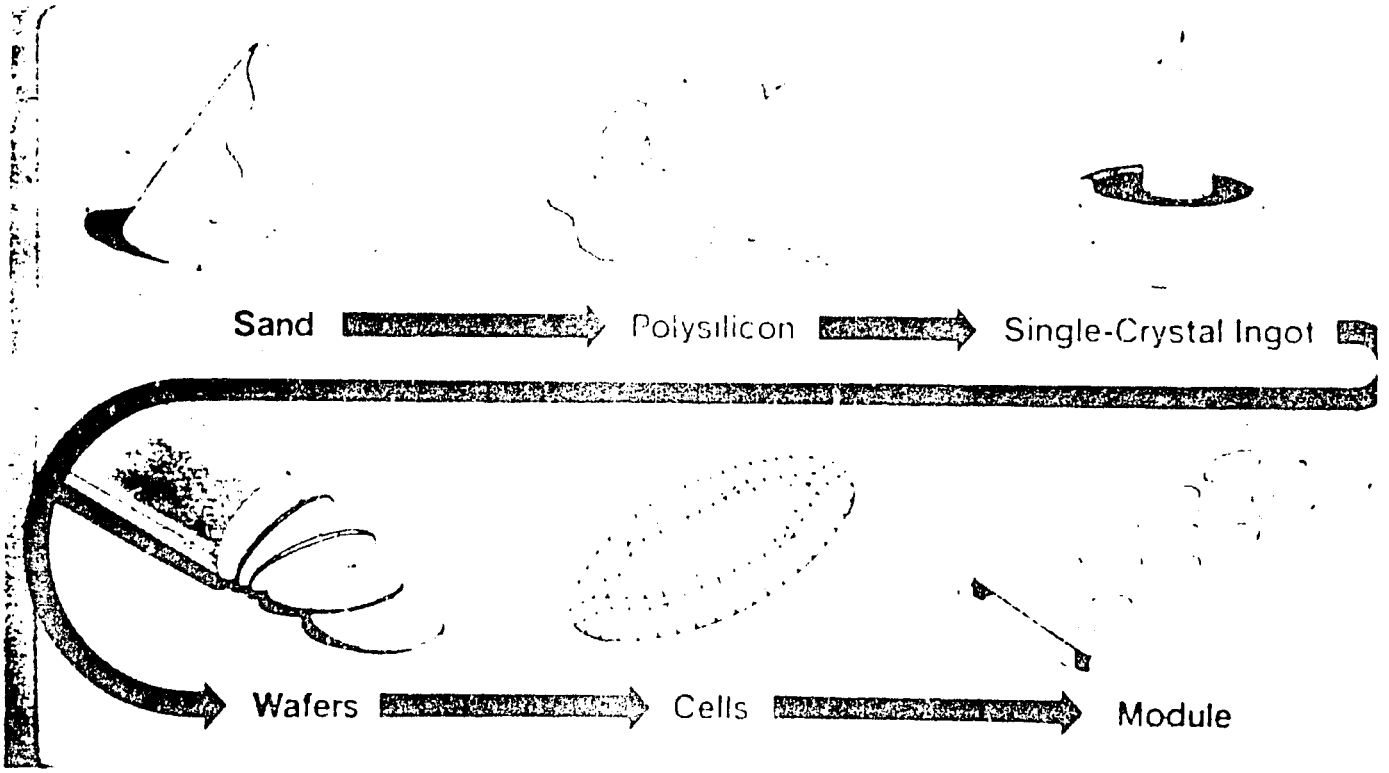
First generation technology (Exhibit 3-1) consists primarily of single-crystal silicon cells cut from circular ingots. A second type of ingot cell is made from polycrystalline silicon that is cast in the form of a rectangular ingot. However, due to the large material losses incurred through the slicing of ingots into wafers; the incompatibility of ingot growth to automated production processes; and the impossibility (based on inherent electronic properties of silicon) of attaining a high enough conversion efficiency to compensate for these factors, systems based on this technology will not meet long-term cost goals. In light of this fact, new generation technologies have emerged.

Second generation technology (Exhibit 3-2) involves the automated production of silicon material in the form of a ribbon. Ribbon growth results in more efficient use of silicon feedstock and a potentially higher rate of throughput; thus far, however, this technology has exhibited lower performance characteristics than ingot cells.

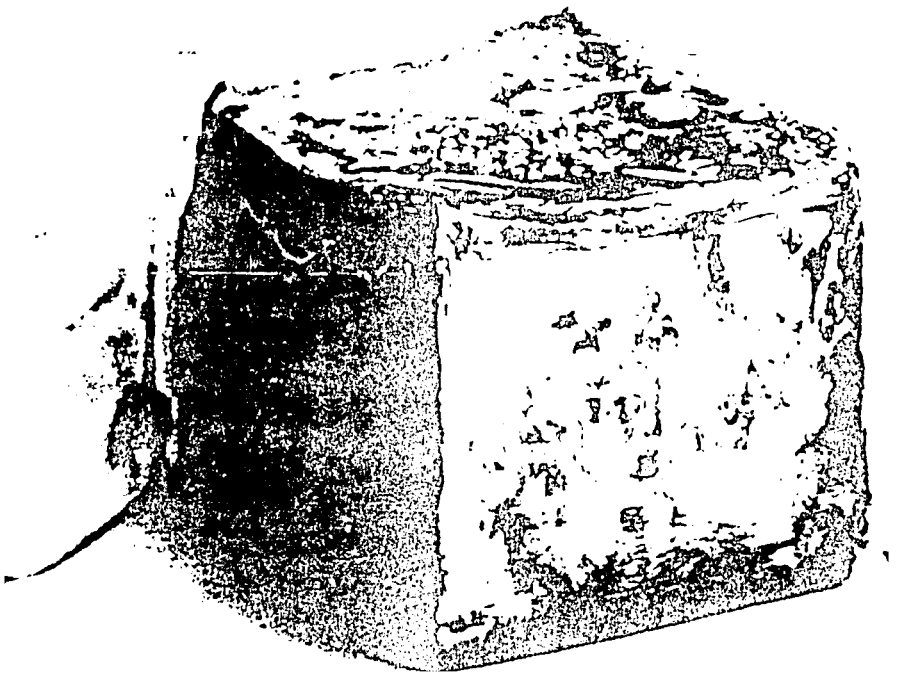
While not as commercially advanced as silicon ingot and ribbon cells, thin-film cells are of interest due to their potential for much lower fabrication costs. They have the advantage of low material requirements (thin-film cells are less than one-hundredth the thickness of silicon ingot cells) while lending themselves to large-scale, continuous-processing techniques (Exhibit 3-3); however, thin-film devices have relatively low efficiencies and in some cases

Exhibit 3.1

FIRST GENERATION CELL TECHNOLOGIES



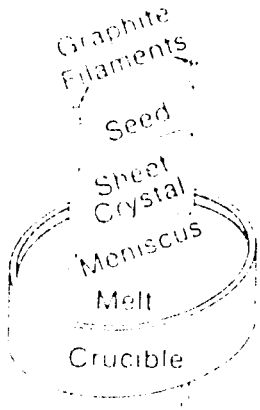
a) SILICON INGOT GROWTH



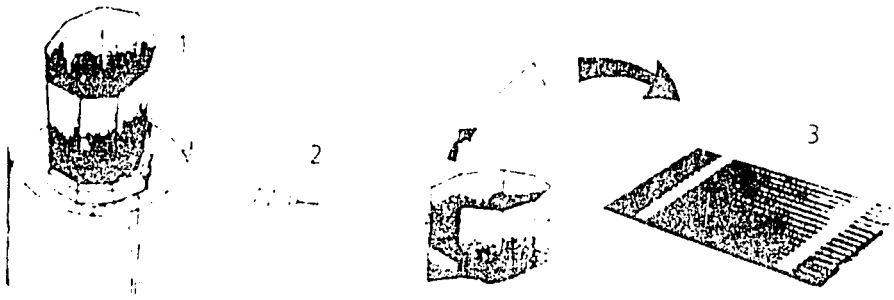
b) POLYCRYSTALLINE CAST

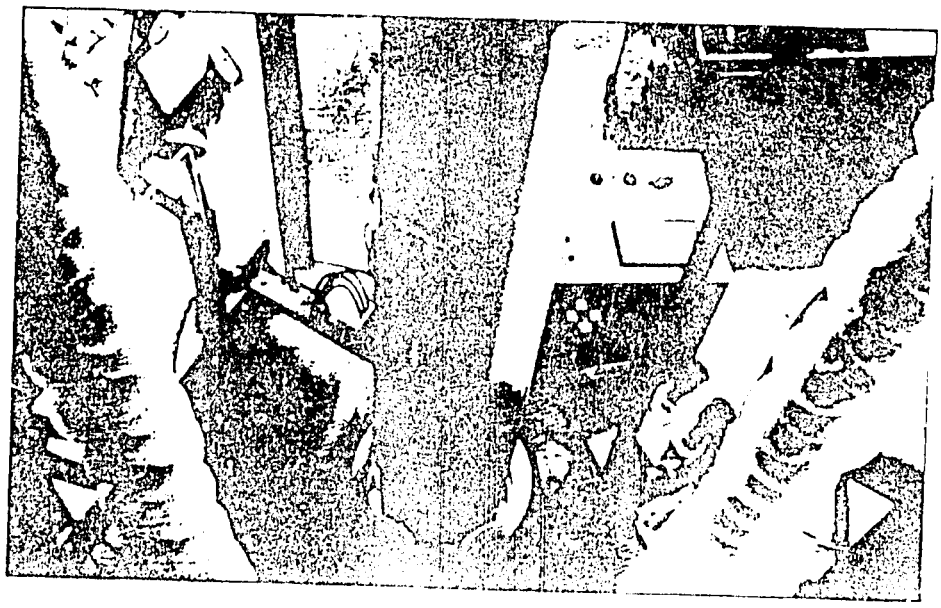
Exhibit 3.2

SECOND GENERATION CELL TECHNOLOGY



a) Edge-Supported Pulling (ESP) Ribbon Growth

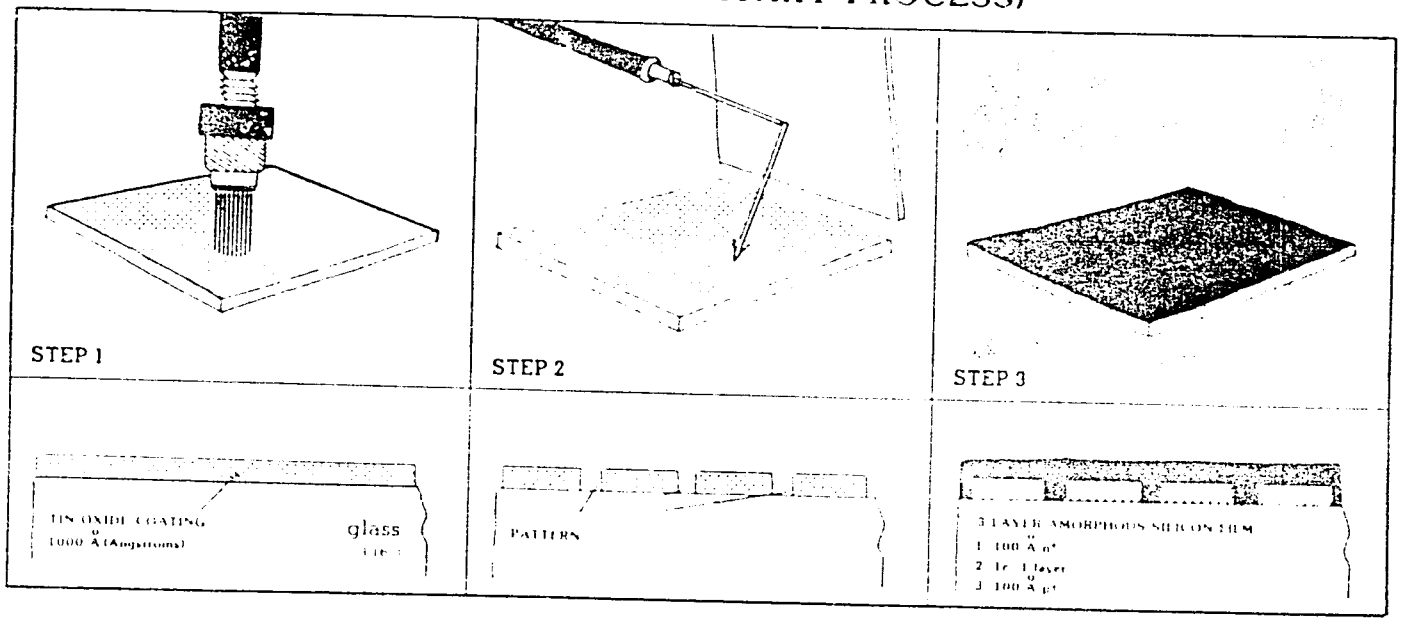


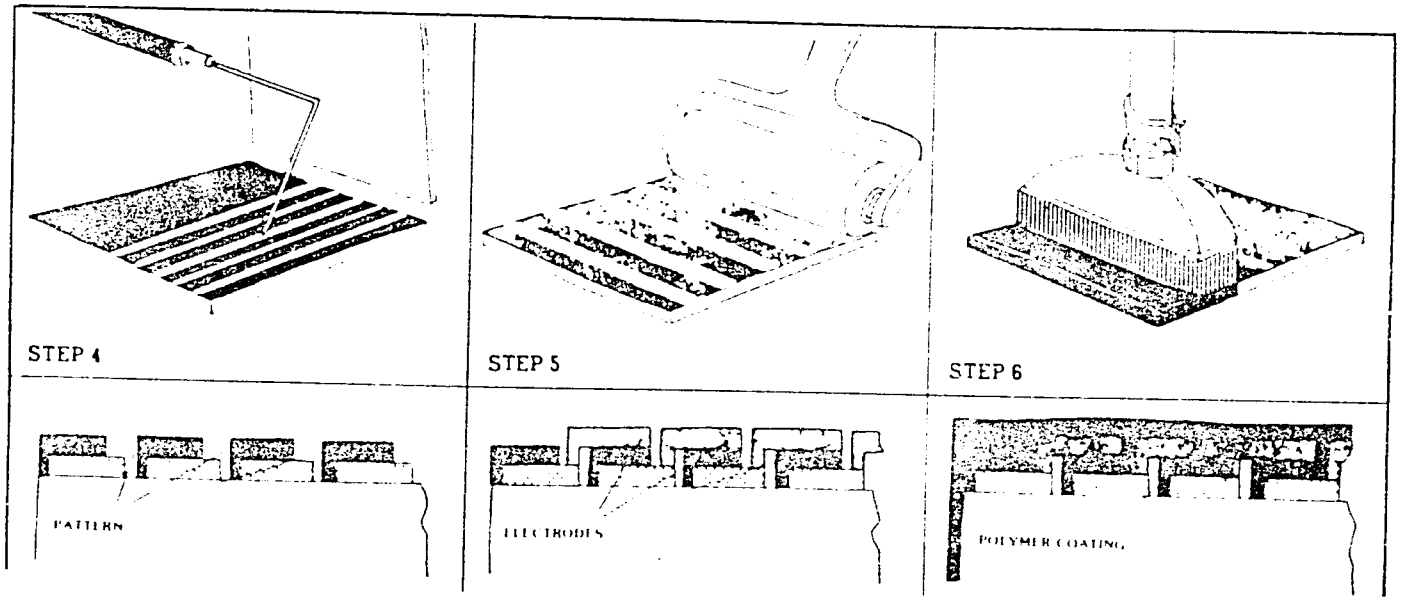


b) Mobil Solar's "Nonagon" Method

Exhibit 3.3
THIRD GENERATION TECHNOLOGY

STEPS INVOLVED IN THE MANUFACTURING OF AMORPHOUS SILICON MODULES (CHRONAR CORP. PROPRIETARY PROCESS)





are unstable.

The most advanced thin-film material is amorphous silicon (a-Si). This material is the only third generation technology to have penetrated the marketplace. It has done so mostly as small cells in consumer products, for which efficiency is a minor concern. The first a-Si power module was just recently introduced (in November 1984) by ARCO Solar. Other thin-films such as cadmium telluride (CdTe), copper indium diselenide ($CuInSe_2$) and gallium arsenide (GaAs) are still in the research stages.

A promising concept for thin-films is multiple-junction cells. These cells consist of different thin films layered on top of each other. Each material absorbs a different region of the solar spectrum and thus results in a higher total conversion efficiency than possible for any one material.

3.1.2 Array Types

3.1.2.1 Modules (Collectors)

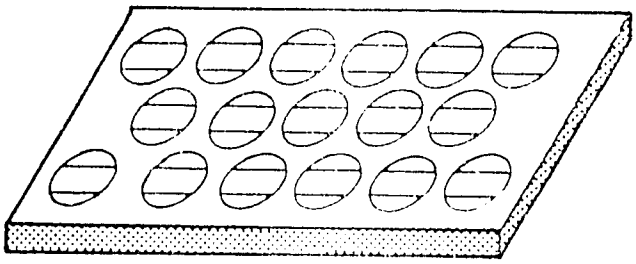
There are two categories of PV collectors: flat plate and concentrator. The majority of currently installed systems use flat-plate modules (Exhibit 3-4). Flat-plate collectors consist of cells that are interconnected and packaged in planar modules. They collect both direct and diffuse radiation.

Concentrator collectors (Exhibit 3-5) offer an approach to PV power generation that reduces the need for lowering the price of high-performance cells. By using configurations that focus direct light onto cells, such as parabolic troughs and fresnel lenses, the cell area required to generate a given output can be reduced by as much as a factor of 1000. However, the cells require some type of cooling, since the high concentration of sunlight raises the operating temperatures of the cell, thus decreasing conversion efficiency.

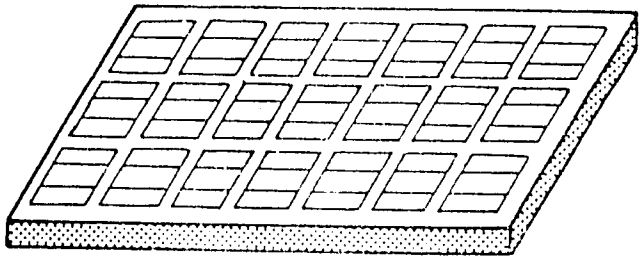
In areas where the direct component of radiation is high (i.e. where there are clear skies), concentrator collectors should be given serious consideration.

Exhibit 3-4

FLAT-PLATE MODULE



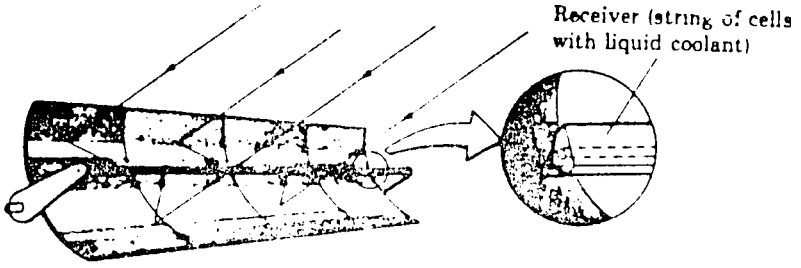
(a) Flat-Plate Module with Circular Cells



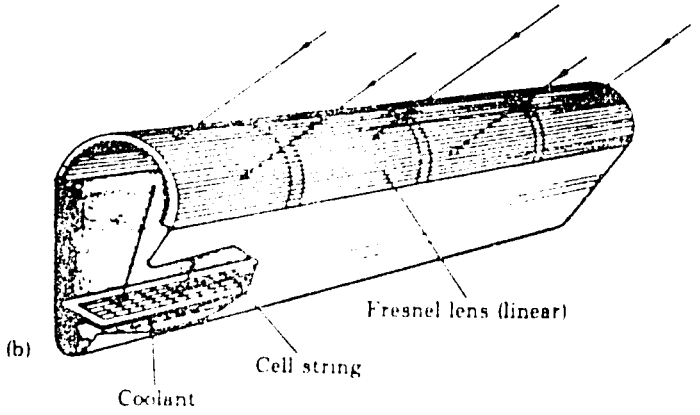
(b) Flat-Plate Module with Square Cells

Exhibit 3.5

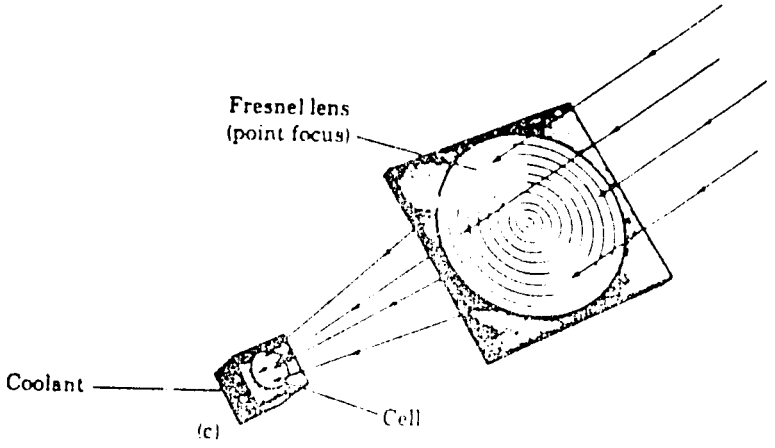
CONCENTRATOR COLLECTORS



a) Parabolic Trough Photovoltaic Concentrator



b) Linear Fresnel Lens Photovoltaic Concentrator



c) Point Focus Fresnel Lens Photovoltaic Concentrator

The basic trade-off between flat-plate and concentrator collectors is as follows. Concentrator systems offer a higher energy density alternative than flat-plate systems (flat-plate systems are approximately 10 percent efficient while concentrator systems are about 14 percent efficient), use less costly silicon, but require tracking mechanisms (as discussed in the next section) and active or passive cooling. Flat-plate systems, although their power output is enhanced when they track the sun, can be effective when fixed but use much more silicon per unit of power produced.

3.1.2.2 Support Structure Types

The selection of an array support structure is dependent upon the module type chosen and the application. Flat-plate modules can be mounted on a fixed structure since they can utilize both direct and diffused radiation. Some designers have used one- and two-axis tracking with flat-plate systems, as they feel improved utilization of the solar resource more than compensates for increased operation and maintenance expenses. For small flat-plate systems, a manually adjustable-tilt structure can be used. This is a very simple design that allows for tilt adjustment on a seasonal basis.

Concentrator PV systems require tracking mechanisms and controls. Parabolic trough concentrator systems have had severe development problems and as a result, are no longer being seriously pursued in the United States. Current development and commercial concentrators use Fresnel lens.

The trade-off between structure types is as follows: the more accurate and instantaneous the tracking, the higher the insolation incident on the cells. At the same time, the costs (initial capital and operation and maintenance costs) increase with complexity in the structure and tracking system.

3.2 BATTERY STORAGE

Batteries are storage devices that use chemical reactions to convert

chemical energy into electrical energy.

The basic building block of a battery is a cell. Battery cells can be connected in series or parallel to form battery banks. The voltages of cells in series are additive, while the current through each is the same. In parallel cells, the voltage across each is the same, while the currents are additive.

Cells are composed of three basic components: (1) the negative electrode, which supplies electrons to the external circuit as it is oxidized during the discharge reaction; (2) the positive electrode, which accepts electrons from the external circuit when it is reduced during discharge; and (3) the electrolyte, which completes the circuit by furnishing the ions (i.e., electrically charged atoms) needed for conductance between the two electrodes.

Batteries are normally classified as either primary or secondary. Primary batteries use active chemicals. After they are discharged, they can only be reused if new chemicals are added (e.g. fuel cells). Secondary batteries are designed to be used repeatedly. Charging and discharging occur through a change in the direction of current. The two most common secondary batteries for PV applications are lead-acid and nickel-cadmium. Lead-acid batteries are the much more frequently used of the two, primarily due to their lower cost.

Lead-acid batteries are sometimes referred to by the type of electrode used (for example, lead-antimony, pure lead, or lead-calcium). Nickel-cadmium cells are constructed in two types, each having slightly different operating characteristics--sintered plate and pocket plate constructions. Both lead-acid and nickel-cadmium cells are manufacturered in sealed and vented configurations, the merits of which will be discussed in Section 4.4.2.

3.2.1 Battery Characteristics

3.2.1.1 Storage Capacity

The storage capacity of a battery can be rated in ampere-hours (A-h) or

watt-hours (W-h). Ampere-hours refer to the amount of current that can be drawn from a battery over a given period of time at a certain voltage and temperature. Watt-hours are the energy equivalent to ampere-hours: ampere-hours multiplied by the output voltage yields watt-hours.

Storage capacity is a function of the discharge rate, temperature and storage time:

Discharge Rate - This term refers to the time over which the battery is discharged. The slower current is drawn from the battery, the greater the capacity.

Temperature - As temperature decreases, storage capacity is reduced. For example, capacity of a lead-acid battery is reduced on the order of 6-11 percent (depending on discharge rate) when battery temperature drops from 25°C to 10°C. As temperature decreases, the rate of decrease in capacity increases.

Storage Time - Battery capacity decreases while standing. This is referred to as self-discharge. Throughout their lifetime, lead-acid batteries with calcium grids have a self-discharge rate of about 0.25 percent per week at 25°C. New lead-antimony batteries have a self-discharge rate of approximately 4 percent per week at 25°C, and it increases five-fold near the end of life.

Although batteries are rated as having a certain capacity, there is a limit to the amount of usable capacity, which is less than the rated capacity. Discharging the battery beyond this point can result in permanent damage to the battery. This limit is referred to as the allowable depth of discharge, where the depth of discharge is the percentage of battery capacity that has been discharged. The voltage associated with this point is called the cut-off voltage (The usable amount of energy is therefore the ampere-hour capacity times the output voltage times the allowable depth of discharge). As temperatures decrease, the allowable depth of discharge also decreases, thus reducing usable capacity.

The state-of-charge (SOC) is the percentage of battery capacity that is charged. Thus, 100 percent minus the depth of discharge equals the SOC.

3.2.1.2 Battery Life

A battery has both a chemical life and a cycle life. The minimum of the two determines the overall lifetime of the battery. Chemical life is a function of temperature, corrosion and sulfation (section 3.2.1.5.).

Cycle life is identified as the number of cycles a battery can go through before failure, where a cycle is designated as the discharge and subsequent recharge of battery capacity to its initial level. Cycle life is a strong function of the percentage of discharge that occurs in each cycle.

Extended operation at elevated temperatures (>32°C) can significantly reduce cell life. For example, chemical battery life is approximately halved when cell temperature is raised from 25°C to 38°C.

Battery life is reduced in lead-acid cells by a phenomenon called "gassing" (see section 3.2.1.4).

3.2.1.3 Efficiency

Battery efficiency is defined as the battery's output divided by the battery's input. Input and output can be identified in terms of energy (W-h) or charge (A-h). The A-h efficiency is higher because the input voltage to a battery is higher than the output voltage (voltage also varies slightly during both charging and discharging). Efficiency decreases with decreasing temperature and is reduced by gassing (see next section).

3.2.1.4 Gassing

Gassing occurs in lead-acid batteries when they are charged passed 100 percent SOC--hydrogen and oxygen gases are boiled off from the battery fluid, decreasing the fluid level, and thus exposing the battery plates. Some gassing is beneficial in that it prevents stratification within the battery. However, excessive gassing reduces the efficiency and life of batteries, and also presents a potentially hazardous situation in terms of the gases it produces. To avoid

gassing, the charge rate should be reduced during the gassing period (i.e. when the battery approaches full charge).

3.2.1.5 Sulfation

Sulfation refers to the formation of large lead-sulfate crystals on the plates of lead-acid cells (instead of the very small crystals normally found). When sulfation occurs--the result of being left in a low SOC for long periods of time--the battery is very difficult to recharge. Regulated gassing helps reduce sulfation.

3.2.1.6 Memory Effects

Sintered-plate nickel-cadmium cells that are subjected to a repetitive shallow depth of discharge tend to exhibit "memory loss." This phenomenon results in an apparent loss of capacity. The problem can be mitigated by deep discharging and subsequently recharging the battery.

3.2.1.7 Equalization

Internal differences, such as temperature or self-discharge rates, among the cells of a lead-acid battery result in inequalities in SOC during service. It is necessary to periodically correct this condition to avoid over discharging on reversing the weaker cells, resulting in premature cell failure. This is accomplished by a periodic equalizing charge, which is a prolonged charge at the finishing rate (the rate at which the battery is charged near 100 percent SOC to regulate gassing).

3.2.2 Battery Selection

Prior to selection of a battery, the designer should have an understanding of under what conditions it will operate:

- Discharge rate
- Depth of discharge in each cycle

- Remoteness (in terms of maintenance needs)
- Temperature

From there, one can decide which is the most appropriate type of battery for the system.

Lead-acid batteries have been the predominant type used in PV applications. This is due to the much higher cost associated with nickel-cadmium batteries. However, nickel-cadmium batteries have several attractive features: they can withstand 5-10% overcharging; are not subject to sulfation; do not require equalization; and are less affected by temperature variations and high discharge rates. These factors have generally not been substantial enough to compensate for the cost, as evidenced by the trend among major battery manufacturers to produce lead-acid types for PV applications (see Chapter 9). In fact, several of the manufacturers that formerly sold both lead-acid and nickel-cadmium batteries have since limited themselves to lead-acid. In light of these facts, battery selection is generally made among the different lead-acid types. Exhibit 3-6 summarizes characteristics of the most commonly used lead-acid batteries, lead-antimony and lead-calcium cells. If more detailed information about battery operating characteristics is desired, the publication Handbook for Battery Energy Storage Photovoltaic Power Systems, (Bechtel National, Inc., NTIS No. SAN-2192-T1, Nov. 1979) is recommended.

3.3 POWER CONDITIONING SYSTEM

The power conditioning system refers to the "black box" that connects the PV array to the loads and, if applicable, the utility grid. The components that make up this black box are a combination of regulators, solid-state controls and logic circuitry, inverters and converters.

Exhibit 3.6

COMPARISON OF LEAD-ACID BATTERY CHARACTERISTICS

BATTERY TYPE	MAJOR CHARACTERISTICS
Lead-antimony	• Less expensive • Longer cycle life • Subject to gassing • Require water addition • Subject to sulfation • Require equalization
Lead-calcium	• Longer chemical life • Less gassing • Less frequent water addition • Less likely to sulfate • Equalization not required

3.3.1 Self-Regulated Power Systems

In certain PV applications, a power conditioning subsystem is not necessary. Examples of these situations are as follows:

1) A d.c. application with storage, but where the peak current output is less than 5 percent of the charge capacity of the batteries. This type of system is referred to as trickle charge, for the PV provides just enough current to keep the batteries "topped off" without overcharging.

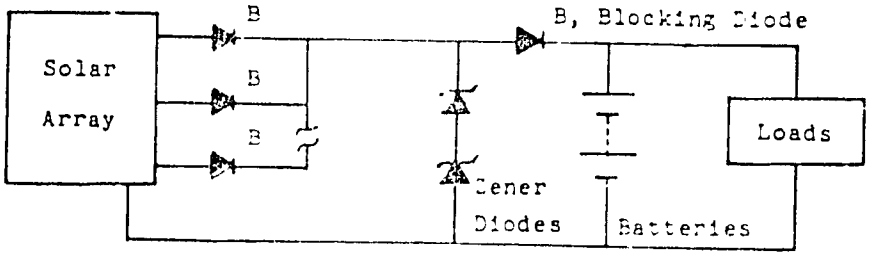
2) A direct current (d.c.) application with no storage, operating in a relatively constant ambient temperature. The voltage corresponding to the maximum power point is a function of temperature. Therefore, if temperature is constant the operating voltage is constant. If the load can be properly matched to the array such that the array will operate at the design voltage, active regulation is not necessary since the voltage will remain constant.

3.3.2 Regulators and Controllers

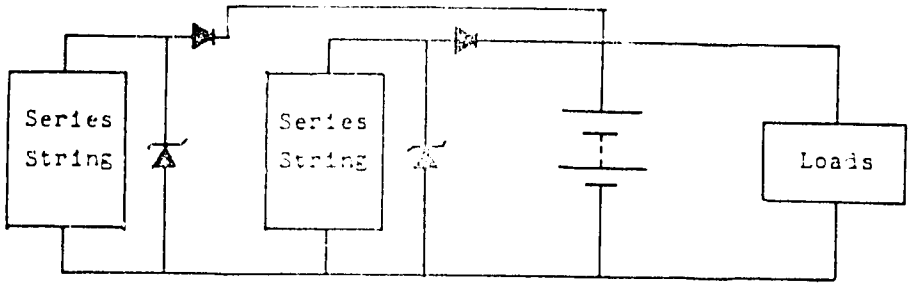
Most PV systems require voltage regulation. Regulators are used to limit array output in order to prevent battery overcharge and maintain constant voltage to the loads. Regulators can be characterized by their method of power dissipation--series or shunt.

Shunt-type regulators use zener diodes, transistors, contactors or solid-state relays to shunt excess array current to ground (Exhibit 3-7 a, b, c). Series-type regulators use transistors, contactors or solid-state relay elements to switch off or reduce the flow of current from the array to the battery (Exhibit 3-7 d, e). Series regulators consume power at all times, whereas shunt regulators dissipate only that power not required by the loads.

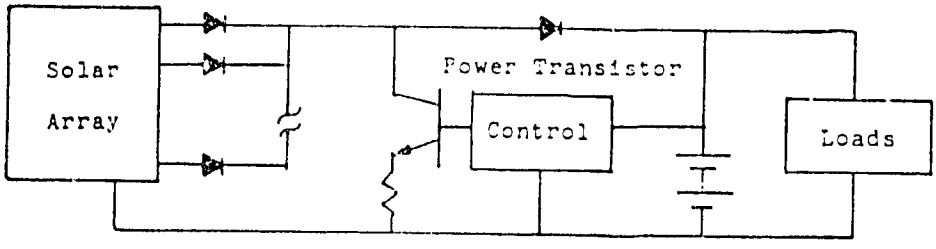
Exhibit 3.7
METHODS OF POWER REGULATION



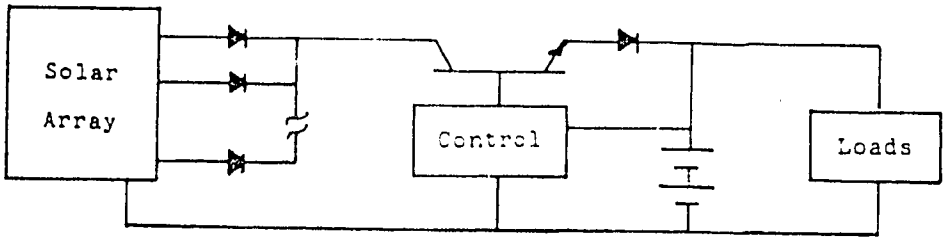
(a) Array, Passive, Shunt Regulation



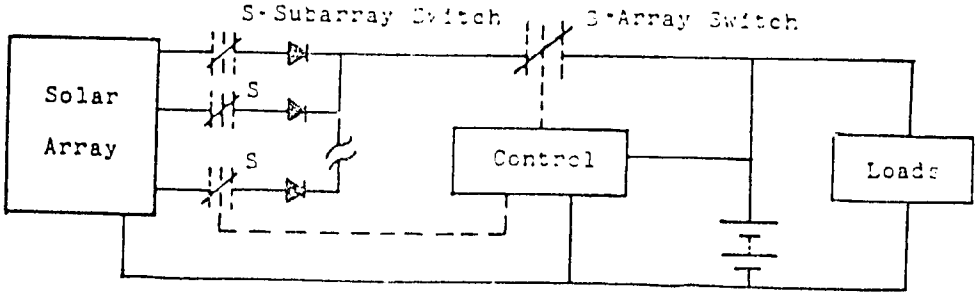
(b) String (or Subarray), Passive, Shunt Regulation



(c) Array, Active, Shunt Regulation



(d) Array, Active, Series Regulation



(e) Array (or Subarray), Active, Series Regulation

The simplest type of regulator involves a passive method of controlling the regulation function, using a zener diode (Exhibit 3-7 a, b). Zener diodes can accommodate power and voltage from a few watts to 50 watts and up to 200 volts. Passive control results in a relatively wide voltage cutoff band. For larger systems and/or more accurate regulation, it is necessary to use active control systems (Exhibit 3-7 c, d, e) Regulators with active control systems are more sophisticated, providing for more precise voltage regulation, proportional current control and often for the adjustment of voltage control to compensate for changes in battery temperature.

The term "controller" is generally associated with the more sophisticated regulators. Controllers perform the basic voltage regulation functions as well as incorporate more precise load management capabilities (e.g., prioritized load shedding). "Controller" and "regulator" are often used interchangeably.

Controllers/regulators can be designed to activate current-shunting or controlling elements for the entire or for portions of the array output; to provide for time-modulated on/off control signals; and to activate high and low voltage limit controls to protect the batteries and other loads. One of the most sophisticated of the controllers is the maximum power point tracker. This type of controller continuously samples and adjusts PV array power output such that it is a maximuum.

3.3.3 Inverters

An inverter is used to convert d.c. power to a.c. power such that it can interact with a utility grid or a.c. loads. The precision in which this conversion takes place dictates the cost of the equipment. The precision required by the system is determined by the loads.

The primary indication of the quality of the output is its wave form. Perfect a.c. is in the form of a sine wave. Inverters produce quasi-sine wave

(also referred to as square wave) or sine wave a.c. The selection of one type or another depends on the loads. For resistive elements and some motors, simple square wave a.c. is acceptable. For turntable motors and precision equipment, however, sine-wave a.c. is necessary. In cases where the user wants to link to a utility grid, only sine-wave quality a.c. is acceptable. Because the prices associated with the inverters that produce these wave forms vary significantly, it is important for purchasers to recognize the minimum acceptable quality of power for their loads.

Another important characteristic of an inverter is its efficiency. Efficiency varies somewhat with the type of inverter. Inverters can be classified into solid-state or rotary. Solid-state inverters have higher efficiencies--in the range of 70-95 percent. Rotary inverters have efficiencies of less than 85 percent. However, despite the lower efficiencies, rotary inverters can be more effective in motor start-ups. In general, inverter efficiency decreases with decreasing load.

Manufacturers often offer specialized circuits and switches for their inverters. For example, some offer circuits designed for motor start-ups, where high peak currents are necessary. Others offer automatic on/off switches which eliminate power consumption when not in use.

There are three basic types of inverters: line-commutated, self-commutated and stand-alone. In a line-commutated inverter, switches are triggered by the timing on the utility lines. The switches of a self-commutating inverter are triggered by an internal clock in the inverter. Self-commutated inverters are more expensive due to the additional circuitry; however, some are capable of operating in stand-alone mode. Stand-alone inverters can operate only in stand-alone mode.

"Inverter systems" are generally purchased in the case of utility-interactive applications. This system acts as the entire power conditioning

subsystem, as it includes the inverter, necessary control functions such as over-current protection and current surge capabilities, as well as options such as maximum power point tracking.

In stand-alone systems, the inverter is purchased as one component of the power conditioning subsystem. Control functions and maximum power tracking (if desired) are housed within the regulator/controller.

3.3.4 D.C.-to-D.C. Converters

A d.c.-to-d.c. converter is used to step d.c. voltage up or down. For example, if the PV array produces 240 volts d.c. but the loads require 48 volts d.c., then a d.c.-to-d.c. converter is necessary. In general, a PV system should be designed such that a d.c.-to-d.c. converter is not necessary since it adds to cost and detracts from efficiency.

In summary, power conditioning can be designed to any level of sophistication However, a PV system should be kept as simple as possible since each step in the power conditioning process reduces system efficiency and each degree of sophistication increases cost. For some applications, end-use products are available in a.c. or d.c. A.C. components are typically cheaper, as a result of mass production, but the added cost of an inverter must also be considered. In reality, many small a.c. motors are d.c. motors converted to a.c. If such a motor is used, d.c. to a.c. losses are incurred twice-once in the motor and once in the inverter of the PV system. Therefore, in small motor applications, it is best to design a d.c. system.

3.4 Instrumentation and Controls

Identification of instruments and controls for a PV system must be examined in the context of the purpose of the instrumentation. That is to say, is the

instrumentation being used to operate or monitor the PV system? For example, an unattended system designed for cathodic protection does not require any instrumentation. On the other hand, an agricultural processing system in an educational setting used to evaluate optimum system design may justify a highly instrumented system.

Aside from the purpose of the instrumentation, other factors to consider are the necessary sophistication required to achieve that purpose and the distance the system is from institutional support. These factors are interrelated, in that the farther the installation is from the monitoring institution or repair facility, the less elaborate the instrumentation should be. For example, take the case of measuring the discharge flow rate of a pump. Four options are available:

(1) A bucket of a specific volume and a stopwatch will determine an instantaneous flow rate.

(2) A basic in-line flow meter with float also shows an instantaneous flow rate.

(3) A stripchart recorder measures and records the flow rate continuously.

(4) A flow meter with solid-state magnetic pickup and automatic data transfer provides continuous, long-term monitoring.

Exact knowledge of the flow rate will not improve system operation or reliability. However, in terms of evaluating the design, flow rate can be very important. A second point to be made from this example is related to the cost involved with the increase in sophistication. If only an instantaneous reading is needed, it is best to use the simplest and least costly option--option one. The third option would undoubtedly fail in a very remote site as soon as the special paper and ink pens were exhausted. The fourth option has been used successfully in Mali to acquire data for detailed computer-aided analyses.

For attended systems, the minimum instrumentation and controls for continued operation of given type systems are as follows:

Applications with Battery Storage

- a voltmeter on the control panel
- low voltage disconnect control (battery protection)
- circuit breaker/fuse protection between all loads and the batteries

Pumping

- low water level protection for the pump (especially in situations of low well-yield rates with respect to draw)

Refrigeration

- low-high temperature alarm with manual reset
- thermometer
- run-time meter

Agricultural Processing

- ammeters on all motors

One level above minimum instrumentation involves training an operator to perform simple and safe system/component trouble-shooting and repair. In this situation, the following additional instruments are recommended: a portable voltmeter, portable ammeter and run-time meters.

Moving to a higher level of instrumentation and control is recommended only for systems that are being used for R&D and are located near test/educational centers. The number of features that could be added to an instrumentation package is too large to enumerate here. Even in the case of a given instrument (like the flow meter discussed earlier), there can be numerous alternatives, varying in their levels of sophistication. The costs associated with various options for instrumentation and control vary significantly. Therefore, the following basic rules of thumb are recommended:

(1) If the instrument is not necessary, given the purpose of the system, do not include it.

(2) If an instrument is necessary, use the simplest alternative to meeting the need.

(3) The complexity of the instrumentation and control should be inversely proportional to the distance between the system and technical expertise.

4.0 SYSTEM DESIGN CONSIDERATIONS

4.1 OVERVIEW

In designing any type of system, be it PV or not, there are a few basic principles to keep in mind:

(1) Keep the system as simple as possible.

(2) Use local labor and materials whenever possible.

(3) To the degree possible, involve the ultimate users in the conceptualization, design, installation, start-up and testing of the system.

These items may seem almost too obvious to state, yet it is surprising how many times these rules have been violated.

Designing involves a series of tradeoffs, all of which eventually boil down to cost. Exhibit 4-1 identifies steps in the system design process. These steps are discussed in the following sections.

4.2 LOAD CHARACTERISTICS

4.2.1 Load Profile

Establishing a load profile is the first step in designing a PV system. The questions that must be answered are:

(1) what loads will be powered by the system;

(2) how much power is consumed by each of the loads;

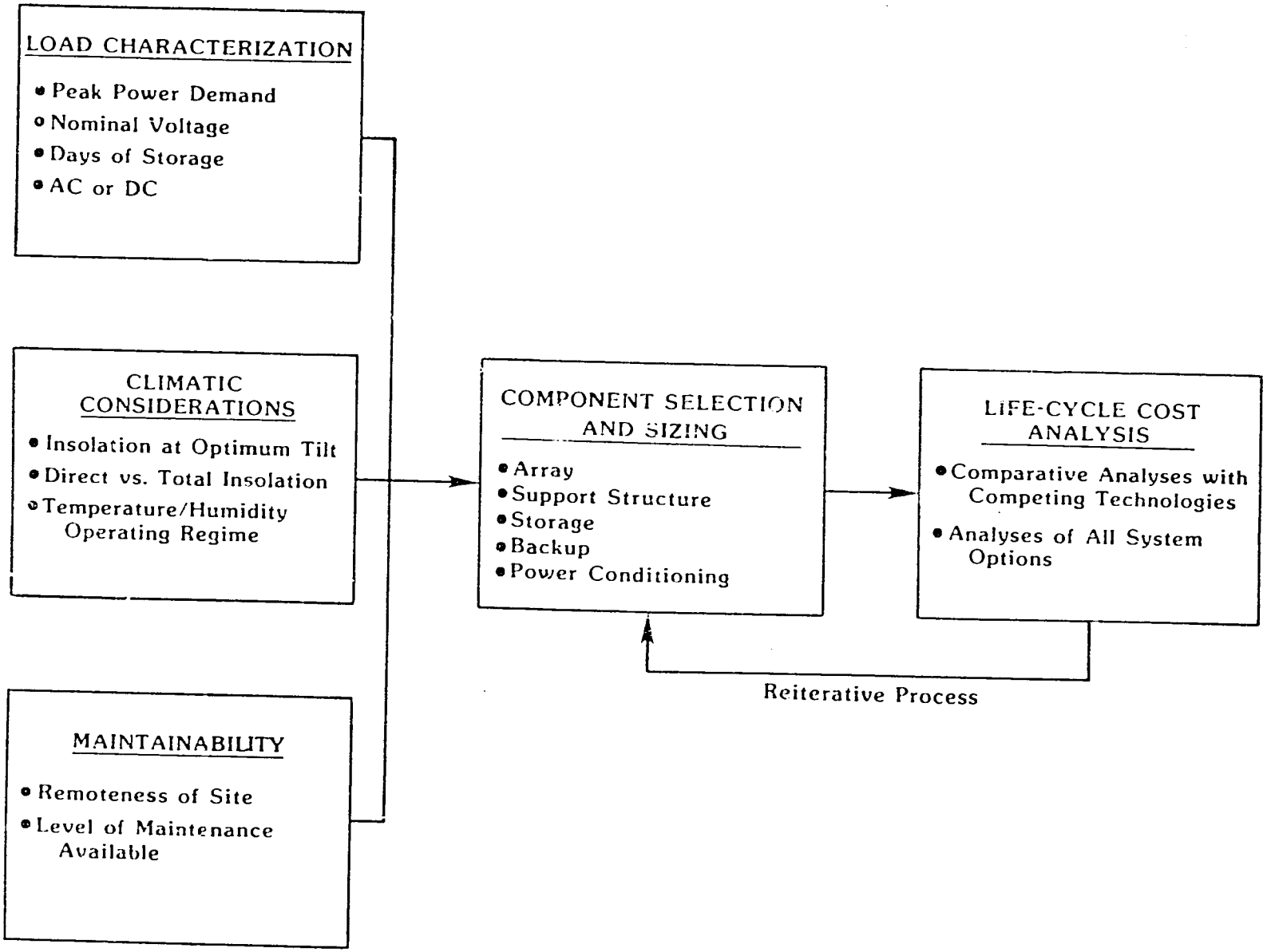
(3) what is the nominal voltage of the loads;

(4) how long are each of the loads to be operated each day; and

(5) at what time of day and week/month/year will each load be operated.

From the load profile, the peak power demand and the total amount of energy required during the day are determined, indicating the size of the system. The input voltage for the loads determines the nominal voltage of the system. The time of day that the energy is required is important in terms of whether to include storage. For example, since lighting is required at night and PV output is during the day, a storage system or an alternative power source is necessary.

Exhibit 4.1
SYSTEM DESIGN PROCESS



4.2.2 Required Reliability

It is important to know how critical it is that the loads be supplied with power at a given time. For example, because of critical operational requirements a telecommunications system may have to operate twenty-four hours a day. In this case, a large PV and storage system (to supply the load at night and during a series of cloudy days) and possibly even a backup system may be considered. On the other hand, battery storage or backup may not be needed in a pumping system because it is sufficient for it to pump only during times when it is sunny (the pumped water can be stored in a tank). Typical battery storage systems are sized based on 3-10 days storage depending on required reliability and weather patterns (typical consecutive number of sunless days). However, some systems have been designed with as much as 30 days of storage.

If several loads are powered by a given PV system, load priorities should be set. In the case where PV output on a given day is low and/or the batteries are at a low state-of-charge, loads should be disconnected in the order of reverse priority. This load-shedding can be done manually by an operator or automatically if designed for in the power conditioning system.

4.2.3 A.C. Versus D.C. Loads

Since PV arrays produce d.c. electricity, the simplest and most efficient type of PV system involves using d.c. loads. However, there are situations when one would elect to have an a.c. system:

- o utility-interactive systems
- o the required loads are only available in a.c.
- o the required loads are significantly more expensive in d.c. such that the difference in cost justifies the purchase of an inverter

4.3 CLIMATIC CONSIDERATIONS

4.3.1 Resource Availability

Given the load profile, the solar resource determines the size of the PV array needed to supply the load. The degree to which variations in the resource during the day does not match the load profile determines the need for storage. The use of loads during the day is more efficient since losses through the batteries are bypassed. Thus, in sizing the system, losses incurred through the use of loads at night should be accounted for. Based on the sizes of the array and storage arrived at, it can be determined whether there is sufficient resource to make the system cost-effective.

Solar insolation is usually measured using a pyranometer or a pyrheliometer. Pyranometers are the more commonly used of the two. They measure total radiation. They can be modified easily to measure only diffused radiation using a disk to block direct radiation from the sensor. Pyrheliometers are used to measure direct radiation. A procedure for calculating insolation from the clearness index, as well as insolation data from Egypt, can be found in Appendices B and C, respectively.

Assuming there is sufficient solar resource, the type of radiation (direct versus diffuse) can influence the type of modules selected. In areas where there is a large component of direct radiation, concentrator modules may offer an attractive solution. Where direct radiation is not high, flat-plate modules will offer the more cost-effective alternative.

Even if the decision is made to use flat-plate modules, variations in the solar resource throughout the day and year impact the choice of support structure. PV panels are mounted at an angle in order to capture maximum energy from the sun (and also to allow for water runoff). This angle is approximately equal to the latitude of the site. It can be optimized through PV system sizing models; however, array tilt should never be less than 10 degrees, to allow for runoff.

Since the insolation collected is proportional to the cosine of the difference in the sun angle to the surface of the array, small inaccuracies are not particularly a problem. For instance a pointing error of 8° results in only a 1% loss in insolation. At a site where there is a large seasonal variation in the resource, an adjustable tilt array should be considered (this feature will be discussed in section 4.4.1).

In general, PV arrays are oriented due south (in the northern hemisphere) for maximum power output, which occurs at noon. If it is desired that peak output be at some time other than noon (e.g. to better match demand), the array can be shifted accordingly. However, overall system energy output decreases in such a case.

4.3.2 Environmental Considerations

PV systems have been proven reliable under a wide variety of environmental conditions. They have operated successfully in snow-covered regions, deserts and near oceans. However, the temperature and humidity in which the system operates impacts PV array output, battery capacity and life, and electronic equipment performance and therefore should be taken into account.

PV modules are rated at a cell operating temperature of 25°C. Typically, cell operating temperature is higher. For example, in regions near the equator, cell operating temperature can be as high as 65°C, significantly decreasing the rated power. Module manufacturers generally provide temperature correction factors in their product literature to permit de-rating and performance evaluation of systems. The siting of the system and its structural design should encourage airflow to enhance natural cooling.

Battery performance is a strong function of temperature. As temperature decreases, battery capacity is substantially reduced. At high temperatures, although capacity is near maximum, battery life decreases. Also, in particularly

low-humidity environments, battery maintenance in terms of water addition will be affected.

Electronic circuitry is most reliable at lower temperatures and low humidity.

System experience has indicated that it is best to house batteries and power conditioning equipment in an enclosed area to minimize exposure to extremes in environmental conditions.

4.4 MAINTAINABILITY

PV systems require little maintenance compared to other energy alternatives. The little maintenance that is needed, however, varies according to the design of the system. System design should consider the availability of personnel for maintenance. Complex systems with monitoring equipment should be inspected and calibrated monthly. Simple designs require limited maintenance (on the order of twice a year) for battery inspection, array cleaning and control system checkout. Thus, the level of maintenance available should be made clear early in the design stages so that system complexity and autonomy can be designed accordingly.

4.4.1 Module and Support Structure

The first questions of maintainability arise with respect to the types of modules selected. There is a higher degree of maintenance associated with concentrators due to their tracking structures (moving parts). Automatic or manual tracking will require more attended operation than fixed flat plates. Thus, unattended systems should not employ concentrator modules or flat-plate tracking structures unless there is a proven high reliability for those components. An adjustable-tilt array could be attractive (that is if there is a seasonal variation in solar resource). In this case, tilt could be changed every three months during a maintenance visit. For systems that utilize a fulltime operator, or that may be located near a monitoring institution, system maintainability

should play a minor role in the selection of module type compared to the other considerations discussed in this chapter.

4.4.2 Battery Types

Battery selection is also a function of available maintenance. Sealed batteries require little maintenance (perhaps cleaning of battery terminals). Vented batteries, on the other hand, also require the addition of water (approximately every 3-6 months in average humidity environments). Battery caps with catalysts that recombine hydrogen and oxygen to form water are available. These caps reduce water loss.

4.4.3 Array Oversizing Considerations

In most environments, it has been shown that array washing does not significantly affect PV system output; however, in dry, dusty regions there can be significant accumulation, thus reducing output. For systems that are essentially unattended, the PV arrays can be oversized such that the necessary power is produced. For attended sites, this oversizing can be eliminated if periodic washing is performed.

4.4.4 User Acceptance

An important consideration that is often ignored is user acceptance of the system. A system that is accepted by the users and regarded as their own has a high probability of success. They will make sure the system is maintained and that it operates, if they see the system serves them. The earlier the end-users are involved in the chain of system conceptualization to operation, the higher the probability of user acceptance and the clearer their perception of system capabilities.

4.5 COMPONENT SELECTION AND SIZING

This section discusses basic considerations involved in the integration of

components into a PV system.

Sizing a stand-alone system is dependent primarily on load and resource. One method of sizing a stand-alone system is based on meeting demand at worst-month conditions (i.e., based on supplying the loads during the month of poorest solar resource). This approach is used when power to the load is critical. A method often used when loads are not as critical is to size to average insolation over the year.

Sizing a grid-interactive system is less dependent on the solar resource. In cases where the PV system will not contribute a significant fraction of the grid's capacity, the sizing of the PV system is somewhat arbitrary. It is based on the amount of money available for investment and the degree of autonomy desired. In other cases, particularly in isolated grids, the impact of PV on the other generating systems must be considered, and the effects must be balanced.

Several computer and hand calculated models (both for stand-alone and utility-interactive systems) are available for sizing PV systems. Computerized models include PV F-Chart, SOLCEL-II and PVFORM. Many systems houses have also developed proprietary sizing models. An example of a manual sizing procedure for stand-alone systems is given in Appendix A.

4.5.1 Array

The selection of an array type (flat-plate or concentrator) is governed by climatic and maintainability considerations as discussed in the previous sections. The ultimate decision, however, should be based on a life-cycle cost analysis. Thus, if concentrator systems show potential based on initial considerations, both concentrator and flat-plate systems should be carried through complete analyses.

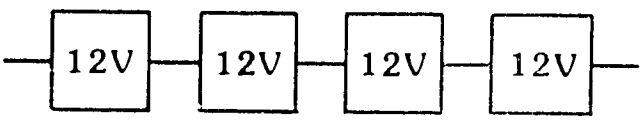
The size of the array is dependent on the power demand and the nominal voltage of the system. It is important to match the array operating voltage to

Exhibit 4.2
ARRAY SIZING

SYSTEM OUTPUT REQUIREMENTS: 360 Watts
48 Volts

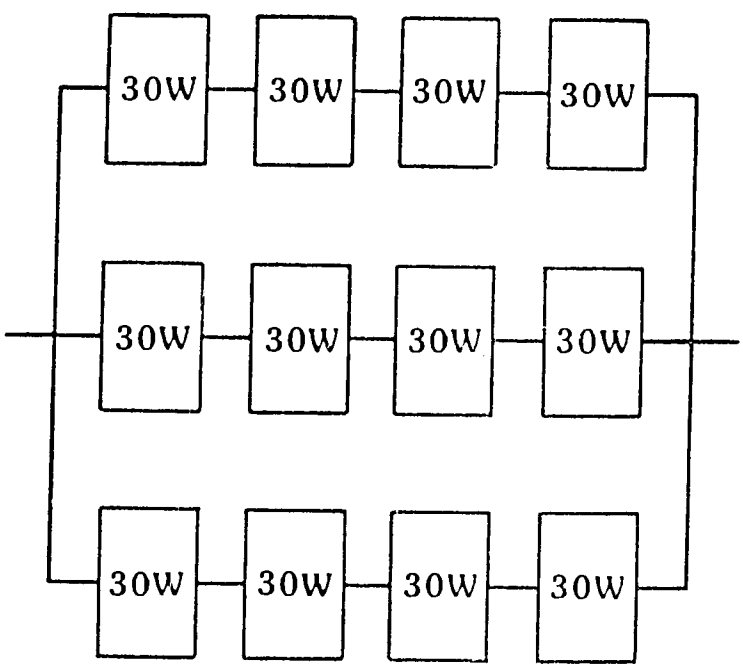
MODULE SPECIFICATIONS: 30 Watts (De-rated)
12 Volts

NUMBER OF MODULES IN SERIES: $\frac{48 \text{ Volts}}{12 \text{ Volts}} = 4$



12 + 12 + 12 + 12 = 48 Volts

NUMBER OF PARALLEL STRINGS: $\left(\frac{360 \text{ Watts}}{4 \text{ Modules}}\right)\left(\frac{30 \text{ Watts}}{\text{Module}}\right) = 3$



(12 Modules)(30 Watts/Module) = 360 Watts

the load voltage. This ensures that the array operates as close to its maximum power level as possible, thus optimizing efficiency. The operating voltage of the system is determined by the number of modules connected in series (Exhibit 4-2). Basically this is determined by taking the nominal voltage of the system and dividing by the nominal operating voltage of a module (since voltages in series are additive). Once the number required in series is known, the number of parallel strings is determined using the total amount of power required. The total power demand divided by the power output of one string (i.e., the number of modules in series times the power output of one module) is the number of parallel strings required. It is important to de-rate power output from the module due to temperature effects and insolation not being $1000W/m^2$.

4.5.2 Support Structure

Once the type of modules and the frequency of people to maintain a system are determined, the type of support structure can be chosen. The design must consider wind loading and soil bearing strength as constraints. Many module manufacturers sell modules in prepackaged, pre-wired groups of modules which simplify field installation procedures.

4.5.3 Storage

The number of batteries required in series and in parallel is determined in a similar way as for modules. The number in series is the nominal voltage of the system divided by the nominal voltage of the battery. The number in parallel is the total desired storage capacity (in Amp-hours) divided by the capacity of a single battery. The total desired capacity is found by taking the rated capacity and dividing by the allowable depth of discharge (approximately 0.8 for deep discharge and 0.2 for shallow discharge batteries). Deep discharge batteries are almost always the type used in stand-alone applications (deep discharge of a shallow battery significantly affects battery life and could

cause catastrophic failure). It is also recommended that only batteries with the same voltages and capacities be in the same circuit.

4.5.4 Backup Systems

The key question that arises in evaluating the need for and type of backup system is: is the occasional loss of power critical? If the loss is not critical, there is no need to add the complexity of a backup system; however, if it is critical, a contingency plan is necessary.

The primary causes of power loss are as follows:

Design

- More load than expected
- Less insolation than expected
- Maintenance shutdown

Hardware Failures

- Load device failure
- Power conditioning equipment failures
- Array failures (rare)
- Degradation (rare)
- Battery failures (rare)

Natural

- Lightning
- Consecutive sunless days
- Cold weather effect on batteries

4.5.4.1 Potential Backup Systems

The potential choices for backup are the following:

- o None (e.g., visit on demand, carry spare parts)
- o Manual (e.g., pumping, pedaling)
- o Engine/Generator

- Primary Battery
- Emergency Solar-Rechargeable Battery
- Emergency Fossil-Rechargeable Battery
- Utility grid

The best backup is spare parts combined with responsive technical expertise. Where remoteness or lack of infrastructure prevents this, manual backups are a viable, low-cost alternative. Hand pumping can be used for village water on an emergency basis, although provisions must be made in the inital design for hand pumping. Centrifugal pumps cannot be manually operated, but positive-displacement pumps can. For small radio systems, pedal-powered generators can be used in emergencies.

For larger pumping operations or large-power operations, an engine can be justified for the backup system. To maintain the engine for emergency operation, it must be started and checked periodically. The maintenance costs associated with this periodic operation must be factored into the analysis.

Battery backups can be the most desirable. Primary batteries can be used in some circumstances. Once discharged, they must be manually replaced, so the maintenance costs could be high. If standby rechargeable batteries are used, battery replacement can be avoided. For example, lead-acid batteries could be used that have their charge maintained by the solar cells, but are not connected to the main battery-storage system (which is used for nonemergency energy storage). The advantage of the solar-recharged battery is that it can recover from an emergency condition without separate servicing by a mechanic. The batteries might also be recharged by a portable generator. The portable generator would be especially useful as a backup in the rare circumstance of extremely low insolation for many days.

Utility backup is as reliable as the utility. In the U.S., for example, utility power is probably the most reliable source of energy; however, in

developing countries, utility grids are often unreliable and are therefore the reason for using a PV system.

The advantages and disadvantages of the various backup systems are outlined in Exhibit 4-3.

4.5.4.2 Appropriateness of Various Backup Systems

The appropriateness of various backup systems depends on the application, whether loss of power is critical, and whether the system is attended. Exhibit 4-4 indicates the appropriateness of backup system according to these considerations.

4.5.4.3 Integration of Backup into PV System

Once the type of backup has been selected, it must be integrated with the PV array. This can be done through means such as a manual transfer switch, a remote manual transfer switch or an automatic transfer switch.

A manual transfer switch is clean, direct and involves no energy loss; however, it requires detection and then on-site correction.

A remote manual transfer switch can be used for remote sites--especially those with a telemetry system that transmits when the system is not performing properly. A second communication link can be supplied (i.e., two-way telemetry) such that a person at a central station can radio the site for the backup to come on. This type of switching requires an activator and human monitoring, but there are no energy losses in the process.

Automatic switchover is also possible. The sensing and controlling function results in a continuous power drain through the power conditioning system. It is possible to arrange so that power drain occurs only during periods when the backup is on, so the total energy loss would be less.

4.5.5 Power Conditioning

The power conditioning system can be designed to any level of sophistication. Each step in the "conditioning" process reduces overall system efficiency, and

Exhibit 4.3

ADVANTAGES & DISADVANTAGES OF VARIOUS BACKUP SYSTEMS

BACKUP SYSTEM	ADVANTAGES	DISADVANTAGES
None	Simple	Noncritical Applications Only
Manual	Simple Reliable	Require Attendance
Engine	High Power	Frequently Won't Start High Maintenance
Primary Battery	Can be Remote Reliable	One Time Use Only
PV Recharged Battery	Can be Remote Reliable	Cannot Recover without Sun
Fossil-fueled Recharged Battery	Can be Remote Reliable	Fuel & Engine Transport
Utility Grid	Can be the Most Reliable	Cannot be Remote Requires Sophisticated Power Conditioning

Exhibit 4.4
APPROPRIATENESS OF VARIOUS BACKUP SYSTEMS

APPLICATION	UNATTENDED		ATTENDED	
	CRITICAL	NONCRITICAL	CRITICAL	NONCRITICAL
Radio	Battery, Alarm	None	Battery, Pedal	None
Lighting	Battery, Alarm	None	Engine	None
Pump	Battery, Alarm	None, Alarm	Engine	None
Refrigerator	Battery, Alarm	None, Alarm	Engine	None, Alarm
TV	Battery, Alarm	None	Battery, Pedal	None
Cathodic Protection	Battery, Alarm	None, Alarm	Battery, Alarm	None, Alarm
Field Instruments	Battery, Alarm	None, Alarm	Engine, Battery, Alarm	None, Alarm

each degree of sophistication increases cost. Therefore, the power conditioning system should be kept as simple as possible without sacrificing the necessary functions and quality. Options that should be considered include:

- o maximum power point tracking
- o extent of load management
- o level of instrumentation
- o alarm/signaling mechanisms
- o manual versus automatic features

4.5.5.1 Controller/Regulator

The controller/regulator must be matched to the specified input and output voltages. The acceptable voltage input range for the loads dictates the necessary preciseness of control.

4.5.5.2 Inverter

The size of inverter needed for the system is based on the peak load demand. It is important to consider both average and peak demand because inverter performance is best at full power. However, future plans for system expansion should be incorporated. Standby power (no load power) should also be examined, as it can be a significant load on the system.

The quality of the sine wave output from the inverter is dependent on the loads. Quasi-sine output is quite acceptable for resistive loads, whereas sine output is necessary for loads such as capacitor-start motors.

4.5.6 Life-Cycle Cost Analysis

Life-cycle cost analyses are critical in terms of PV systems since they have high intial capital cost but very low annually recurring costs. The design process is an iterative one between selecting and sizing components and performing life-cycle cost analyses for the various options.

For example, a series of analyses may include assessments of the following type systems:

- o flat-plate versus concentrator systems
- o properly sized inverter with the purchase and incorporation of an additional inverter five years later to accomodate expansion versus initial oversizing
- o a.c. loads with an inverter versus d.c. loads
- o competing technologies (e.g., battery systems, diesel systems, hybrid systems)

4.6 SAFETY

System design and operating procedures must be adequate to prevent injury to people and to prevent or minimize damage to the equipment. The following protective measures should be taken, particularly where system voltages are above 30 volts d.c.

Structure Grounding--the array structure and power control panel frame should be connected to buried metallic counterpoise. Connections to the array structure should be made at several locations to ensure reliability.

Disconnects--disconnects (in the form of switch gear and circuit breakers) should be included in the design to allow for isolation of portions of the system prior to maintenance and for shorting of the power mains in emergency situations.

Utility Power Disconnect--automatically disconnects the PV system from the grid in the event of a utility failure.

Fuses/Circuit Breakers--these should be provided between all major components to protect the equipment from overload.

Grid Isolation--a transformer is used to protect the PV system from a.c. feedback and the grid from the injection of d.c.

Lightning Protection--in regions of high thunderstorm activity, it may be advisable to install grounded lightning rods. Varistors (electrical "release valves") should also be installed to protect circuitry against large current surges.

Security Fence--it is recommended that the PV arrays be enclosed by a fence to prevent unauthorized persons and livestock from harming themselves and/or the system.

Battery Enclosure--it is recommended that the batteries be housed in a structure. Similar reasons apply as to the justification for security fence

around the arrays (as well as battery protection from inclement weather). If using vented batteries, it is important that this structure have adequate ventilation to prevent the explosion of hydrogen liberated during battery charging. Within this battery area, a supply of fresh water should be kept if vented batteries are used. This is to flush a person's eyes and skin if splashed with electrolyte (acid and water mixture).

Load Enclosures--equipment that turns on automatically (such as a pump that starts when water in a storage tank drops to a pre-determined level) should be enclosed to prevent injury to bystanders.

4.7 SPARE PARTS

The decision to stock spare parts at the site is based on the tradeoff between the impact of system downtime while replacement parts are ordered and shipped and the cost of buying parts that may never be used. There are a couple points worth mentioning about designing a system and designating appropriate spare parts: first of all, the existence of spare parts is useless if no one has the ability to make the repair. Secondly, effort should be made to use equipment manufactured in-country (or equipment that is compatible with that in-country) wherever possible.

A typical set of spare parts to be purchased with the initial system and kept on site is as follows:

Modules--the number of spares should be approximately 3 percent of the total number needed for the system. Spare modules may be incorporated into the array such that the array is actually oversized (i.e. no "spares" per se). Incorporation of the spares in this way helps maintain both the system charging voltage and power level.

Batteries--a reserve of approximately 2 percent of the total capacity of the battery bank (The spare modules can be used to trickle-charge the spare batteries.). Also spare battery lugs should be included.

Fuses--two replacements for each fuse in the system.

Diodes--spare bypass and blocking diodes, as well as surge protectors (varistors) should be kept on hand.

Controllers--capacitors, indicator lamps, internal switches, relays and circuit boards depending on cost and potential for failure.

Loads--bulbs, ballasts, pump repair kit (e.g., seals), grinding wheels, bearings....

Manufacturers recommend certain spare parts with their equipment. Upon reviewing their recommendations, selections can be made based on the costs of the spares, central or site storage, and the cost of system downtime. Another important consideration is the rapid evolution of modules and power conditioning equipment -- it may be difficult to find replacement parts for certain components after several years and hence be cheaper to replace the entire component (e.g. controller).

4.8 SPECIFICATIONS IN THE RFP

Within the technical section of an RFP, certain information must be provided by the purchaser such that the responder can design the system as well as submit a responsive bid. These two steps that the responder must perform require different levels of input as discussed in the sections that follow.

4.8.1 Input to System Design

The more detail that is provided by purchasers, the better the responder will understand the nature of the request and thus the closer the system can be designed to the purchaser's expectations (technical and financial). Any doubts in the designer's mind will result in an elevated bid.

First of all, adequate background about the desired system should be given:

- o What is the purpose of the system (e.g., demonstration, training, R&D, commercial)?
- o Where is the system going to be installed (e.g., latitude, distance to technical expertise, accessibility)?

Information on the equipment desired, the climate and available resources, and maintainability should be included as indicated below.

Equipment Detail

- o Preferences on equipment supplied (e.g., module design, sealed versus vented batteries)
- o Technical specifications for existing/required loads

- Indication of demand (e.g., required hours of operation, amount of water pumped to what head)
- Required reliability of each load (consequences of system downtime)
- Specifications for instrumentation desired (e.g., telemetry)
- Specifications for system protection and safety equipment (e.g., enclosures, alarms)

Resource and Climate Data

- Insolation and, in the case of water pumping, water resource data
- Ambient temperature (highs, lows and averages)
- Humidity
- Frequency of extreme, unique, or performance-limiting conditions (e.g., dust storms, high winds, hail, fog, earthquakes)
- Cloud cover (consecutive number of sunless days)

Maintainability

- Available maintenance for the system (e.g., none; regularly scheduled visits by what skill level of person; trained system operator of what skill level)
- Available enclosures (e.g., battery room of what size)

Whenever possible, diagrams, maps and site layouts should be provided. Any known dimensions or distances should be identified. An important note to remember, however, is that while detailed specifications are encouraged, they may not allow for a creative bid.

4.8.2 Input to Development of Bid

The items discussed in the previous section addressed that information required by the bidder to design the system; however, additional items must be specified by the purchaser in order for the bidder to submit an uninflated quote. They are as follows:

- Clear indication of what the reponder is expected to provide (and thus include in the bid) and what the purchaser will provide
- Points of responsibility in the transfer of equipment (e.g., Does the bidder just have to ship equipment to a given port, and then the

purchaser is responsible for transfer to the site?)

- Proof of performance (What is the limit of the contractor's responsibility for technical performance?)
- Required equipment warranty
- Turnkey system or in conjunction with in-country organization or local people
- Labor support (Provided by the purchaser? If no, what are approximate local labor rates?)
- Type of manuals, if any, to be provided with the system (e.g., startup and testing, operation and maintenance, in what language)
- Spare parts (Are they to be included with the system?)
- Continued technical support (To be provided by the contractor?)
- Local availability of materials (e.g., cement, water, lumber, iron)

5.0 SYSTEM IMPLEMENTATION AND OPERATION

5.1 INSTALLATION REQUIREMENTS

5.1.1 Factory Assembly

For all field installations, it is advisable that as much system assembly as possible be performed at the factory. Array panels, regulators, inverters, controls, instrument board and so forth can be assembled and inspected prior to shipment to the installation site.

5.1.2 On-site Installation

Installation requirements at the site can be categorized as either construction or electrical. Construction tasks are as follows:

- o Prepare the site by removing all brush, performing minor leveling, and providing drainage
- o Construct buildings and enclosures for instrumentation, controls, switchgear, batteries, array and loads, as required
- o Construct foundation and erect support structure
- o Trench and lay control lines from array and loads to the control panel
- o Physically install array, loads and power conditioning subsystem

Electrical tasks include:

- o Wire the array
- o Wire the loads
- o Connect power conditioning subsystem, instrumentation and protection circuits

An installation procedure indicating the sequence of these various tasks is detailed in Exhibit 5-1.

5.1.2.1 Labor

Construction tasks can be performed by local unskilled labor under the direction of an experienced individual. Electrical tasks require a skilled electrician; however, where repetitive procedures are involved, local people

Exhibit 5.1
INSTALLATION PROCEDURE

TASK:	COMMENTS:
SITE PREPARATION	• Removal of Brush • Minor Leveling • Drainage
BUILDINGS/ENCLOSURES CONSTRUCTION	• To House Instrumentation, Controls, Switchgear and Batteries, as Required
SUPPORT STRUCTURE CONSTRUCTION	• Construction of Foundation • Erection of Array Support Structure
UNDERGROUND CONDUITS/ OVERHEAD LINES	• Laying/Stringing Power Control Lines between Array, Power and Control Panel, and Loads
MODULE MOUNTING	• Mount Modules on Support Structure
ARRAY ENCLOSURE CONSTRUCTION	• Around Perimeter of Array
ARRAY WIRING	• Connection of Panels and Power Busses
POWER CONDITIONING SUBSYSTEM INSTALLATION	• Mounting and Connection of Regulator, Controls, Instrumentation, and Safety and Electrical Protection Circuits
LOAD INSTALLATION	• As Specified in Manufacturer's Instructions
LOAD ENCLOSURES	• As Required for the Safety of Bystanders
FINAL CONNECTIONS	• Final Electrical Connections between Array, Power Conditioning and Loads
CHECKOUT	• All Electrical Circuits • All Construction

can be trained under the supervision of an electrician.

5.2 ACCEPTANCE TESTS

After the photovoltaics system installer has completed the installation, the client must be satisfied that the system will perform to meet his needs. To do this, an acceptance test should be devised by the client with specific quantifiable pass/fail criteria. This test should be communicated (as part of the installation contract) to the installation and equipment contractor so that they know specifically what their system or equipment will be expected to do. This can be done in a number of ways. One is to let the contractor check the system out and then let the client do essentially a repeat check. Another way is to have the installer (using his equipment) do the acceptance test under the watchful eye of the client. Yet another way is to structure the contract such that the contractor is required to warranty his equipment for a period of time after installation.

No matter which method is used, it is one of the most important decisions the client must make. If the client devises a test that is too loose, he risks getting a system which will not do the job he wants. If the acceptance test is too rigorous he will not get a responsible contractor to bid on the contract -- or worse will get an unqualified contractor to bid on it at an exorbitant price.

5.2.1 Equipment Needed

The following is a minimum list of general equipment needed to do a functional photovoltaics systems test:

Pyranometer

Voltmeter

Ammeter

Equipment to draw I-V curves

Ohmeter for grounding checks

Temperature measuring equipment using thermocouples or temperature transducers.

Power supply

Current-limited ammeter, for Hi-Pot tests

Standard mercury bulb thermometer

5.2.2 Standard Testing Procedures for PV Panels and Systems Supplied by Manufacturer

At the module level, consult the data furnished by the manufacturer on open circuit voltage. Measure this voltage and after correcting for temperature difference compare the values. This is a rough integrity check. If the figure is within 10 percent -- OK. It is not necessary to take a pyranometer reading to determine precise agreement with the manufacturer's data. If you cannot get any reading there is an open in the circuit and it must be resolved before installing the module in an array.

Finish the mechanical installation first. Then (for safety) do the electrical connections at a time when there is very little sunlight on the array.

After the system electrical connections are made, take an open circuit voltage reading between the positive and negative terminals. The readings should be within a few precent of the sum of the module voltages in series. If not, the defective component must be repaired or replaced before going further in the systems installation.

5.2.3 Performance Tests

To check performance, a day should be chosen which is relatively cloudless with at least 85 percent full sun. The test should be done between two hours before solar noon and two hours after solar noon.

Set up pyranometer on (or near) one of the modules which make up the array. It should be in the same plane as the module and not have any reflections or

light absorption different from the array itself.

Connect I-V curve tracer to circuit to be measured.

Connect temperature measurement equipment to a representative module or a specific cell in that module.

Record the following data:

Ambient air temperature,

Angle between a line perpendicular to the module surface and a line from the surface of the module to the sun,

Cell temperature,

Pyranometer reading,

Wind direction and velocity.

Take several I-V curves over a period of about an hour.

Calculate the power using the temperature, irradiance, and geometry corrections as necessary to normalize the readings to those specified in the acceptance test specifications.

5.2.4 Hi-Pot Test

The purpose of the hi-pot test is to determine if there are any shorts between the electrically active photovoltaic system and the ground or any other conductive part of the system.

For safety, this test should be done at a time when there is relatively little sun or the array is covered.

Short the positive and negative leads of the branch circuit together.

Using a power supply, or special equipment designed to do hi-pot tests, connect one of the (power supply) leads to the shorted photovoltaic module leads. Connect the other lead to the electrically conductive but physically isolated frame. If the current leakage is more than 100 microamps, then there is a problem somewhere in the array and it must be repaired before the photovoltaic system can be accepted by the client.

5.2.5 Continuity Check for Grounding Circuit

Connect one lead of an ohmeter to the ground peg; connect the other to a frame member on the individual modules. There should be good continuity between any of these members.

5.3 SYSTEM START-UP

It is essential, from both operator and equipment safety standpoints, to follow a systematic start-up procedure. A basic procedure for the start-up of a stand-alone system is outlined in Exhibit 5-2. A few points to keep in mind follow.

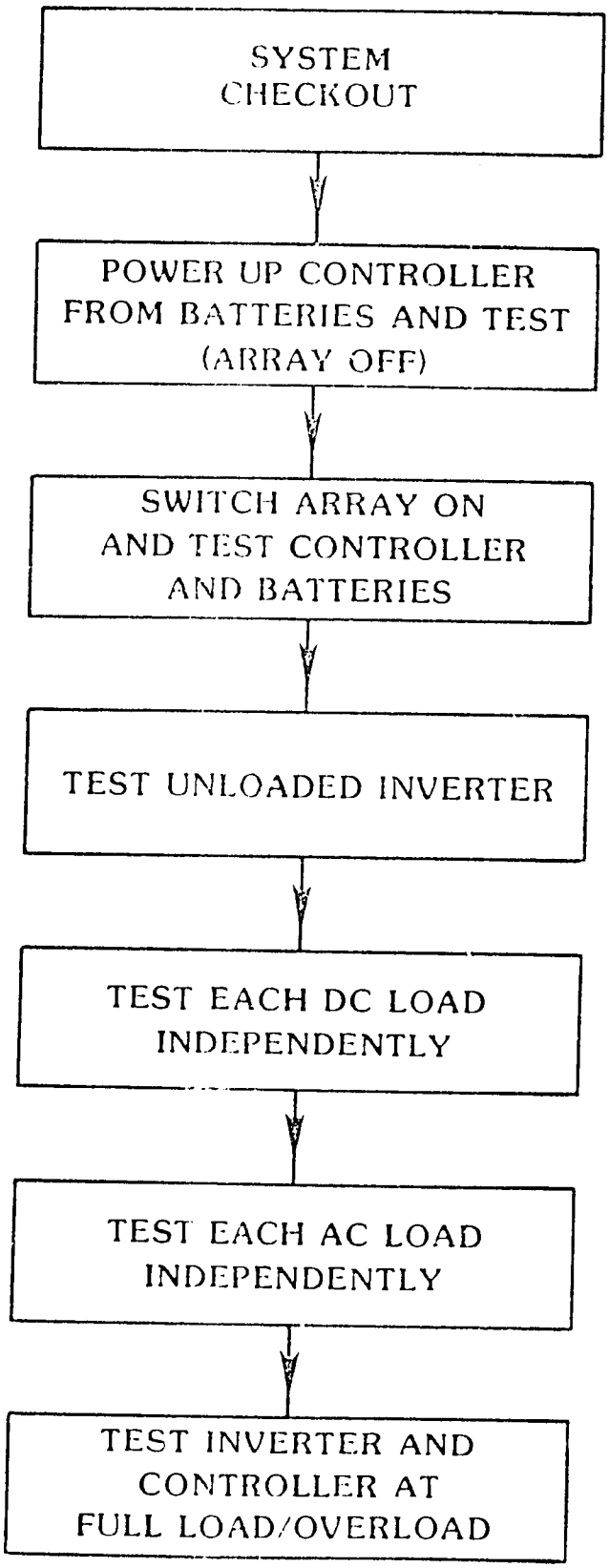
- o Components should be tested independently of one another to the extent possible.
- o Initial switching-on of the array should be done in the early morning or late afternoon (In case power conditioning components have not been properly "burned in" by the manufacturer, they should not be subjected suddenly to full power.).
- o In systems with battery storage, the batteries should never be turned off prior to the array; similarly, the array should never be turned on prior to the batteries.

5.4 OPERATION AND MAINTENANCE

PV systems do not require an attendant to operate. They do require maintenance, but significantly less than most other energy systems. Inspection and maintenance visits are therefore recommended on a regular basis. The frequency of these visits is dependent upon system complexity and location. Initially, monthly visits are recommended. Once the particular system's maintenance schedule is understood, visits every three months may prove to be all that is necessary. Typical tasks during these visits are listed below.

- o Check wiring and connectors for cracking, rodent damage, fraying, etc.
- o Check modules for cracked cells, interconnect corrosion, etc.
- o Clean array surface if needed
- o Check battery electrolyte level and add water as needed (applies to

Exhibit 5.2
EXAMPLE STAND-ALONE SYSTEM START-UP PROCEDURES



vented cells)

- o Perform battery equalization every six months
- o Clean battery terminals as needed
- o Inspect lightning protection system (varistors)
- o Check controls every six months (e.g., manually trigger alarms)
- o If proper equipment is available, check instrument calibration every six months

Manufacturers generally provide operation and maintenance instructions with their equipment that should be followed. It is also a good habit to maintain records of the visits, in terms of all faults and deterioration detected in system components and functions. Usually a local person can be trained to perform all of these tasks.

5.5 PERFORMANCE MONITORING

The ultimate purpose of performance monitoring is to improve/modify designs of systems and components to fit new applications. It is therefore recommended only in the context of an R&D center. The basic questions that must be answered are:

(1) Is the system producing as much energy as predicted?

(2) Are the loads consuming as much energy as predicted?

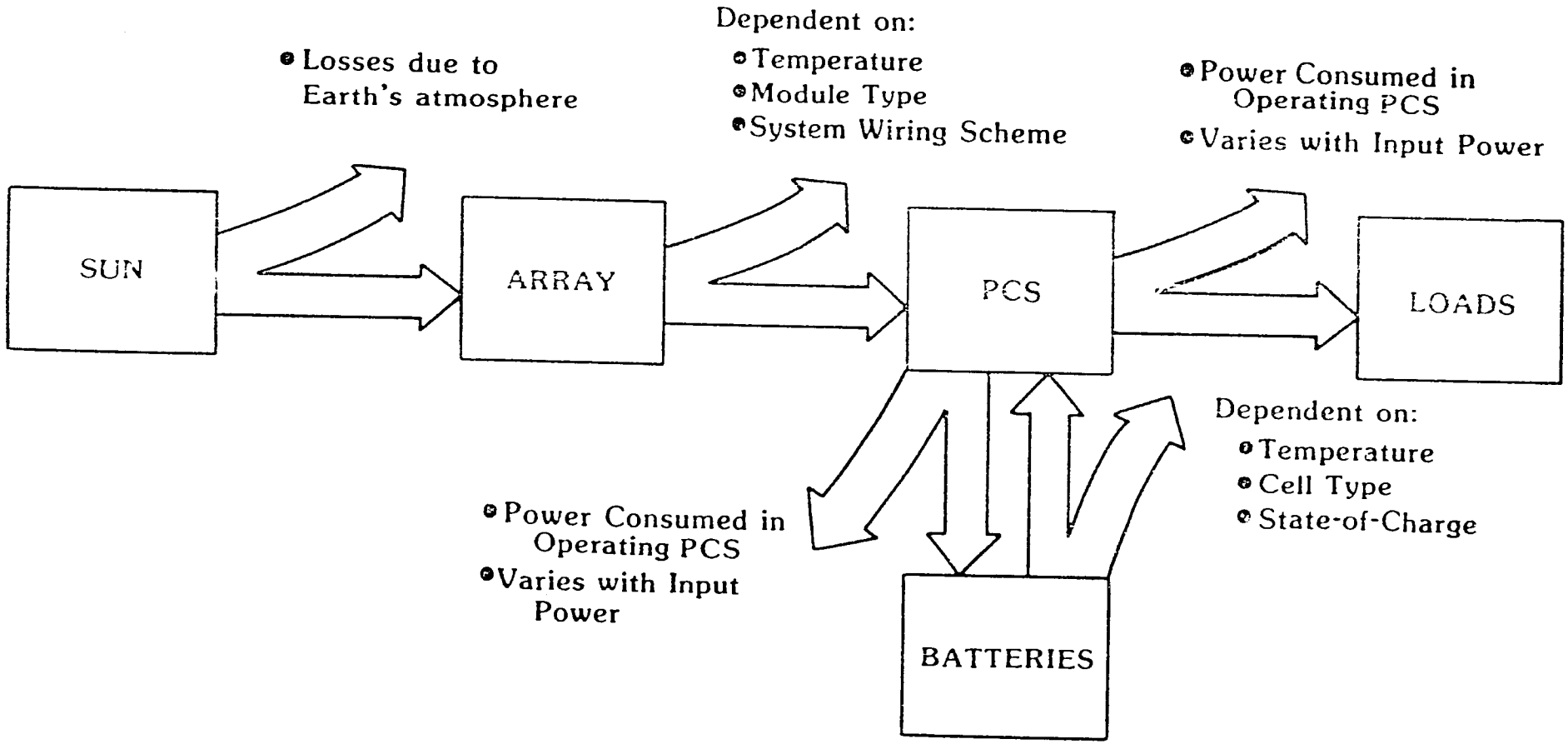
These questions can be answered by evaluating the energy flows indicated in Exhibit 5-3.

The energy flows can be measured using a pyranometer, amp-hour (A-h) meters and run-time meters as indicated below.

Solar Resource Verification: Using a pyranometer, insolation can be monitored and then compared to data used in designing the system.

Array Performance Verification: Watt-hours measured coming out of the array during a certain period of time divided by Watt-hours predicted coming out of the array during the same period.

Exhibit 5.3
ENERGY FLOWS



Battery SOC Estimate: The current into the battery divided by the current out of the battery both over a given period of time, starting at full charge (This can be done with an instrument that continuously records ampere-hours in and out of the battery).

Load Profile Verification:

-- A-h measured into the loads over a period of time divided by A-h predicted into the loads over the same period

-- Run time measured over a period of time divided by run time predicted over the same period

Overall System Performance: A-h measured out of array during given time period minus the A-h measured to the loads over same time equals A-h surplus or deficit. If there is a sustained surplus, the array was oversized or the loads were underutilized. If there is a sustained deficit, battery life is threatened.

Whether the data acquisition system is automatic or manual, it should be performed only where technical expertise is readily available. This statement is based on the following two points:

(1) the accuracy and amount of data is inversely proportional to distance from technical expertise

(2) accuracy is not proportional to cost (for example, digital recording A-h meters are costly, while their accuracy is difficult to maintain).

6.0 SPECIAL CONSIDERATIONS IN EGYPTIAN ENVIRONMENT

6.1 DUST STORMS

Such storms result in dust accumulation on modules and battery terminals. Thus, the frequency of maintenance visits may be dictated by necessary cleaning of arrays and batteries. The frequency can be reduced by oversizing the array and by adequate enclosure of the battery bank. PV modules should also be mounted on a high enough structure from the ground such that dust/sand does not drift at the bottom of the array.

6.2 TEMPERATURE & HUMIDITY

The high temperatures encountered in Egypt reduce PV module output and decrease battery life. Low humidity also increases evaporation of water from vented batteries, thus increasing the frequency of maintenance. Batteries should be sheltered in such a way as to optimize passive cooling.

6.3 SOLAR RESOURCE

Egypt has very high solar insolation. In particular, there is a large component of direct radiation, indicating that concentrator collectors should be examined as a potential option. Resource data for Egypt can be found in Appendix C.

6.4 DESERT RODENTS

Special attention should be given during maintenance visits to the inspection of wires for gnawing by rodents. Protection of the wires with metal shielding is encouraged.

7.0 CURRENT R&D THRUSTS

The key thrusts of PV R&D are to reduce the cost and raise the efficiency of systems so they are competitive in a wider variety of applications. Cost and performance targets are indicated in Exhibit 7-1. PV systems can be divided into the modules and the balance of system (BOS).

7.1 BOS R&D

BOS technologies can be divided into area-related and power-related. Area-related BOS components include structures, foundations and interconnect wiring. Power-related BOS components consist of the power conditioning equipment. Additional significant improvements in area-related BOS are unlikely to come from further research. Improvements in power conditioning is mainly a function of advancements in the electronics industry. For example, a prototype now exists for a solid-state inverter that can fit in the palm of one's hand. The greatest advancements in BOS technologies, however, will come from better designs, achieved through increased experience and mass production.

7.2 MODULE R&D

The majority of current PV research is directed toward improvements in the modules. There is a constant tradeoff between the cost and efficiency of the cells--the technologies that are most developed, so far have involved the most expensive processes. The maturity of various PV technologies are indicated in Exhibit 7-2.

7.2.1 Single-Crystal Silicon

Single-crystal silicon is the most stable and highest efficiency silicon material used in commercial PV applications. R&D efforts continue at increasing efficiency toward silicon's theoretical limits and at reducing material costs.

Exhibit 7.1

US DOE LONG-TERM (LATE 1990'S) TECHNICAL GOALS

	Flat Plate Systems	Concentrator Systems
Module Efficiency*	13%-17%	23%-29%
Module Cost	$40-$75/m²	$90-$160/m²
Balance-of-System Costs		
—area-related	$50/m²	$100/m²
—power-related	$150/kW	$150/kW
System Life-Expectancy	30 years	30 years

*Measured at 28°C and AM 1.5.

(1982 DOLLARS)

7.2.2 Cast Polycrystalline Silicon

Cast polycrystalline silicon cells are less efficient than single-crystal cells; however, the costs involved in "growing" a single crystal are higher than for casting an ingot. R&D also concentrates on improving efficiency and reducing material costs.

7.2.3 Silicon Ribbon

Ribbon cells offer a more automated production process; however, once again, manufacturing cost reductions have been at the sacrifice of further efficiency. R&D efforts are underway to resolve generic growth impediments and performance-limiting characteristics.

7.2.4 Concentrators

Concentrator technologies offer the opportunity to use much smaller cells (1 inch versus 4 inches in diameter) and generate more power per unit area. R&D in this area involves increasing concentration ratios and heat dissipation from the cells, developing improved tracking mechanisms, and producing lower cost collectors.

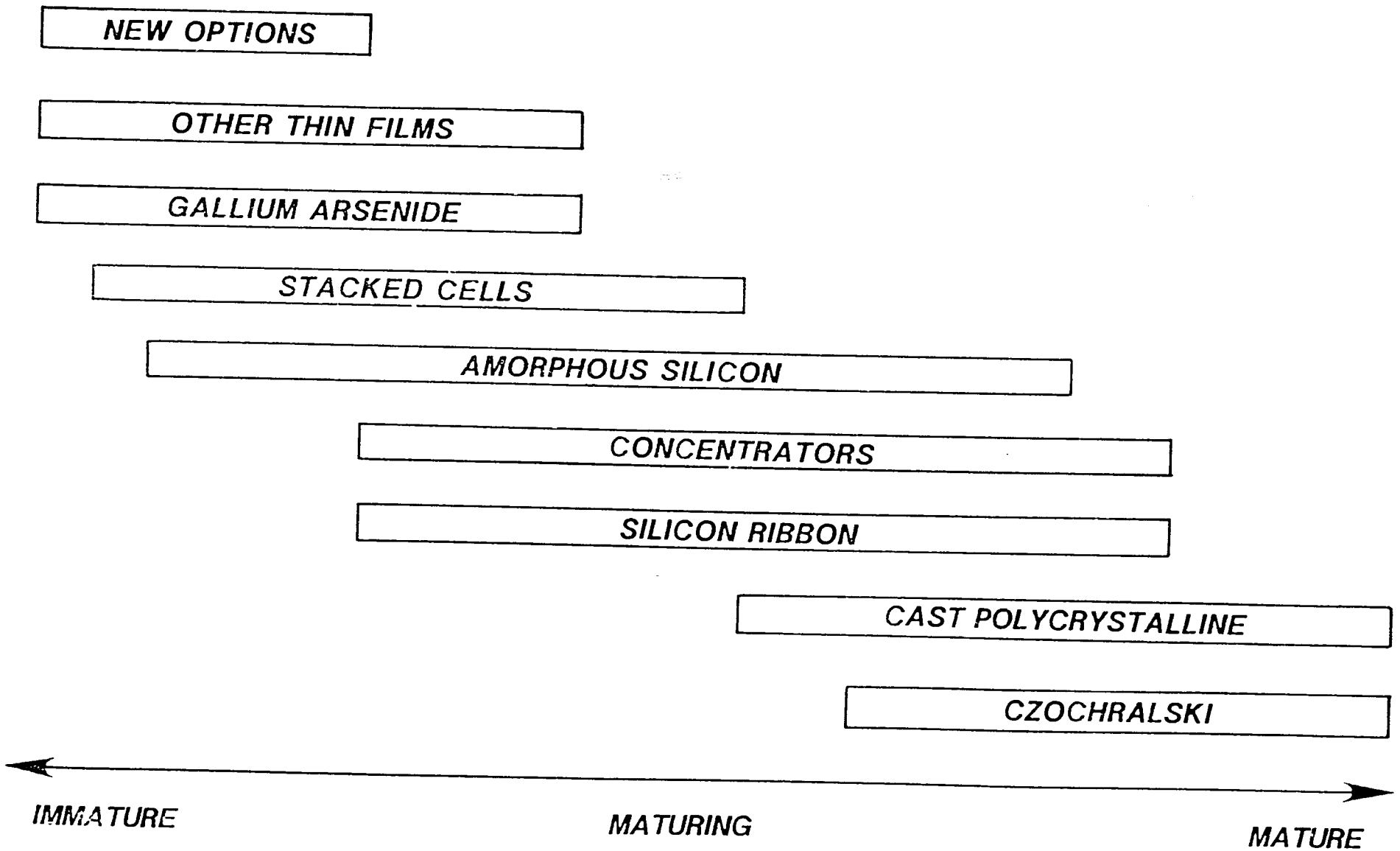
7.2.5 Amorphous Silicon

Amorphous silicon (A-Si) technology is probably the most publicized PV material of recent years. A-Si cells use 100 times less silicon than single-crystal cells. Therefore, its potential for inexpensive products is very high. However, A-Si has the lowest efficiency and stability of any of the other more mature options. R&D in this field has been dedicated to increasing efficiency, lifetime, stability and production automation.

7.2.6 Other Options

The other options in Exhibit 7-2 are still in preliminary research stages. Gallium arsenide (GaAs) is looked at with promise as a thin-film material in

Technology Maturity



stacked cells. In single-crystal form, GaAs alloys have yielded the highest efficiency of any material to date and are extremely stable; however, GaAs is an expensive material and therefore has only been used experimentally for space applications. As a thin film in a stacked cell for a concentrating system, GaAs may prove to be cost-effective.

8.0 PHOTOVOLTAIC APPLICATIONS

Photovoltaics is a practical energy source for any application requiring electricity. Its suitability for a specific application at a given location will depend on many factors, both economical and logistical. The following discussion of applications is based on applications presently being used or tested worldwide. Descriptions of representative PV applications are shown in Appendix D - Photovoltaic Project Site Visit Book.

8.1 COMMUNICATIONS

One of the earliest applications, and currently the most common, is the use of PV systems to provide critical power for communication systems. Fully accepted by the worldwide communications industry as a simple, viable, high quality, reliable and economic source of power, PV systems have been installed to provide critical power for:

- Microwave repeaters
- UHF and VHF radio repeaters: remote and mobile telephones, police and taxi communications
- Mobile radio systems: emergency medical communications
- TV and satellite repeaters and ground stations
- Educational TV systems
- Supervisory control systems: intrusion detection, highway call boxes, storm warning signs, fire alarm systems, dangerous material detectors
- Situation and environmental monitors

The range of uses for PV-powered communication systems is also extremely broad. Early applications emphasized telephone communications for fixed or mobile audio systems. Later, commercial TV and educational TV applications expanded the use of PV power into video communications. At this time, digital data telemetry applications also began for remote control or monitoring uses. Most recently, PV is being incorporated into systems for computer and entertainment

communications and as the principal power for key satellite ground stations.

The total number of new PV communication installations of all types is now approaching 10,000 per year worldwide. These sites provide power for voice, video, and/or digital data communications. Operational environments range from deserts in the Middle East and hot, humid mountain tops in Southeast Asia to the very edge of the Arctic Circle. Load power from several watts to several thousand watts has been supplied both economically and reliably.

8.2 RURAL ELECTRIFICATION

Although they have been in use for more than 5 years, PV rural electrification systems represent a relatively new application when compared to PV-powered communications. The rural electrification area is possibly more significant, however, in terms of future growth potential. About 2500 new PV-powered rural electrification systems were installed worldwide in 1983, and the amount is doubling annually. These sites range from one module systems for individual, isolated homes to complete electricity generation and distribution systems (i.e., mini-utilities) for rural villages. Early sites were typically rated at 2 kWp or less, but recent sites have been implemented up to 350 kWp.

The earliest PV rural electrification systems provided primary power for lighting, water pumping, communications, and/or medical refrigeration for remote settlements in developing regions; power for similiar systems for remote homes; and power for forest lookout or park facilities. More recent systems, however, have included many more functional devices. A PV system installed in Tunisia in 1983 provides power for:

- Two stores, a mill, a beauty shop, and a coffee shop;
- Lights, refrigerators, and televisions in 22 homes;
- A clinic, a mosque, a cultural center, and school;
- A series of street lights;

- A farmhouse; and
- Two drip-irrigation agricultural systems.

The total rated capacity of the PV components of this system is 35 kWp. This Tunisian site demonstrates the quantity and variety of functional components that can be powered by a relatively small PV rural electrification system. The largest rural electrification system installed to date is a 350 kWp system in Saudi Arabia. It provides 700 villagers in 3 towns with power for lighting, televisions and radios, water pumping, farm irrigation and other domestic uses.

A significant driving force behind the past and projected growth in rural electrification applications is the development of special d.c. functional components for use with PV power systems. These components include water pumps, lights, medical refrigerators, desalination and water purification systems, evaporative coolers, television sets, and other entertainment devices. New inverter systems to provide more efficient a.c. power further extend the list of available functional devices by providing power for a.c. components, such as clothes washers, which are already widely available.

Further rural electrification systems will include mini-utilities that will supply power for rural settlements, thus helping to provide the advantages of progress and urbanization to rural areas. Such systems have already been proven in demonstration applications, and negotiations for commercial system installations are now in progress. PV, therefore, is a prime candidate for supplying power to both small villages or medical center sites, as well as to entire communities.

8.3 WATER PUMPING

The use of PV power systems for water pumping applications is similar in its development to the use of PV systems in village electrifcation applications. Many rural electricity systems being installed have a water pumping capability.

Communities generally need only one power system; however, many more water pumping systems are typically required to support the large number of farms involved. The availability of PV-powered water pumps has thus created a completely independent market for these systems.

There are two principal types of PV-powered water pumping systems available today. These include:

- Deepwell or tubewell systems that are used to provide clean and safe water for human or animal drinking and washing, or for irrigation.
- Surface supply systems that are used to provide water for irrigation or for animal consumption.

Commercially avilable PV-powered water pumping systems can supply water from surface sources with head depths from 0 to 1 meter or from wells as deep as 120 meters. Typical flow rates range from 5 cubic meters per day to more than 250 cubic meters per day. For even greater flexibility, both d.c. and a.c. systems are now available.

In the past, diesel systems, human labor, or animals have been used as the principal sources of power for rural water-pumping systems. PV systems provide a simple and economic alternative to the diesel systems for all types of water pumping. In this case, the PV alternative provides the same amount of power without requiring any fuel or extensive maintenance--major diesel cost elements.

Modularity of the PV system also allows the use of a new and more efficient type of irrigation--drip irrigation. Because diesels are not typically available in small sizes, drip irrigation could not be used previously for small farms. Smaller, portable PV systems are also especially useful in areas where large numbers of small fields are to be surface water irrigated. Again, portability is not generally available with a diesel system.

Using a PV system is also beneficial where human labor or animals are the principal power sources for pumping water because it allows humans the time to pursue much more productive activities. The PV alternative can also avoid

the "milk and meat loss" associated with the use of farm animals as the power source. Both of these advantages supply additional food inputs to the humans involved and improve the standard of living not only for the users, but also for the entire community.

8.4 CORROSION PROTECTION

Traditional corrosion protection systems have depended on either the availability of utility power or on other approaches that are expensive. The development of the PV alternative has given these industries a new, economical, and effective solution to this corrosion problem.

In this application, the PV systems supply power for electrical circuits called cathodic protection (CP) systems. Electrical current from the PV array is used to counteract natural corrosive currents generated when metallic devices are buried in the ground. These protection circuits are used on many wellheads, pipelines, bridges, storage tanks, and other metallic structures. Approximately 1000 new PV-powered CP systems are now being installed worldwide every year. Typical power ratings for these sytems range from 70 Wp to 2.5 kWp. Because the modular nature of the PV system allows users to customize systems for many different corrosion protection requirements, the use of PV for this application is expected to increase significantly in the future.

8.5 NAVIGATION AIDS

Aids to navigation (navaids) provide essential transportation safety information for air and sea traffic. Almost all navaids are located at remote sites where they are exposed to severe weather and corrosion-causing environments. Because human lives and valuable cargo depend upon the proper operation of these systems, their reliability is critical. Photovoltaic systems are an economical and reliable solution to the power source problem for these applications. Many thousands of PV-powered navaids have been installed around the world, and

more than 5000 new sites are being added every year. Fully functional and operating systems over 10 years old have demonstrated the highly reliable nature of the PV alternative in the extremely corrosive and demanding navaid environments.

Buoy-mounted PV systems typically provide power for warning lights, fog horns, or a combination of both signals. The PV ratings for these systems range from a low of 7 Wp to a high of 200 to 250 Wp. If communication or telemetry functions are included, system size may increase. Similar warning light systems are used to signal aircrafts of major geographic and man-made obstructions. Larger PV power systems, up to 2.0 to 3.5 kWp, are used for lighthouse applications. In all of these cases, photovoltaics has been proven to be less expensive than the more traditional energy sources.

8.6 RAILROADS

The use of PV systems for railroad applications is one where reliability is also essential. In this case, the PV systems supply power for track circuits and crossing gates, which provide critical protection for both humans and cargo. The track circuits monitor the location and direction of any operating trains on a given railroad network. Using this key information, railroad system controllers can coordinate railroad traffic to ensure safe operation of the network. Crossing gates ensure the protection of the general public. More than 1000 new PV-powered track circuits or crossing gates are now being installed worldwide each year.

In addition to the control circuit applications, railroads are using PV power systems for several other key uses. Based on the successful experience of the communications industry, the railroads are using PV to power their own critical communications systems. Railroads also use PV systems to supply power for cabooses and for railway stations in locations where utility power is not available.

8.7 UTILITY NETWORK POWER

Although PV technology as a source of utility network power is not yet economical in all areas of the world, progress made to date has proven that the application is feasible. A number of utility-interactive applications have thus been identified and implemented. This list includes:

- Individual residences
- Schools
- Small residential communities
- Commercial centers and office buildings
- Utility sub-station generation
- Central station utility generation

Practical utility system components have already been developed and used in demonstration projects as well as in true commercial applications. Various system integration concepts are being tested by numerous utilities that are also funding major programs in PV development. These developments offer not only the practical utility-scale use of PV systems, but also flexibility in the way PV technology can be implemented. With proper storage backups, PV systems can even be used as a source for independent mini-utilities, eliminating the need for costly utility extensions (which in the U.S. can range from 15,000 to 50,000 dollars per miles). The technology, therefore, not only offers a supplemental source to utility power, but also could supply an independent utility network of its own.

Several utility PV applications ranging from 100-Wp sub-station power systems to 7.5-kWp residential systems to 6.5-MWp central station power systems are in operation or under construction. The initial phases of a planned 100-MWp central station plant are also currently under construction. AC line-inter-tied inverters and control systems have been designed and manufactured for this wide range of application sizes as well as for larger ones planned for the near future.

8.8 OTHER APPLICATIONS

As shown in the previous sections many practical and economical applications for PV power sytems have developed over the past 10 years as the technology has been commercialized. An abbreviated list of other major applications is shown below.

- o Automotive, Marine and Industrial Battery Chargers
- o Consumer Products (e.g., Calculators, Watches, Toys)
- o Desalination
- o Electric Fences
- o Emergency/Hazard Lights
- o Recreational Vehicles
- o Remote Lighting
- o Solar Thermal Circulators

In many cases, the favorable economics of the PV alternative has been the major factor in the increased commercialization of these devices. The use of PV power sources for electric fences, remote lighting, and marine battery chargers are three such applications. The use of PV to power desalination systems is another case where the technology is facilitating the expansion of an existing application. An 8-kWp desalination system provides up to 2.3 m^3 (600 gal) of fresh water daily for Jeddah, Saudi Arabia. In this plant, sea water with 43,000 parts per million (ppm) salt is converted to fresh water with less than 100 ppm salt.

9.0 PRODUCTS

The U.S. PV industry offers a wide variety of equipment to choose from: collectors made from single-crystal, polycrystalline and a-Si materials; concentrator and flat-plate collectors; fixed, adjustable tilt and tracking support structures; controllers, inverters and converters; and d.c. and a.c. end-use equipment. Individual PV system components can be obtained from respective manufacturers, or their distributors; turn-key systems can be purchased through systems integrators and some module manufacturers. Several of the major manufacturers also supply packaged systems for certain applications.

This chapter organizes U.S. manufacturers' products. Information is presented on matrices by component as follows:

- Modules (Exhibit 9-1)
- Support Structures (Exhibit 9-2)
- Batteries (Exhibit 9-3)
- Regulators/Controllers (Exhibit 9-4)
- Inverters (Exhibit 9-5)
- Pumping systems (Exhibit 9-6)
- Other packaged systems and end-use components (Exhibit 9-7)
- Manufacturing equipment (Exhibit 9-8)

The information presented is based on product literature obtained through a mailing to U.S. manufacturers. Only those manufacturers who responded are included on the matrices. As such, the information in this chapter is representative of U.S. PV products but not all inclusive. The actual product literature received from the mailing are filed by component in the REFT Project Library.

At the end of this chapter are the names and addresses of all the manufacturers identified in the matrices.

Exhibit 9.1 MODULES

FEATURE / MANUFACTURER	Commercial Power Modules									Peak Power Output (Watts)						
	Flat-Plate	Concentrator	Single-Crystal Silicon	Polycrystalline Silicon	Silicon Ribbon	Amorphous Silicon	Point-Focus Fresnel	Linear-Focus Fresnel	< 10	10-20	20*-30	30*-40	40*-50	50*-75	75*-150	150*-200
ARCO SOLAR	●		●			●			●		●	●	●			
CHRONAR	●					●			●							
ENTECH		●	●					●								
INTERSOL		●	●				●								●	
MOBIL SOLAR	●				●					●	●					●
SOLAREX	●			●					●	●	●	●	●			
SOLAVOLT	●			●								●				
SOLEC	●		●						●	●		●		●		
SOLENERGY	●		●						●	●		●		●		
TIDELAND	●		●						●	●		●				
UNITED ENERGY		●					●								●	

Exhibit 9.2
SUPPORT STRUCTURES

MANUFACTURER \ FEATURE	Pole Mount	Fixed	1-Axis Manual	1-Axis Automatic	2-Axis Automatic
ARCO SOLAR	●	●			C
ENTECH				●	
INTERSOL					●
MOBIL SOLAR		●			
ROBBINS ENG'G					●
SOLAREX	●	●	●	C	
SOLAVOLT	●	●			
SOLEC INT'L	●	●	C		
TIDELAND		●			
UNITED ENERGY*					●
ZOMEWORKS			●	●	

*See Module Literature for Structure Specifications

C - on Custom Basis

Exhibit 9.3
BATTERIES

MANU-FACTURER \ FEATURE	Lead-Antimony (Lead-Acid)	Lead-Calcium (Lead-Acid)	Pure Lead (Lead-Acid)	Nickel-Cadmium	Sealed	Vented
C&D		●			●	●
CHLORIDE			●		●	
DELCO		●			●	
EXIDE			●			●
GNB	●	●			●	
GLOBE			●		●	
NIFE				●		●
SURRETTE	●					●
TIDELAND			●			●

Exhibit 9.4
REGULATORS/CONTROLLERS

FEATURE / MANUFACTURER	Characteristics			Nominal Voltage Input (Volts)					
	Shunt Regulation	Series Regulation	Maximum Power Tracking	6	12	24	36	48	120	240
ARCO SOLAR		●			●	●	●	●		
BOSS	●	●		●	●	●	●	●	●	
CHRONAR-TRISOLAR		●	●		●	●	●	●	●	
HELIOTROPE GENERAL	●	●			●	●				
SOLAREX		●			●	●	●	●	●	●
SOLAVOLT	●	●			●	●	●	●		
SOLEC	●				●	●				
SPECIALTY CONCEPTS	●	●		●	●	●	●	●	●	
TIDELAND						●				

MANUFACTURER \ FEATURE	Available Components						Inverter Characteristics								Inverter Power Output (kVA)			
	Inverter	Frequency Converter	Uninterruptable Power Supply	DC/DC Converter	Rectifier (AC/DC Converter)	AC Regulator	Line-Commutated	Self-Commutated	Stand-Alone Only	Maximum Power Tracking	Single-Phase	Three-Phase	Quasi-Sine Wave Output	Sine Wave Output	<1	1-15	15+-75	>75
ABACUS	●	●	●	●				●		●	●	●		●	●	●	●	
ACHEVAL	●						●				●	●	●			●	●	
AMERICAN POWER CONVERSION	●							●		●	●			●		●		
BOSS				●														
BEST	●		●						●		●		●	●	●	●		
GNB					●													
HEART INTERFACE	●								●		●		●		●	●		
HELIONETICS	●	●						●		●	●	●		●	●	●	●	●
NOVA ELECTRIC	●	●	●					●			●	●		●	●	●	●	
PHOTOELECTRIC	●						●				●			●		●		
POWERMARK	●	●	●			●			●				●	●	●	●		
TESLACO	●							●		●				●		●		
TRIPPLITE	●								●		●		●		●	●		
WINDWORKS	●						●			●	●	●	●			●	●	●

PUMPING SYSTEMS

ORGANIZATION \ FEATURE	Pump Manufacturer	System Supplier	Positive Displacement	Centrifugal	Submersible	Non-Submersible	DC Motor	AC Motor
ARCTIC-KOLD	●			●	●		●	
CHRONAR-TRISOLAR	●	●	●	●		●	●	
GRUNDFOS	●	●		●	●			●
JACUZZI	●	●		●	●		●	
SOLAVOLT		●		●	●		●	●
SOLEC		●		●	●	●	●	
SUNAMP	●	●	●	●	●	●	●	
SUNMILL		●	●			●	●	
WM. LAMB	●	●	●	●	●	●	●	

Exhibit 9.7
OTHER APPLICATIONS AND END-USE COMPONENTS

FEATURE / ORGANIZATION	Systems			Components		
	Desalination	Lighting	Ice Making	Lights	Refrigerators	Water Purifier
ARCO SOLAR				●		
ARCTIC-KOLD					●	
BOSS				●		
MARVAL					●	
MOBIL SOLAR	●	●				
NORCOLD					●	
NORTHSTAR			●			
POLAR PRODUCTS					●	
REC SPECIALTIES				●		●
SEA RECOVERY	●					
SOLEC INT'L		●				

Exhibit 9.8
MANUFACTURING EQUIPMENT

FEATURE / MANUFACTURER	Compatible Materials				
	Single-Crystal Silicon	Polycrystalline Silicon	Silicon Ribbon	Amorphous Silicon	Gallium Arsenide
.CHRONAR				●	
SPIRE	●	●	●	●	●

U.S. PHOTOVOLTAIC INDUSTRY MANUFACTURER'S LISTING

Abacus Controls, Inc.
P.O. Box 893
Somerville, New Jersey 08876
Phone: 201-526-6010
Telex: 888186

Acheval Wind Electronics Co.
361 Aiken Street
Lowell, Massachusetts 01854
Phone: 617-453-0874

American Power Conversion Corp.
89 Cambridge Street
Burlington, Massachusetts 01803-4115
Phone: 617-273-1570

ARCO Solar Inc.
P.O. Box 2105
Chatsworth, CA 91311
Phone: 818-700-7000
Telex: 674838

Arctic Kold
Division, Birken
Manufacturing Company
3 Old Windsor Road
Bloomfield, CT 06002
Phone: 203-242-2211
Telex: 710 4255435

Balance of Systems Specialists, Inc.
7745 E. Redfield Road
Scottsdale, Arizona 85260
Phone: 602-948-9809
Telex: 6835043

Best Power Technology, Inc.
P.O. Box 280
Necedah, Wisconsin 54646
Phone: 608-565-7200
or 1-800-356-5794
Telex: 701934

C&D Power Systems
(Allied Corp.)
3043 Walton Road
Plymouth Meeting, PA 19462
Phone: 215-828-9000
Telex: 681059 CD BAT UW

Chloride
P.O. Box 12936
Tallahassee, Florida 32308
Phone: 904-385-5686

Chronar Corporation
330 Bakers Basin Road
Trenton, New Jersey 08648
Phone: 609-587-8000
Telex: 843394

Chronar - TriSolar Corp.
(Subsidiary of Chronar)
10 De Angelo Drive
Bedford, MA 01730
Phone: 617-275-1200
Telex: 940536 BOSTLX

Delco Electronics
Division of General Motors
2401 Columbus Avenue
Anderson, Indiana 46011
Phone: 317-646-7821

Entech, Inc.
1015 Royal Lane
DFW Airport, Texas 75261
Phone: 214-456-0900

Exide, Inc.
101 Gibraltar Road
Horsham, Pennsylvania 19044
Phone: 215-674-9500
Telex: 476 1127 EXIDE HOSM

Globe Battery
5757 N. Green Bay Avenue
Milwaukee, Wisconsin 53209
Phone: 414-228-1200
Telex: 26650

GNB Batteries Inc.
P.O. Box 4[illegible]40
St. Paul, Minnesota 55164
Phone: 612-681-5000
Telex: 297 036

Grundfos
2555 Clovis Avenue
Clovis, California 93612
Phone: 209-299-9741

Heart Interface, Corp.
1626 S. 341st. Place
Federal Way, Washington 98003
Phone: 206-838-4295
or 1-800-732-3201
Telex: 152656 ABSEA

Helionetics
17312 Easton Street
Irvine, California 92714
Phone: 714-261-8313
TWX: 910-595-2829

Heliotrope General
3733 Kenora Drive
Spring Valley, California 92077
Phone: 619-460-3930

Intersol Power Corporation
11901 W. Cedar Avenue
Lakewood, CO 80228
Phone: 303-989-8710
Telex: 45-4592 GBCINCLWOD

Jacuzzi, Inc.
11151 New Benton Highway
Little Rock, Arkansas 72209
Phone: 501-455-1234
Telex 536446

Wm. Lamb Co.
10615 Chandler Boulevard
North Hollywood, CA 91601
Phone: 213-980-6248
Telex: 295528 LAMB UR

Marvel
P.O. Box 9`7
Richmond, Indiana 47374
Phone: 317-962-2521
Telex: 810-459-1628

Mobil Solar Energy Corp.
16 Hickory Drive
Waltham, MA 02254
Phone: 617-890-1180
Telex: 951272 MOBIL SOLAR WHA

NIFE Incorporated
George Washington Highway
P.O. Box 100
Lincoln, Rhode Island 02865
Phone: 401-333-1179

Norcold
1501 Michigan Street
P.O. Box 180
Sidney, Ohio 45365
Phone: 513-492-1111

North Star Ice Equipment
Corporation
P.O. Box 70668
Seattle, Washington 98107
Phone: 206-784-4500

Nova Electric Manufacturing
Co., Inc.
263 Hillside Avenue
Nutley, New Jersey 07110
Phone: 201-661-3434

Photoelectric Inc.
7038 Convoy Court
San Diego, California 92111
Phone: 619-292-7811

Polar Products
2908 Oregon Court, Bldg. I-11
Torrance, CA 90503
Phone: 213-320-3514
Telex: 4940451 POIAR LSA

REC Specialties, Inc.
530 Constitution Avenue
Camarillo, California 93010
Phone: 805-987-5021
Telex: 662203 RECSPECCAMA

Robbins Engineering, Inc.
3461 N. Jamacia Blvd.
Lake Havasu, Arizona 86403
Phone: 602-453-1738

Sea Recovery
P.O. Box 349
San Pedro, California 90733-0349
Phone: 213-519-7801

Solarex Corporation
1335 Piccard Drive
Rockville, MD 20850
Phone: 301-948-0202
TWX: 7108289709
Telex: 248-359

U.S. PHOTOVOLTAIC INDUSTRY MANUFACTURER'S LISTING
(Continued)

Solar Electric Specialties
P.O. Box 537
Willits, California 95490
Phone: 707-459-9496

Solavolt International
3646 E. Atlanta Avenue
Phoenix, AZ 85040
Phone: 602-231-6408
Telex: 249901 SOLUR

Solec International, Inc.
12533 Chadron Avenue
Hawthorne, CA 90250
Phone: 213-970-0065
TWX: 9103256215 SOLECHWTH

Solenergy Corp.
171 Merrimac Street
Woburn, MA 01801
Phone: 617-938-0563
Telex: 95-1677

Spire Corp.
Patriots Park
Bedford, MA 01730
Phone: 617-275-6000
Telex: 951072

Sunmill
GPL Industries
P.O. Box 306
La Canada, California 91011
Phone: 213-956-6603

Sun Amp Systems Inc.
7702 East Gray Road
Scottsdale, Arizona 85260
Phone: 602-951-0699
Telex: 757326

Surrette Storage Battery
Co., Inc.
P.O. Box 3027
Salem, MA 01970

Teslaco
490 South Rosemead Blvd.
Suite 6
Pasadena, CA 91107
Phone: 213-795-1699

Tideland Signal Corporation
4310 Director's Row
P.O. Box 52430
Houston, Texas 77052
Phone: 713-681-6101
Telex: 762 327 or 762 356

Tripp Lite
500 No. Orleans
Chicago, Illinois 60610
Phone: 312-329-1777

United Energy Corporation
420 Lincoln Centre Drive
Foster City, California 94404
Phone: 415-570-5011
Telex: 172624

Windworks, Inc.
Box 44A, Route 3
Mukwonago, Wisconsin 53149
Phone: 414-363-4088

Zomeworks
P.O. Box 25805
Albuquerque, New Mexico 87125
Phone: 505-242-5354

APPENDIX A: STAND-ALONE SYSTEM SIZING

(EXCERPT FROM FUNDAMENTALS AND APPLICATIONS OF PHOTOVOLTAICS COURSE MANUAL, FLORIDA SOLAR ENERGY CENTER, OCTOBER 1984)

STAND-ALONE PHOTOVOLTAIC SYSTEM DESIGN

The intent of this section is to develop the capability to design and size a stand-alone photovoltaic system utilizing battery storage.

Stand-alone or nonutility connected photovoltaic systems usually consist of a photovoltaic array, a battery bank and related balance-of-system (BOS) components designed to meet the power requirements of a given load.

The design of stand-alone systems is readily accomplished by systematically considering the load to be powered, the type and size of batteries required, photovoltaic array size, additional electrical and structural components, and costs.

Load Evaluation

Evaluation of the load (i.e., the energy and power requirements of the equipment to be served by the photovoltaic system) is the first step in the design process.

Equipment to be powered by PV should be as energy efficient as possible. In lighting applications, for example, fluorescent or sodium vapor lights should be selected over less efficient incandescent. Using dc equipment, thereby eliminating the inverter, results in more efficient utilization of energy.

The end result of the load evaluation should be a load profile over 24 hours for a typical day of each month. This will be required in order to size both the battery bank and the PV array.

In summary, load evaluation is accomplished as follows:

1. Determine equipment power and energy requirements (watts and watt-hours)
2. Specify equipment electrical characteristics (voltages, ac or dc)
3. Evaluate/improve equipment efficiencies
4. Determine load profile.

Battery Storage Sizing

The battery storage system is sized independent of the photovoltaic array. The equipment load is converted from watt-hours to ampere-hours at the system dc voltage in order to size the battery bank.

The battery system is sized for the worst case and should be assumed to carry the entire load for a fixed number of days. The number of days of storage to use is a subjective judgment arrived at by considering "actual conditions" and how much they may vary from "average conditions" at the location. Generally this is a site specific variable and typical storage periods range from 3 to 10 days (although some storage periods are as high as 30 days).

Battery capacity, in units of amp-hours, is temperature dependent and manufacturers' ratings should be corrected for temperature in order to serve the load as intended.

Once the required number of amp-hours has been determined, batteries or cells can be selected and the battery bank designed using manufacturers' information and desired depth of discharge. The total number of batteries needed is the product of the number of series batteries (to build up the voltage) and the number of parallel batteries (to build up the capacity).

In summary, battery storage sizing is accomplished as follows:

1. Determine load amp-hr requirement
2. Correct amp-hr for temperature
3. Determine the number of batteries (cells) required.

Photovoltaic Array Sizing

The size of the photovoltaic array is determined by considering the available solar insolation, the tilt of the array and the characteristics of the photovoltaic modules being considered.

The available insolation striking a photovoltaic array varies throughout the year and is a function of the tilt of the array. If the load is constant, the designer must consider the time of the year with the minimum amount of sunlight (typically December or January). Knowing the insolation available (at tilt) and the power output required, the array can be sized using module specifications supplied by manufacturers.

Although it is energy (watt-hours) that is consumed by the loads, PV modules are current-producing devices. Voltages are established by the load or battery bank. Consequently, in systems where the voltage is permitted to vary, the designer should consider current (rather than voltage) in sizing the array. Both "peak" power and current (at peak power) are available from manufacturer specifications.

Using module peak current and daily insolation (in peak sun hours), the average amp-hours of current delivered by a photovoltaic module for one day of the "worst" month can be determined. The amp-hours required by the load determined previously are adjusted (upwards) because batteries are less than 100 percent efficient. (Usually 80 percent battery efficiency is assumed.) Then, knowing the requirements of the load and the capability of a single module at the location during the worst month, the array can be sized.

In summary, photovoltaic array sizing is accomplished as follows:

1. Determine available sunlight (daily average for worst month)
2. Select array tilt, and candidate modules
3. Size array (compute daily amp-hour output)
4. Evaluate array/battery combination.

Balance-of-System (BOS) Components

Balance-of-system design involves the design and selection of additional components such as wiring voltage regulators, power conditioners, disconnects, blocking and bypass diodes, mounting structure, etc.

The voltage regulator, or charge controller, is an important device when using batteries. The regulator controls the current and voltage input to the batteries and protects them from damage. Regulators should be used unless the PV array voltage can be closely matched to the battery voltage.

The power conditioner (i.e., inverter or a dc-to-dc converter) provides the interface between the PV system and the loads. It should be electrically matched to the array output and compatible with all loads.

Alarms and cut-offs (disconnects), are often used in photovoltaic systems to warn of low voltage across the battery bank, and to disconnect loads to protect it from damage.

When using batteries it is absolutely essential that a fused disconnect be provided at the battery bank for protection.

Diodes are electrical devices which are used to both block current flow from the battery bank to the photovoltaic array (at night) and to protect the modules. Bypass diodes are used to allow current to bypass inoperative modules (in a series string) of a large array. Other components, such as varistors (for surge protection), disconnects, and fuses (for overcurrent protection) should be used throughout the system.

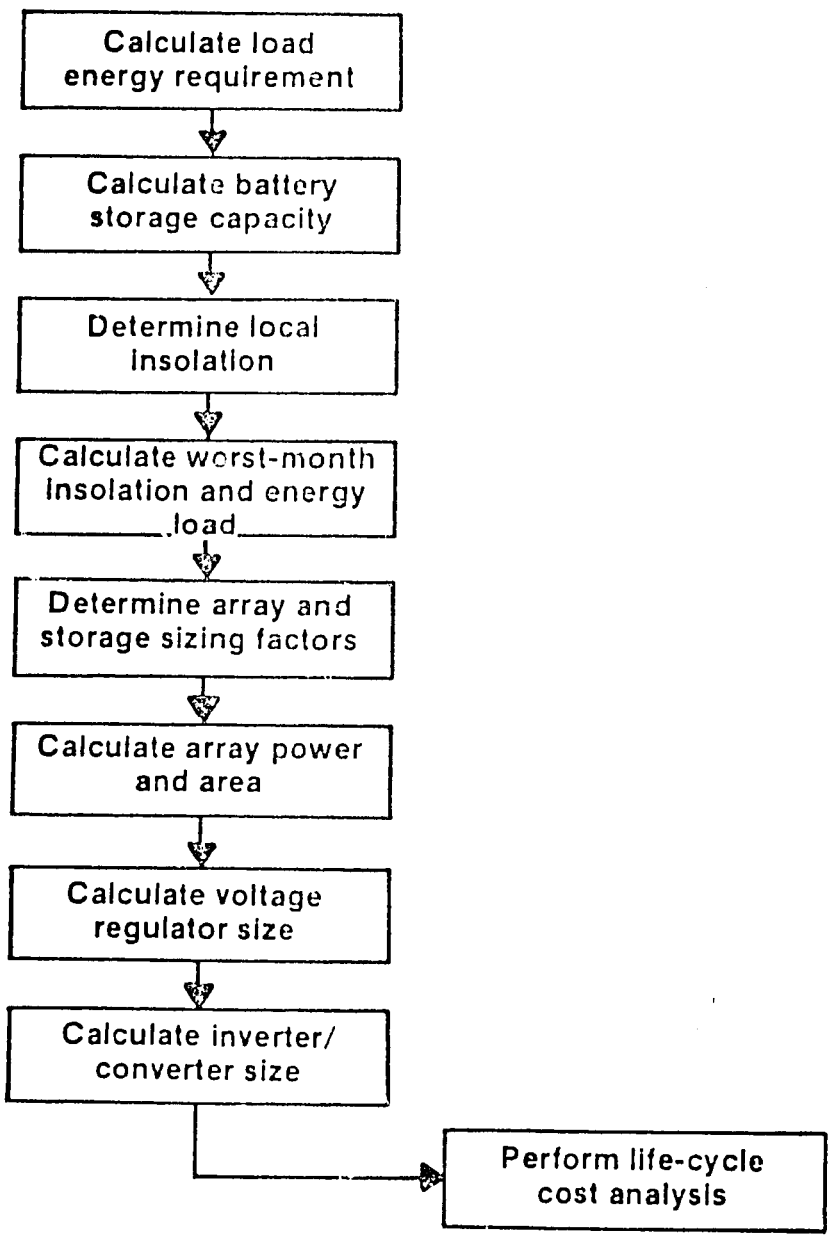
In summary, balance of system design is accomplished by considering the requirements for:

1. Voltage regulators
2. Power conditioners
3. Alarms, cut-offs, diodes, etc.

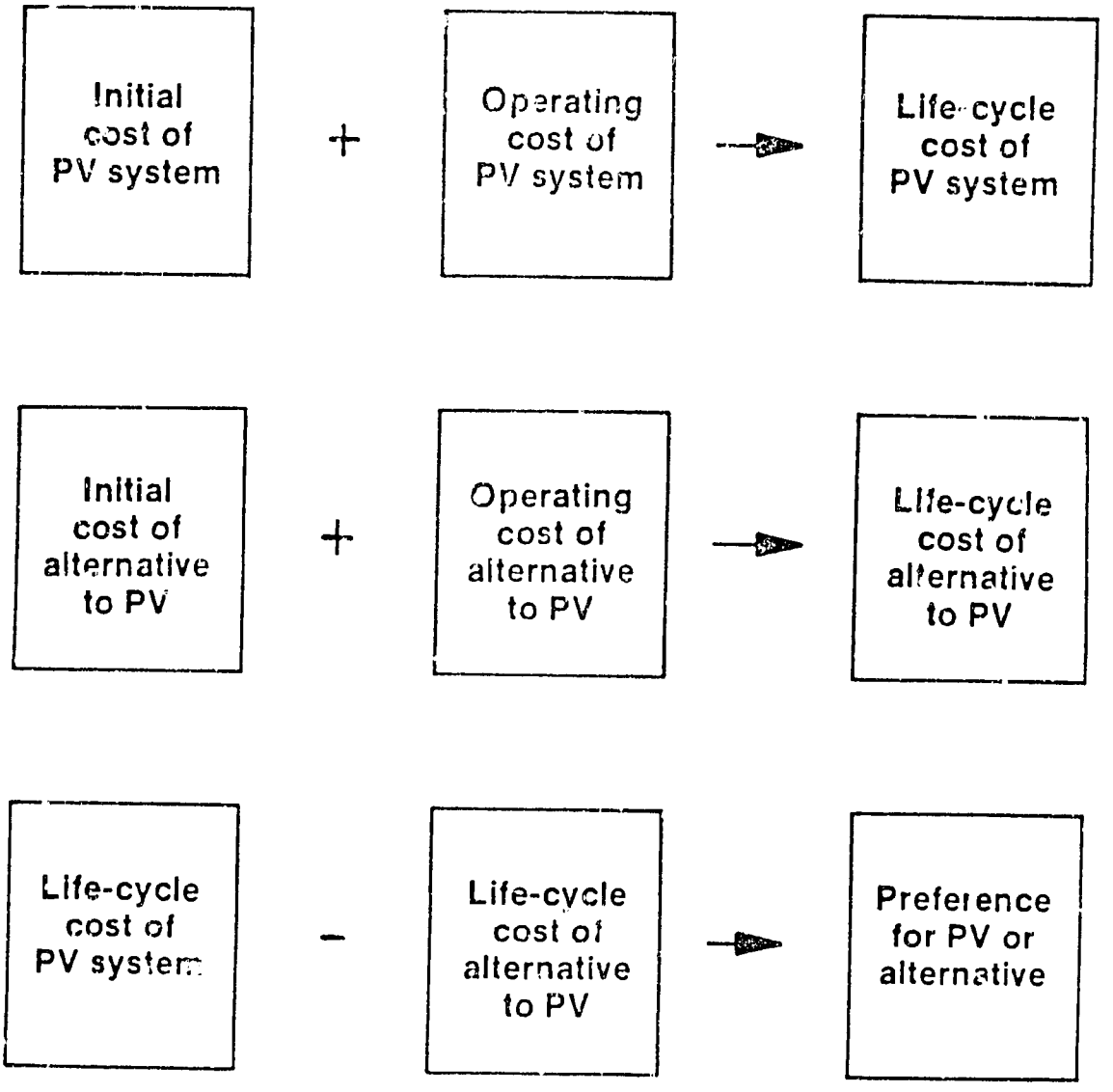
Cost Analysis

Economic evaluation of the PV system, including comparison with other energy-producing alternatives, is an important part of the design process. If a comprehensive economic analysis is desired, life cycle costs can be computed.

Sizing a remote, stand-alone PV system



Determining PV system cost effectiveness



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SIZING OF STAND-ALONE PHOTOVOLTAIC SYSTEMS

Worksheet

APPLICATION _____

LOCATION _____ LATITUDE _____

A. LOADS

A1 Inverter efficiency (decimal) _____

A2 Battery bus voltage _____ volts

Component	(A3) Rated Wattage	(A4) Adjustment Factor 1.0 for dc (A1) for ac	(A5) Adjusted Wattage (A3/A4)	(A6) Hours Per Day Used	Energy Per Day (A5xA6)

A7 Total energy demand per day _____ watt-hours

A8 Total amp-hour demand per day (A7/A2) _____ amp-hours

B. BATTERY SIZING

DESIGN MONTH _____ DESIGN TEMPERATURE _____

B1 Days of storage desired/required _____

B2 Desired depth-of-discharge limit (decimal) _____

B3 Required usable capacity (A8xB1) _____

B4 Amp-hour capacity of selected battery*/cell _____

B5 Useful battery capacity (B4xB2) _____

B6 Number of batteries in parallel (B3/B5) _____

B7 Number of batteries in series (A2/battery voltage) _____

B8 Total number of batteries (B6xB7) _____

* Use amp-hour capacity at a rate of discharge corresponding to the total storage period, B1.

C. PV ARRAY SIZING

OPTIMUM TILT _____ DESIGN MONTH _____

C1 Total energy demand per day (A7) _____ watt-hours

C2 Battery round-trip efficiency (0.80-0.85) _____

C3 Required array output per day (C1/C2) _____ watt-hours

C4 Selected PV module max power voltage x 0.9 _____ volts

C5 Selected PV module power output at 1000 watts/m^2 and NOCT _____ watts

C6 Peak sun hours at optimum tilt* _____ hours

C7 Energy output per module per day (C5xC6) _____ watt-hours

C8 Operating temperature derating factor, DF (0.80 for hot climates and critical applications; 0.95 for moderate climates and non-critical applications) [DF x C7] _____ watt-hours

* $\frac{kWh}{m^2\text{-day}} = \frac{1\ kW}{m^2}$

C9	Number of modules required to meet energy requirements (C3/C8)	_____	modules
C10	Number of modules required per string (A2/C4) rounded to next higher integer	_____	modules
C11	Number of strings in parallel (C9/C10) rounded to next higher integer	_____	strings
C12	Number of modules to be purchased (C10xC11)	_____	modules

D. BOS REQUIREMENTS

1. A voltage regulator is recommended unless array output current (at 1000 w/m^2 conditions), less any continuous load current, is less than 5% of the selected battery bank capacity (at the 8-hour discharge rate).

2. Wiring should be adequate to ensure that losses are less than 1% of the energy produced.

3. In low voltage (i.e., less than 50 volts) systems, germanium or Schottky blocking diodes are preferred over silicon diodes.

4. Fuses, switches, and other components should be selected to satisfy both voltage and current requirements.

5. All battery series branches should contain fuses.

6. Fused disconnects are strongly recommended to isolate the battery bank from the rest of the system.

APPENDIX B: CALCULATION OF SOLAR INSOLATION

(EXCERPT FROM PHOTOVOLTAIC STAND-ALONE SYSTEMS: PRELIMINARY ENGINEERING DESIGN HANDBOOK, NASA LEWIS RESEARCH CENTER, AUGUST 1981)

INSOLATION

11.1 INTRODUCTION

The purpose of this section is to present the calculational tools for determination of the insolation on a tilted surface. The quantity that is required for system sizing is the average daily insolation for a given month on the tilted array surface. Four numbers are needed to perform the calculation of average daily insolation. These are: the clearness index or $\overline{K}_H$; the latitude angle of the site; the tilt angle of the array; and the reflectance of the ground in front of the array. The clearness index is the ratio of the average monthly horizontal insolation to the extraterrestrial horizontal insolation. $\overline{K}_H$ varies from month to month with the lowest values usually occurring in the winter.

In Appendix A, monthly values of $\overline{K}_H$ are tabulated for a number of cities in the United States and throughout the world. The locations listed are grouped according to country. If there is no listing for a proposed site, then the closest listing should be used as long as the general weather conditions are similar. (Note that the values of $\overline{K}_H$ in Appendix A must be divided by 1000 before they are input to the insolation calculation programs described in the following sections).

The equations that form the basis for the insolation calculation programs are presented in Exhibit 11.1-1. A sample calculation is given in Exhibit 11.1-2. A table listing the reflectances of various types of ground covers is presented in Exhibit 11.1-3.

INSOLATION COMPUTATION FOR A SOUTH-FACING ARRAY

A. Select Latitude (L), Day of Year (Day) Ground Reflectance (ρ) and Array Tilt (ϕ) (0° for Horizontal)

B. Obtain the monthly average clearness index, $\bar{K}_H$, from Appendix A.

C. Compute the Solar Hour Angle at Sunset

$$\cos\theta_{SS} = -\tan L \tan\delta$$

L = Latitude

$$\sin\delta = \sin(\text{declination angle}) = \sin(23.45)\sin\left(\frac{284 + \text{day}}{365} \times 360^{\circ}\right)$$

D. Compute the Solar Hour Angle at Sunset for the Tilted Surface

$$\cos\theta_{TS} = -\tan(L - \phi)\tan\delta$$

E. Determine which Sunset Occurs First

$$\theta = \min(\theta_{TS}, \theta_{SS})$$

F. Compute the Extraterrestrial Irradiance on a Plate Held Normal to the Sun's Rays

$$S_O = 1.356\left(1 + 0.0167\cos\left(\frac{\text{Day}}{365} * 360\right)\right)^2 \text{ kW/m}^2$$

G. Compute the Extraterrestrial Insolation on a Horizontal Surface

$$S_{OH} = S_O \frac{24}{\pi}\left(\cos L \cos\delta \sin\theta_{SS} + \frac{\pi\theta_{SS}}{180}\sin L \sin\delta\right) \frac{\text{kWh}}{\text{m}^2\text{-Day}}$$

H. Compute the Horizontal Insolation

$$S_H = \bar{K}_H * S_{OH}$$

I. Compute the Diffuse-Insolation Factor (Ref. 11-1) ($K_D = S_D/S_H$) for the monthly average insolation:

$$K_D = \left\{0.230 + \theta_{SS}/165 - \left[0.095 + \theta_{SS}/220\right] * \cos\left[114.6 * (\bar{K}_H - 0.9)\right]\right\}$$

J. Compute the daily-direct radiation factor

$$R_D = \frac{\cos(L - \phi)}{\cos L} * \left\{\frac{\sin\theta - \frac{\pi}{180}\theta\cos\theta_{TS}}{\sin\theta_{SS} - \frac{\pi}{180}\theta_{SS}\cos\theta_{SS}}\right\}$$

K. Compute the average daily insolation on the tilted surface

$$L_T = S_H\left\{(1 - K_D)R_D + \tfrac{1}{2}(1 + \cos\phi)K_D + \tfrac{1}{2}(1 - \cos\phi)\rho\right\}$$

where ρ = ground reflectance (See exhibit 11.1-3)

INSOLATION COMPUTATION EXAMPLE: WASHINGTON, D.C.

A. Let: $L = 38.95^{\circ}$, Day = 15 (Jan), $\phi = 55^{\circ}$

B. Find from Appendix A: $\overline{K}_H = 0.417$

C. Compute: $\sin\delta = \sin(23.45) * \sin\left(\frac{284+15}{365} * 360\right) = -0.36094$

$\delta = -21.16^{\circ}$

$\cos\theta_{SS} = -(\tan 38.95)(\tan(-21.16)) = 0.31286$

$\theta_{SS} = 71.77^{\circ}$

D. Compute: $\cos\theta_{TS} = -\tan(38.95 - 55)\tan(-21.16) = -0.11134$

$\theta_{TS} = 96.39^{\circ}$

E. Set: $\theta = \min(71.77, 96.39) = 71.77^{\circ}$

F. Compute: $S_O = 1.356 * \left(1 + 0.0167 * \cos\left(\frac{15}{365} * 360\right)\right)^2 = 1.400\ kW/m^2$

G. Compute: $S_{OH} = 1.400 * \frac{24}{\pi} * \left[\cos(38.95)\cos(-21.16)\sin(71.77) + \left(\frac{\pi * 71.77}{180}\right)\sin(38.95)\sin(-21.16)\right]$

so $S_{OH} = 4.328\ kWh/m^2 - day$

H. Compute: $S = 0.417 * 4.328 = 1.805\ kWh/m^2 - day$

I. Compute: $K_D = \left\{0.230 + 71.77/165 - \left[0.095 + 71.77/220\right] * \cos\left[114.6 * (0.417 - 0.9)\right]\right\} = 0.426$

J. Compute: $R_D = \frac{\cos(38.45 - 55)}{\cos(38.95)} *$

$$\frac{\sin(71.77) - (\pi * 71.77/180) * \cos(96.39)}{\sin(71.77) - (\pi * 71.77/180) * \cos(71.77)}$$

$= 2.416$

K. For $\rho = 0$:

$$I_T = 1.805 * \left\{(1 - 0.426) * 2.413 + \tfrac{1}{2}(1 + \cos 55) * 0.426 + \tfrac{1}{2}(1 - \cos 55) * 0\right\}$$

so $I_T = 3.106\ kWh/M^2 - day$

GROUND REFLECTANCES FOR VARIOUS SURFACES

Ocean	0.05
Bituminous concrete	0.07
Wheat field	0.07
Dark soil	0.08
Green field	0.12 to 0.25
Grass, dry	0.20
Crushed rock surface	0.20
Concrete, old	0.24
Concrete, light colored	0.30
Paved asphalt	0.18
Concrete, new	0.32
Snow, fresh	0.87
Snow, old	0.50

References: (11-2, 11-3)

APPENDIX C: SOLAR RESOURCE DATA FOR EGYPT

(EXCERPT FROM PHOTOVOLTAIC POTENTIAL IN EGYPT ECONOMIC AND MARKET DATA EL-KHESHIN, HABIB, EL-FOULY, FEBRUARY 1985)

TABLE (1)

SUNSHINE DURATION

MONTHLY MEAN VALUES

1972-1976.

Ser.	STATION	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	ANNUAL
1	Sidi-Barrani	6.9	7.8	7.9	9.0	10.8	12.2	12.1	12.1	10.6	9.2	8.4	6.8	9.5
2	Marsa-Matruh	6.9	7.7	7.9	9.0	10.6	11.7	12.1	11.9	10.5	8.9	8.0	6.4	9.3
3	Alexandria	6.4	7.8	8.2	9.1	10.6	11.8	12.0	11.3	10.3	9.6	7.3	6.2	9.2
4	Damietta	7.2	8.3	8.4	9.7	11.4	12.5	12.3	11.9	10.7	9.7	8.1	6.6	9.7
5	Port-Said	7.0	7.8	8.4	9.1	11.2	12.1	12.1	11.6	10.5	9.7	8.0	6.8	9.5
6	Tahrir	7.4	7.9	8.8	9.8	11.0	12.2	12.2	11.8	10.6	9.6	7.8	7.3	9.7
7	Tanta	7.2	8.1	8.7	9.9	11.0	11.5	12.0	11.4	10.7	9.5	8.3	7.2	9.7
8	Bahteem	7.0	8.3	8.6	9.6	10.8	11.9	11.8	11.2	10.4	9.8	8.2	7.7	9.6
9	Almaza	7.6	7.8	8.6	8.9	11.2	11.9	11.4	11.4	9.5	9.4	8.2	7.6	9.5
10	Giza	7.8	8.2	8.8	9.6	11.2	12.2	12.0	11.5	10.5	9.8	8.5	7.7	9.8
11	Siwa	8.3	9.3	9.1	9.3	11.1	12.3	12.6	12.1	10.7	9.7	8.7	8.0	10.1
12	Kharga	9.1	9.7	10.2	10.4	11.5	12.2	12.4	12.0	11.0	10.6	9.9	9.5	10.7
13	Minya	8.7	9.4	9.5	10.1	11.4	12.5	12.6	12.0	10.8	10.2	9.2	8.3	10.4
14	Burghada	9.4	9.7	9.7	10.1	11.5	12.8	12.7	12.1	11.2	10.4	9.7	9.1	10.7
15	Aswan (1975-1977)	9.4	9.2	9.4	10.6	11.8	12.4	12.3	11.6	10.9	10.5	10.0	9.6	10.6
16	El Aiwant 80-82	7.7	8.8	9.8	10.3	10.2	10.0	9.9	9.6	9.6	9.2	7.9	7.1	9.2

Table (2)

Hourly average of the Solar Irradiation (KW/m^2)

On a clear day in Helwan (Cairo)

Time	Jan.	Feb.	Mars	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
6	-	-	-	0.22	0.37	0.39	0.31	0.25	0.20	-	-	-
7	-	0.36	0.56	0.58	0.61	0.63	0.61	0.57	0.57	0.53	0.45	0.16
8	0 7	0.65	0.82	0.77	0.75	0.76	0.75	0.75	0.76	0.75	0.70	0.65
9	0.86	0.82	0.95	0.87	0.84	0.83	0.81	0.84	0.85	0.86	0.84	0.82
10	0.94	0.93	0.91	0.91	0.88	0.87	0.87	0.85	0.88	0.89	0.90	0.91
11	0.97	0.97	1.04	0.93	0.91	0.90	0.87	0.89	0.91	0.91	0.93	0.93
12 (noon)	0.99	0.99	1.05	0.93	0.91	0.91	0.88	0.90	0.91	0.92	0.93	0.95

TABLE (3)

AVERAGE DAILY ARRAY INSOLATION (KWH/SQ.M./DAY)
CLEARNESS NUMBER (KT),MEAN MONTHYLY TEMPERATURE (TM,DEG C),
AND MONTHLY AVERAGE WIND SPEED (WS,M/S)

Cairo
Latitude : 30.12°

SURFACE TILT (DEGREES UP FROM HORIZONTAL)

Month	HOR	10	20	30	40	50	60	70	80	VERT	KT	TM °C	WS M/sec
Jan.	3.28	3.71	4.04	4.30	4.45	4.50	4.44	4.30	4.04	3.80	.574	13.8	3.5
Feb.	4.30	4.75	5.08	5.30	5.40	5.37	5.22	4.95	4.57	4.19	.600	15.0	3.6
Mar.	5.34	5.66	5.87	5.93	5.87	5.68	5.37	4.93	4.40	3.86	.610	17.4	3.9
Apr.	6.45	6.59	6.59	6.44	6.16	5.75	5.23	4.60	3.88	3.19	.640	21.1	3.9
May	7.28	7.28	7.06	6.71	6.24	5.64	4.93	4.16	3.36	2.63	.662	24.7	3.6
Jun	7.79	7.65	7.35	6.87	6.31	5.61	4.80	3.96	3.11	2.42	.690	27.3	3.2
Jul	7.55	7.47	7.22	6.80	6.29	5.65	4.91	4.12	3.30	2.60	.680	27.9	2.9
Aug	7.02	7.09	6.99	6.75	6.39	5.88	5.26	4.54	3.76	3.05	.673	27.9	2.9
Sep	6.11	6.38	6.53	6.51	6.36	6.06	5.64	5.10	4.44	3.79	.670	26.1	3.1
Oct.	5.01	5.48	5.64	6.04	6.11	6.04	5.84	5.48	5.00	4.49	.649	23.4	3.3
Nov	3.68	4.17	4.56	4.84	5.02	5.07	5.00	4.82	4.51	4.19	.566	19.3	3.0
Dec	3.12	3.57	3.94	4.22	4.40	4.48	4.46	4.33	4.10	3.87	.575	15.2	3.3

TABLE (3) (CONTINUED)

AVERAGE DAILY ARRAY INSOLATION (KWH/SQ.M./DAY)
CLEARNESS NUMBER (KT) MEAN MONTHLY TEMPERATURE (TM, DEG C),
AND MONTHLY AVERAGE WIND SPEED (WS,M/S)

HELWAN
Latitude: 29.5°

SURFACE TILT (DEGREES UP FROM HORIZONTAL)

Month	FOR	10	20	30	40	50	60	70	80	VERT	KT	TM °C	WS m/sec
Jan	3.41	3.86	4.20	4.47	4.63	4.68	4.62	4.47	4.20	3.95	0.57	13.1	2.8
Feb	4.37	4.82	5.17	5.39	5.48	5.46	5.30	5.03	4.64	4.26	0.60	14.7	3.4
Mar	5.75	6.10	6.32	6.39	6.32	6.11	5.78	5.31	4.74	4.15	0.66	17.3	4.3
Apr	6.69	6.84	6.84	6.68	6.39	5.96	5.42	4.77	4.03	3.31	0.66	21.2	4.7
May	7.44	7.41	7.21	6.85	6.38	5.77	5.04	4.25	3.43	2.69	0.68	24.3	4.7
Jun	7.91	7.77	7.46	6.98	6.41	5.69	4.87	4.03	3.16	2.46	0.70	27.4	4.7
Jul	7.86	7.77	7.51	7.09	6.55	5.88	5.11	4.29	3.43	2.71	0.71	28.1	5.1
Aug	7.19	7.26	7.16	6.92	6.54	6.02	5.39	4.65	3.85	3.12	0.69	27.7	3.9
Sep	6.25	6.53	6.68	6.66	6.50	6.20	5.77	5.21	4.54	3.87	0.67	26.2	4.2
Oct	4.81	5.27	5.60	5.80	5.87	5.80	5.60	5.27	4.80	4.31	0.61	23.5	4.4
Nov	3.71	4.20	4.60	4.88	4.06	5.11	5.05	4.86	4.55	4.23	0.55	19.1	3.9
Dec	3.12	3.57	3.94	4.20	4.40	4.48	4.46	4.33	4.10	3.86	0.56	14.5	3.1

TABLE (3) (CONTINUED)

AVERAGE DAILY ARRAY INSOLATION (KWH/SQ.M./DAY)
CLEARNESS NUMBER (KT), MEAN MONTHLY TEMPERATURE (TM, DEG, C),
AND MONTHLY AVERAGE WIND SPEED (WS,M/S).

Mersa Motrah
Latitude : 31.20

SURFACE TILT (DEGREES UP FROM HORIZONTAL)

Month	HOR	10	20	30	40	50	60	70	80	VERT	KT	TM °C	WS m/sec
Jan	3.20	3.73	4.18	4.52	4.76	4.87	4.87	4.74	4.49	4.17	0.574	12.8	6.1
Feb	4.26	4.79	5.20	5.49	5.65	5.66	5.55	5.29	4.91	4.45	0.634	13.0	6.1
Mar	5.87	6.00	6.02	5.91	5.67	5.30	4.81	4.23	3.55	2.86	0.685	15.1	6.3
Apr	6.72	6.71	6.54	6.23	5.80	5.24	4.59	3.84	3.10	2.36	0.672	17.4	5.7
May	7.82	7.81	7.60	7.25	6.74	6.10	5.34	4.47	3.60	2.75	0.711	20.1	4.9
Jun	8.40	8.27	7.95	7.45	6.82	6.06	5.17	4.25	3.29	2.45	0.740	23.3	5.1
Jul	8.31	8.32	7.95	7.50	6.92	6.19	5.34	4.43	3.49	2.62	0.746	24.9	5.2
Aug	7.53	7.63	7.57	7.32	6.92	7.38	5.70	4.89	4.00	3.13	0.722	25.5	4.7
Sep	6.51	6.86	7.04	7.06	6.92	6.63	6.18	5.58	4.88	4.10	0.712	24.3	4.4
Oct	4.85	5.34	5.72	5.96	6.06	6.01	5.82	5.48	5.02	4.48	0.641	21.6	4.3
Nov	3.54	4.09	4.54	4.89	5.10	5.20	5.16	5.00	4.72	4.34	0.576	18.1	4.8
Dec	2.90	3.44	3.89	4.24	4.50	4.63	4.65	4.58	4.34	4.08	0.556	14.4	5.9

TABLE (3) (CONTINUED)

AVERAGE DAILY ARRAY INSOLATION (KWH/SQ.M./DAY),
CLEARNESS NUMBER (KT), MEAN MONTHLY TEMPERATURE (TM, DEG C),
AND MONTHLY AVERAGE WIND SPEED (WS, M/S)

Kharga

Latitude: 25.48°C

Month	SURFACE TILT (DEGREES UP FROM HORIZONTAL)										KT	TM	WS
	HOR	10	20	30	40	50	60	70	80	VERT		°C	m/sec
Jan	4.56	5.15	5.62	5.97	6.18	6.24	6.16	5.93	5.56	5.15	0.69	13.9	3.1
Feb	5.63	6.18	6.60	6.86	6.95	6.91	6.68	6.31	5.80	5.23	0.73	16.2	3.5
Mar	6.59	6.97	7.19	7.23	7.13	6.87	6.44	5.88	5.20	4.49	0.72	20.2	4.2
Apr	7.44	7.57	7.53	7.33	6.97	6.46	5.82	5.07	4.23	3.41	0.72	25.3	4.5
May	8.09	8.01	7.76	7.35	6.78	6.10	5.27	4.40	3.49	2.70	0.74	29.2	4.8
Jun	8.29	8.10	7.72	7.19	6.55	5.75	4.87	3.96	3.05	2.34	0.74	32.2	5.5
Jul	8.19	8.04	7.71	7.22	6.59	5.83	4.94	4.05	3.11	2.34	0.74	31.9	4.3
Aug	7.77	7.81	7.68	7.37	6.92	6.31	5.56	4.72	3.82	2.95	0.74	31.7	4.0
Sep	7.08	7.37	7.49	7.45	7.25	6.87	6.35	5.68	4.91	4.09	0.75	29.4	4.7
Oct	6.03	6.55	6.92	7.14	7.18	7.06	6.77	6.32	5.73	5.08	0.73	27.1	4.5
Nov	5.07	5.69	6.19	6.19	6.75	6.80	6.67	6.39	5.96	5.47	0.70	20.5	4.0
Dec	4.44	5.07	5.57	5.95	6.20	6.29	6.24	6.02	5.69	5.29	0.72	15.5	3.3

TABLE (3) (CONTINUED)

AVERAGE DAILY ARRAY INSOLATION (KWH/SQ.M./DAY)

CLEARNESS NUMBER (KT), MEAN MONTHLY TEMPERATURE (TM, DEG C),

AND MONTHLY AVERAGE WIND SPEED (WS,M/S)

Aswan
Latitude: 24.12°C

ASWAN
24.12 LATITUDE

SURFACE TILT (DEGREES UP FROM HORIZONTAL

Month	HOR	10	20	30	40	50	60	70	80	VERT	KT	TM °C	WS m/sec
Jan	4.93	5.48	5.90	6.19	6.35	6.33	6.19	5.89	5.45	4.99	0.73	15.5	4.1
Feb	5.96	6.44	6.79	6.96	6.99	6.85	6.56	6.12	5.54	4.94	0.76	17.8	4.3
Mar	7.15	7.44	7.58	7.55	7.35	6.98	6.47	5.83	5.07	4.32	0.78	22.0	4.7
Apr	7.78	7.83	7.70	7.42	6.98	6.40	5.67	4.86	3.97	3.15	0.76	26.9	4.8
May	8.44	8.28	7.93	7.43	6.77	5.97	5.08	4.17	3.23	2.50	0.77	30.5	4.5
Jun	8.56	8.28	7.83	7.22	6.48	5.61	4.71	3.74	2.86	2.40	0.773	33.4	4.6
Jul	8.38	8.15	7.75	7.20	6.50	5.67	4.77	3.84	2.94	2.34	0.76	33.5	4.2
Aug	8.03	7.99	7.76	7.39	6.84	6.15	5.35	4.46	3.53	2.70	0.76	33.3	4.2
Sep	7.04	7.25	7.28	7.17	6.87	6.44	5.86	5.15	4.35	3.54	0.74	31.1	4.4
Oct	6.00	6.42	6.68	6.79	6.75	6.54	6.20	5.70	5.09	4.45	0.71	27.9	4.2
Nov	5.37	5.92	6.33	6.61	6.73	6.68	6.49	6.14	5.65	5.13	0.723	21.8	4.2
Dec	4.78	5.36	5.82	6.13	6.32	6.35	6.22	5.96	5.54	5.10	0.74	17.0	4.0

TABLE (4)

ANNUAL FREQUENCY OF WEATHER PHENOMENA IN A SELECTION OF MET. STATIONS IN EGYPT.

STATIONS	FREQUENCY OF DAYS OF						
	Fog (1)	Mist (2)	Total 1+2	Dust or Sand rising (3)	Dust or Sand-storm (4)	Total 3+4 (5)	Total annual (6)
Marsa-Matruh	7.4	4.5	11.9	12.7	7.2	19.9	31.8
Alexandria	20.1	21.5	41.6	7.9	2.4	10.3	51.9
Port-Said	1.8	2.9	4.7	4.6	2.0	6.6	11.3
Cairo	19.7	25.1	44.8	11.1	3.2	14.3	59.1
Almaza	16.2	15.9	32.1	9.0	3.7	12.7	44.9
Minya	5.1	7.6	12.7	3.4	0.9	4.3	17.0
Assiut	2.0	3.4	5.4	5.0	2.0	7.0	12.4
Luxor	0.1	2.0	2.1	2.7	1.5	4.2	6.3
Hurghada	0.1	1.7	1.8	4.5	1.8	6.3	8.1

TABLE (5)

CLOUDINESS.

HOURLY MEAN VALUES

IN THE PERIOD (0600-1800)

STATION	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	ANNUAL
Sidi-Barrani	4.6	3.9	3.2	3.4	2.5	1.8	1.4	1.5	1.7	2.5	3.7	4.1	2.9
Marsa-Matruh	4.5	3.9	3.4	3.5	2.5	1.5	1.3	1.9	1.9	2.5	4.1	4.4	3.0
Alexandria	5.1	4.5	3.7	3.9	2.4	2.0	2.1	2.8	2.7	3.9	4.8	5.3	5.5
Damietta	3.3	3.6	2.8	3.1	1.6	0.8	0.7	1.2	1.3	1.6	3.1	3.4	2.2
Port-Said	2.8	2.9	2.3	2.5	1.4	0.7	0.7	0.9	1.0	1.3	2.3	3.0	1.8
Tahrir	3.5	3.7	2.9	3.2	1.9	0.8	0.6	1.1	1.4	1.4	3.2	3.7	2.3
Tanta	3.2	3.3	2.6	2.6	1.8	0.8	0.9	1.3	1.3	1.4	3.1	3.2	2.1
Bahteem	2.8	3.0	2.3	2.7	1.4	0.4	0.5	0.9	1.0	1.1	2.2	2.7	1.8
Almaza	3.2	3.7	2.9	3.1	1.8	0.6	0.9	1.2	1.3	1.4	2.9	3.2	2.2
Giza	3.0	3.2	2.5	2.8	1.7	0.6	0.5	0.8	1.1	1.1	2.5	3.0	1.9
Siwa	3.1	2.8	2.5	2.6	1.9	0.4	0.3	0.6	0.7	0.8	2.0	2.6	1.7
Kharga	1.8	1.8	1.3	1.6	1.1	0.2	0.2	0.2	0.2	0.2	1.0	1.3	0.9
Minya	2.3	2.4	2.1	2.3	1.5	0.3	0.2	0.3	0.4	0.4	1.7	2.0	1.3
Gurghada	2.3	2.4	2.0	2.3	1.3	0.1	0.3	0.2	0.3	0.3	1.4	2.1	1.3

APPENDIX D: PV PROJECTS SITE VISIT BOOK

THIS APPENDIX CONTAINS SUMMARIES AND PHOTOGRAPHS OF A VARIETY OF PV SYSTEMS THAT ARE OPERATING TODAY. THEY ARE REPRESENTATIVE OF THE RANGE OF APPLICATIONS THAT ARE BEING POWERED BY PV SYSTEMS THROUGHOUT THE WORLD.

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Georgetown University Intercultural Center

LOCATION: Washington, D.C.

DATE OPERATIONAL: Oct 1984

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Solarex polycrystal silicon modules
- Integrated into roof of a functional university building
- Grid Interactive

PRODUCTION CAPACITY

- 320 Kw

OPERATIONAL HISTORY

- Excellent Results for first ten months of operation
- Architecturally pleasing

BUDGET HISTORY

PROJECT CONTACT

Georgetown University Plant Engineering Dept.
Jean Salnier 202-625-4025

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: U.S. Navy Instrumentation Package for Sea State and Weather Reporting

LOCATION: 3 and 19 km off shore of Panama City Fla. on platform

DATE OPERATIONAL: 1982

CURRENT STATUS:

SYSTEM DESCRIPTION

- Battery storage, powered by SolEnergy modules model 1294G

PRODUCTION CAPACITY

- 200 watts continuous (system)

OPERATIONAL HISTORY

- Some junction box corrosion and cracked modules, but reported outstanding success

BUDGET HISTORY

PROJECT CONTACT: J.F. Schaefer, New Mexico Solar Energy Institute
Los Cruces, N. Mexico

REFERENCE: ASME Paper
"Operational Experience with Large PV Power Systems Placed on Offshore Platforms"

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Lovington Square Shopping Center

LOCATION: Lovington, New Mexico

DATE OPERATIONAL:

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- Solar Power Corporation Modules - Single Crystal Silicon
- Experimental System
- Operated by Lea County Electric Cooperative

PRODUCTION CAPACITY

- 100 kW

OPERATIONAL HISTORY

- Inverter Problems
- Diode Connector Problems in Junction Box

BUDGET HISTORY

PROJECT CONTACT

- Sandia National Laboratories
  Eldon Boes, 505-844-5634

REFERENCE

- 17th IEEE PVSC page 1001
- 16th IEEE PVSC page 1060

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Wilcox Hospital

LOCATION: Kauai, Hawaii

DATE OPERATIONAL:

CURRENT STATUS: Photovoltaics no longer operational

SYSTEM DESCRIPTION

- Linear Parabolic concentrator with active cooling
- Applied Solar Energy Cells - Single Crystal Silicon
- Tracking System built around Acurex solar-thermal desigr

PRODUCTION CAPACITY

- 35 Kw

OPERATIONAL HISTORY

- Tracking System Worked OK
- Many problems with PV cell encapsulation design
- Glass superstrate failures
- Ground Fault Failure
- Corrosion Problems due to climate

BUDGET HISTORY

PROJECT CONTACT

REFERENCE: 16th IEEE PVSC page 984, 988

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Radio Relay System

LOCATION: Camp Pendleton California, Marine Corps Base

DATE OPERATIONAL: 1980

CURRENT STATUS: ARCO ASI-16 2000 Single Crystal Silicon Modules

SYSTEM DESCRIPTION

- o Power for emergency radio and radio repeaters.

PRODUCTION CAPACITY

- o 3.2 Kw

OPERATIONAL HISTORY

- o For one year, outstanding success

BUDGET HISTORY

PROJECT CONTACT: G.H. Watson, Naval Civil Engineering Laboratory, Port Hueneme, CA 93043

REFERENCE: 16th IEEE PVSC page 999

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: BDM Building

LOCATION: 1801 Randolph Rd. S.E.
Albuquerque, New Mexico

DATE OPERATIONAL: 1982

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Single Axis Tracking
- Paradolic linear concentrator
- Applied Solar Energy Corporation cells
- Single Crystal Silicon
- Active cooling - waste heat is used to supply 50% of heating load

PRODUCTION CAPACITY

- 50 Kw Electrical

OPERATIONAL HISTORY

- Lower than predicted efficiency
- System has suffered some wind damage
- Roof mounting design has caused problems

BUDGET HISTORY

- Funding by BDM

PROJECT CONTACT: Wayne Kauffman, BDM Inc.
1801 Randolph Rd. S.E., Albuquerque, New Mexico

REFERENCE: BDM Report A-84-318-TR

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Dallas - Fort Worth Airport

LOCATION: Dallas - Fort Worth Airport Texas

DATE OPERATIONAL:

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- System Design - Entech
- Experimental Concentrator System
- Fresnel Lens
- Active cooling by water which is used to heat boiler feed water for airport
- Roof mounted
- ASEC single crystal silicon cells

PRODUCTION CAPACITY

- 25 kW

OPERATIONAL HISTORY

- Good results for Experimental systems
- Tracking problems
- Pump and drain problems with coolant
- Dirty Arrays from Jet Exhaust

BUDGET HISTORY

PROJECT CONTACT

REFERENCE: 17th IEEE PVSC page 1001, 1060

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Various Residential Systems

LOCATION: Pearl City, Hawaii

DATE OPERATIONAL:

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Utility Interactive
- Supports four apartments
- 112 ARCO Solar Modules
- Single Crystal Silicon

PRODUCTION CAPACITY

- 4 Kw

OPERATIONAL HISTORY

- Water damage inside power conditioning unit enclosure
- Gemini Inverter failure

BUDGET HISTORY

- Funded through Sandia National Laboratories

PROJECT CONTACT

REFERENCE: Sandia National Laboratories
Report No. 84-7016

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Residential Systems

LOCATION: Molokai, Hawaiian Islands

DATE OPERATIONAL:

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- 112 ARCO Solar Modules
- Single Crystal Silicon
- Supports one house

PRODUCTION CAPACITY

- 4 Kw

OPERATIONAL HISTORY

- Best efficiency of three Hawaiian Arrays
- Very Good Success
- Some circuit breaker trips due to time-of-wetness sensor failure
- Overall system efficiency about 7%

BUDGET HISTORY

- Funded by DOE

PROJECT CONTACT

REFERENCE: Sandia National Laboratories Report
No. SAND 84-7016

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Residential System

LOCATION: Honolulu Hawaii

DATE OPERATIONAL:

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- 56 ARCO Solar Modules
- Single Crystal Silicon
- Support the Power needs of the one house
- Grid Interactive

PRODUCTION CAPACITY

- 2 Kw

OPERATIONAL HISTORY

- Gemini Inverter Failed
- Inverter Relay Failed
- Did not produce anticipated amount of energy in 1982 but did in '83
- System efficiency about 6%

BUDGET HISTORY

- Funded by DOE

PROJECT CONTACT

REFERENCE: Sandia Report 84-7016

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: El Paso Electric Company

LOCATION: El Paso, Texas

DATE OPERATIONAL: Jan 27, 1981

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- System with Battery Storage Powers un interruptible power supply
- 134 V output
- Primarily for utility orientation and visitor publicity
- Solar Power Corporation modules
- Single Crystal Silicon

PRODUCTION CAPACITY

- 17.6 kW

OPERATIONAL HISTORY

- System operates automatically with little problem
- Overall efficiency about 5-6%

BUDGET HISTORY

PROJECT CONTACT

E - Hernandez
El Paso Electric Co.
El Paso Texas

REFERENCE: 16th IEEE PVSC p. 1002

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: MIT Lincoln Labs

LOCATION: Varied

DATE OPERATIONAL: Varied

CURRENT STATUS: Varied

SYSTEM DESCRIPTION

- Lincoln Lab managed a variety of systems
- Range from PV-thermal to conventional single and polycrystal modules

PRODUCTION CAPACITY

OPERATIONAL HISTORY

- Glass superstrate modules are very durable to Hail, Corrosion, etc.
- Losses attributed to 1970 vintage modules and before due to dirt accumulation, poor hail resistance

BUDGET HISTORY

PROJECT CONTACT

S.E. Forman
MIT Lincoln Laboratory
Lexington, Massachussetts 02173

REFERENCE: 16th IEEE PVSC page 1198

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaic

PROJECT TITLE: Mead, Nebraska

LOCATION: Mead, Nebraska, University of Nebraska

DATE OPERATIONAL: July 1977

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- o Early JPL Block II modules from Solarex and Solar Power
- o Single Crystal silicon

PRODUCTION CAPACITY

- o 25 Kw

OPERATIONAL HISTORY

- o Carefully controlled maintenance record
- o Many failures from cracked calls
- o Modules were not designed for redundancy, therefore cracks were very detrimental to power
- o Many failed interconnects due to improper design

BUDGET HISTORY

PROJECT CONTACT

S.E Foreman
MIT Lincoln Laboratory
Lexington, MA 02173

REFERENCE: 16th IEEE PVSC page 1198

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: University of Texas - Arlington

LOCATION: Arlington, Texas

DATE OPERATIONAL: Nov 1978

CURRENT STATUS: not operational

SYSTEM DESCRIPTION

- Block II vintage modules
- Single crystal silicon

PRODUCTION CAPACITY

- 7.5 Kw

OPERATIONAL HISTORY

- Many modules were destroyed by improper maintenance procedure
- Modules were shorted in full sun causing hot - spots, delaminations, and charred areas
- Other modules failed because of improper interconnect design

BUDGET HISTORY

PROJECT CONTACT

S. Foreman
MIT Lincoln Laboratory
Lexington, MA 02173

REFERENCE: 16th IEEE PVSC page 1198

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: WBNO

LOCATION: Bryan, Ohio

DATE OPERATIONAL: August, 1979

CURRENT STATUS: Operational (with replacement modules)

SYSTEM DESCRIPTION

- Provides power for daytime AM radio
- Solarex modules
- Single Crystal Silicon
- Grid Interactive

PRODUCTION CAPACITY

- 20 Kw

OPERATIONAL HISTORY

- Modules were plaged by problems
- Interconnect fatigue
- Hail damage
- Encapsulant delamination
- Replacement with more modern modules (spring 1984)

BUDGET HISTORY

PROJECT CONTACT

Erich Schalla
Solarex Corporation
1335 Piccard Drive
Rockville, Maryland 20850

REFERENCE: 16th IEE PVSC page 1198

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: MIT Lincoln Lab Test sites

LOCATION: Lexington, Concord Massachussettes

DATE OPERATIONAL: May 1977, December 1978

CURRENT STATUS: Operational for Experimental Aging Study

SYSTEM DESCRIPTION

- o Sites were set up to do various studies on photovoltaic modules
- o Most of modules were of Block II and Block III vintage

PRODUCTION CAPACITY

- o 35 Kw total

OPERATIONAL HISTORY

- o Modules Had many workmanship problems
- o Poor solder joints
- o cracked cells
- o broken interconnects

BUDGET HISTORY

PROJECT CONTACT

Steve Forman
MIT Lincoln Laboratory

REFERENCE: 16th IEEE PVSC page 1205

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Beverly High School

LOCATION: Beverly Mass

DATE OPERATIONAL: April, 1981

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Flat plat single crystal silicon modules
- Solar power corporation modules
- Grid interactive
- Ground mounted

PRODUCTION CAPACITY

- 100 Kw

OPERATIONAL HISTORY

- Some problems due to ground faults
- Vegetation and Erosion of hill side lot caused problem

BUDGET HISTORY

PROJECT CONTACT

REFERENCE: 16th IEEE PVSC page 1350
17th IEEE PVSC page 1060

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Stand alone PV water pumping

LOCATION: 25 mi N.E. of Las Cruces N.M.

DATE OPERATIONAL: September, 1981

CURRENT STATUS:

SYSTEM DESCRIPTION

- Deep well stock-water pump
- Surplus JPL Block II modules
- Single crystal silicon
- System was installed primarily for Balance-of-Systems optimization

PRODUCTION CAPACITY

- 9.15 Kw

OPERATIONAL HISTORY

- System has worked well
- Fuses blew because fusing was too close to motor capacity

BUDGET HISTORY

PROJECT CONTACT

REFERENCE: 16th IEEE PVSC page 1405

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Desert Development Project

LOCATION: Sadat City, Egypt

DATE OPERATIONAL: 1981

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- o 10 Kw array supplies 220V 50Hz power
- o 3 Kw system prives positive displacement pump

PRODUCTION CAPACITY

- o 10 Kw, 3 Kw

OPERATIONAL HISTORY

- o Reliable performance of both arrays and equipment
- o Initial problems with positive displacement screw pump
- o Good experience with battery maintenance techniques
- o 7.22 percent conversion efficiency

BUDGET HISTORY

PROJECT CONTACT

Mr. Fadel Assabhy

REFERENCE: Evaluation of International Photovoltaic Projects. Meridian Publication in draft.

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Bourkina Fasso Water Pump & Grainmill

LOCATION: Bourkina Fasso (Formerly Upper Volta)

DATE OPERATIONAL: 1979

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Stand alone system with battery storage
- Block II vintage modules
- Single crystal silicon cells

PRODUCTION CAPACITY

- 3.6 Kw

OPERATIONAL HISTORY

- Early modules suffered interconnect fatigue failures
- modules have been replaced
- Has been extensively monitored by NASA Lewis for US AID

BUDGET HISTORY

PROJECT CONTACT

Anthony Ratajczak, NASA Lewis

REFERENCE: NASA Technical Memorandum 79318
NASA Technical memorandum 86970

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Traffic Lighting

LOCATION: Dubai, United Arab Emirates

DATE OPERATIONAL: June 1983

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Powered by Mobil Solar modules
- Silicon ribbon cells
- Each "system" consisted of 20w fluorescent tube, 2-35 watt modules, and 12 VDC ballast
- One high mast, traffic circle light was also installed eight 400 w high pressure sodium vapor lamps

PRODUCTION CAPACITY

- 16500 watts

OPERATIONAL HISTORY

- Initial installation problems because of invertors
- Used ferroresonant invertor instead

BUDGET HISTORY

PROJECT CONTACT

Bob Hammond, Mobil Solar

REFERENCE: Evaluation of International P.V. Projects, draft Meridian Corporation report.

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Solarex Stand-alone Industrial Facility

LOCATION: Frederick, Maryland

DATE OPERATIONAL: Oct 1982

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Standalone building designed for industrial facility
- Modules are integrated into the roof of the building
- 3120 2 ft x 4 ft modules
- Polycrystal silicon cells
- Both AC and Battery Storage

PRODUCTION CAPACITY

- 200 Kw

OPERATIONAL HISTORY

- Array has worked well
- Originally problems with instrumentation system

BUDGET HISTORY

- Not available

PROJECT CONTACT

Dan Bumb
Solarex Corporation
1335 Piccard Drive
Rockville, Maryland 20850

REFERENCE: Fifth E.C. Photovoltaics Solar Energy Conference Proceedings p.363

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: McClellan Air Force Base Minimarket

LOCATION: McClellan Air Force Base, CA

DATE OPERATIONAL: 1983

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Utility Interactive, power primarily is used for mini-market
- ARCO Solar module ASI 5-6600 modules
- Single crystal silicon cells
- Ground mounted near mini-market
- Fixed tilt mounting
- BDM Corporation - systems engineers

PRODUCTION CAPACITY

- 40 Kw

OPERATIONAL HISTORY

- Problems with bypass diode sealing
- Some vandalism problems early in project

BUDGET HISTORY

PROJECT CONTACT

W.R. Kauffman
BDM Corporation
1801 Randolph Road S.E.
Albuquerque, N. Mexico 87106

REFERENCE: Fifth European Communty Photovoltaic Solar Energy Conference p. 373

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Village Electrification, Tunisia

LOCATION: Hammam Biadha Sud, Tunisia

DATE OPERATIONAL: Feburary 1983

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- 3 loads, commercial, domestic, public
- Open circut voltage = 290 volts
- Both DC and AC loads
- Solar Power modules
- Single crystal silicon

PRODUCTION CAPACITY

- 29 Kw

OPERATIONAL HISTORY

- Photovoltaics have worked well
- Inverter problems
- Some wiring insulation has deteriorated

BUDGET HISTORY

- USAID funded

PROJECT CONTACT

Dr. Ghaz: Darkazalli
Spire corporation, Patriots Park/Bedford Mass. 01730

REFERENCE: June/July 1983 Issue of Photovoltaics International, page 8

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaic

PROJECT TITLE: Micro-wave Telecommunications

LOCATION: Mt. Namsbamati, Papua New Guinea (more locations added later)

DATE OPERATIONAL: June 13, 1976

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Powers microwave repeater
- 12 V, 1.65 A, 26 watt module
- Solar Power modules
- Single Crystal Silicon

PRODUCTION CAPACITY

- 230 watts per station

OPERATIONAL HISTORY

- Only one failure of voltage regulator
- Dust Accumulation is minor
- Battery maintenance no problem
- Cost-competitive with primary batteries

BUDGET HISTORY

- Cost $26/watt

PROJECT CONTACT

REFERENCE: Evaluation of International PV Projects, Meridian draft publication

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaic

PROJECT TITLE: Research Center, Sanyo Electric Co

LOCATION: Hirakata City, Osaka, Japan

DATE OPERATIONAL: August 1981

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- Amorphous Silicon Modules
- Residential Application
- Lead-Acid Battery Storage
- First Amorphous Silicon Power modules ever used in this application

PRODUCTION CAPACITY

- 2 Kw

OPERATIONAL HISTORY

- Conversion Efficiency 2.3 - 3.1%
- Degradation of about 10% after first month of deployment
- Fill factor decreased about 10%

BUDGET HISTORY

PROJECT CONTACT

Research Center, Sanyo Electric
1-18-31 Hashiridani, Hirakata City Japan

REFERENCE: 16th IEEE PVSC page 1124

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Southeast Regional Experiment Station

LOCATION: Cape Canaveral, Florida

DATE OPERATIONAL: 1982

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 12 flat plate systems totalling 34.1 kWp

PRODUCTION CAPACITY

OPERATIONAL HISTORY

- Five year project consisting of field experiments at various locations in the southeastern U.S. that determine the feasibility of grid-interactive residential PV systems

BUDGET HISTORY

PROJECT CONTACT

Dr. Gerard Ventre
Florida Solar Energy Center
300 State #401
Cape Canaveral, Florida 32920
(305) 783-0300

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Oklahoma Center for Science and Arts

LOCATION: Oklahoma City, Oklahoma

DATE OPERATIONAL: February 1982

CURRENT STATUS: Operating

SYSTEM DESCRIPTION:

- 135 kW roof-mounted system consisting of flat plate modules and reflectors to augment insolation

PRODUCTION CAPACITY:

- Excess power is used by on-site facilities or fed into the Oklahoma Gas and Electric Company grid.

OPERATIONAL HISTORY:

BUDGET HISTORY:

PROJECT CONTACT:

Dr. Yudi Gupta
Science Applications Incorporated
1710 Goodridge Drive
McLean, Virginia 22102
(703) 827-4783

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Mt. Laguna Federal Aviation Administration Facility

LOCATION: Mt. Laguna, California

DATE OPERATIONAL: August 1979

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 65 kWp flat plate array ground-mounted on a mountain top

PRODUCTION CAPACITY

OPERATIONAL HISTORY

- Demonstrated the feasibility of operating a photovoltaic system in conjunction with diesel electric generators remote from utility lines.

BUDGET HISTORY

PROJECT CONTACT

Mr. Ron Rudolph
Federal Aviation Administration
AF-SEO
P.O. Box 39
Mt. Laguna, California 92048
(619) 442-0347

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Mead Irrigation Project

LOCATION: Mead, Nebraska

DATE OPERATIONAL: July 1977

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 29.3 kW flate plate, ground-mounted PV array

PRODUCTION CAPACITY

- Provides 100% of the power needed to meet the irrigation requirements of an 80 acre cornfield
- Also provides significant portion of the power required for crop drying and fertilizer manufacturing.

OPERATIONAL HISTORY

- One of the first multi-kilowatt PV systems in the western hemisphere

BUDGET HISTORY

PROJECT CONTACT

Dr. Paul E. Fishbach
Institute of Agriculture and Natural Resources
University of Nebraska at Lincoln
Agricultural Engineering Building
East Campus
Lincoln, Nebraska 68583
(402) 472-1626

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Natural Bridges National Monument

LOCATION: Canyon Lands National Park, Utah

DATE OPERATIONAL: June 1980

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 100 kW power from a flat plate ground-mounted array

PRODUCTION CAPACITY

- Provides 90% of the monument's electricity needs
- Also provides power for the Visitor Center, Park Service's employee housing, machine shop, water pumping pressurization pumps and several electric vehicles
- Back-up power provided by a 50 KVA/40 kW diesel generator during periods of low insolation and at night

OPERATIONAL HISTORY

BUDGET HISTORY

PROJECT CONTACT

Mr. Ted Simmons
National Park Service
Rocky Mountain Region
655 Parfet Street
Denver, Colorado 80225
(303) 234-6813

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Sacramento Municipal Utility District (SMUD) Photovoltaic Power Plant

LOCATION: Rancho Seco Generating Site, California

DATE OPERATIONAL: 1984

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 1 MW power system consisting of a ground-mounted single-axis tracking flat plate array

PRODUCTION CAPACITY

- System produces enough electricity to meet the requirements of approximately 300 homes in the utility's service area

OPERATIONAL HISTORY

BUDGET HISTORY

PROJECT CONTACT

Mr. Mark Anderson
Project Manager
Sacramento Municipal Utility District
6201 S. Street
Box 15830
Sacramento, California 95813
(916) 452-3211

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Schuchuli Village Power System

LOCATION: Papago Indian Village, Schuchili, Arizona

DATE OPERATIONAL: December 16, 1978

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 3.5 kWp (peak), 120 volt DC flat plate PV stand-alone power system made up of 192 PV modules
- 2380 ampere-hours of battery storage

PRODUCTION CAPACITY

- Provides electrical power for the village water pump, lights in the homes and community buildings, 15 family refrigerators,a nd a communal washing machine and sewing machine

OPERATIONAL HISTORY

BUDGET HISTORY

PROJECT CONTACT

William J. Bifano
NASA/Lewis Research Center
21000 Brookpark Road (49-5)
Cleveland, Ohio 44135

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: PV-Powered Vaccine Refrigerators

LOCATION: 29 sites worldwide

DATE OPERATIONAL: N/A

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- Systems range from 160 to 360 peak watts with battery storage ranging from 315 to 630 amp-hours.

PRODUCTION CAPACITY

- Refrigerator compartments were within a 0°C to 8°C temperature range 84.7% of the time

OPERATIONAL HISTORY

- 15 of 29 sites forwarded data on production capacity -- data based on 3288 system-site days.

BUDGET HISTORY

PROJECT CONTACT

William J. Bifano
NASA/Lewis Research Center
21000 Brookpark Road (49-5)
Cleveland, Ohio 44135

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Rondulini

LOCATION: Rondulini, Corsica, France

DATE OPERATIONAL:

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 44 kWp composed of modules with rated power output of 36 Wp
- 1 self-commutated inverter, 50 kVA to feed village grid in stand-alone mode
- Back-up power provided diesel generating set, 25 kVA

PRODUCTION CAPACITY

- Provides electricity for homes, lighting and water pumping

OPERATIONAL HISTORY

BUDGET HISTORY

PROJECT CONTACT

Mr. W. Paly
Commission of the European Communities
200 Rue de la Loi
1049 Brussels, Belgium

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Tremiti Island

LOCATION: Tremiti Island, Italy

DATE OPERATIONAL:

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 65 kWp composed of modules with rated power output of 130 Wp and 35 Wp
- Power conditioning system composed of 3 DC/DC converters, each 25 kW with integrated maximum power point tracker
- System provides drinkable water through desalination

PRODUCTION CAPACITY

- System supplies yearly production of 500t. to the village

OPERATIONAL HISTORY

BUDGET HISTORY

PROJECT CONTACT

Mr. W. Paly
Commission of the European Communities
200 Rue de la Loi
1049 Brussels, Belgium

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Lugo 1 MW Facility

LOCATION: Hesperia, California

DATE OPERATIONAL:

CURRENT STATUS: Operational

SYSTEM DESCRIPTION

- 108 two-axis tracker for an operating output of $\pm$ 260 volts at 20 amperes
- Center-tap of each tracker is grounded to a $40/0 copper counterpoise

PRODUCTION CAPACITY

OPERATIONAL HISTORY

BUDGET HISTORY

PROJECT CONTACT

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: SOLERAS

LOCATION: Al Jubaylah, Al Uyaynah and Al Hijrah, Saudia Arabia

DATE OPERATIONAL: September 1981

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 350 kW PV array, point focusing concentrator type
- 1. MW diesel powered generators
- 1.6 MW/hr lead acid batteries
- 300 kVA inverter, dc and ac switchgear
- 13.8 kV transformers
- Solar and weather monitoring subsystem

PRODUCTION CAPACITY

- Array dc power output exceeded 375 kW in February 1982 at an array field efficiency of 10.4%

OPERATIONAL HISTORY

- Concentratory array module progressed from development stage to a commercial high production type within a year

- Essentially trouble-free start-up operation

BUDGET HISTORY

PROJECT CONTACT

PROJECT INFORMATION

TECHNOLOGY AREA: Photovoltaics

PROJECT TITLE: Kythnos

LOCATION: Island of Kythnos, Greece

DATE OPERATIONAL:

CURRENT STATUS: Operating

SYSTEM DESCRIPTION

- 100 kWp composed of modules with rated output power capacity of 125 Wp
- Power conditioning system consists of 4 DC/DC converters, each with 25 kW integrated maximum power point trackers to charge the batteries
- 3 self-commutated inverters, each 50 kVA

PRODUCTION CAPACITY

OPERATIONAL HISTORY

- PV power plant supplies energy parallel to the existing diesel power station and wind converters

BUDGET HISTORY

PROJECT CONTACT

Mr. W. Paly
Commission of the European Communities
200 Rue de la Loi
1049 Burssels, Belgium

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